Design of an Improved Reacher-Gripper

A Major Qualifying Project Report
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Abstract:

Individuals with physical impairments often need assistive devices such as reacher grippers to perform daily activities. Commercial reacher grippers can be difficult to use for individuals with reduced hand and wrist functionality. After evaluating these reacher grippers, a novel design was developed which decreases difficulties associated with using common reacher grippers. The design features electro-mechanical actuation to minimize the hand strength required to operate the device as well as forearm support to alleviate stress on the user's wrist. Additionally, this design allows the claws to fully close in under one second. After performing electrical and mechanical analyses on the proposed design, a first generation prototype was manufactured. The device was subsequently tested for feedback and functionality by typical users with varying physical capabilities. Results indicated the device allows users to comfortably retrieve objects weighing up to four pounds from a distance of 32 inches away.

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Chapter 1: Introduction

Throughout any given day, individuals must perform a multitude of tasks in order to live independently. These include such simple functions as walking up and down steps, using utensils for eating, and reaching to grab objects from a distance. It may be easy to overlook these activities among life's complexities, but if the ability to complete any of these essential tasks is hindered, life can become notably more difficult. To help with such problems, assistive technology can be used to facilitate everyday living. Assistive technology may be defined as, "any product or service designed to enable independence for disabled and older people" (FAST, 2015). Individuals with physical or cognitive disabilities can use such technology to lead lives with reduced or no external assistance.

Physical disabilities are a particularly prevalent cause for assisted living and the use of assistive devices. According to the 2012 disability status report, over 40 million Americans (non-institutionalized) and roughly half of all Americans age 65 or older, were found to have either ambulatory, self-care, or independent living disabilities (Erickson et al., 2014). These categories of disabilities can cause difficulties walking, dressing or bathing, and carrying out daily errands. Specific disabilities of these kinds include arthritis, stroke, myopathy, tetraplegia, hemiplegia, peripheral neuropathy, cerebral palsy, Parkinson's disease, multiple sclerosis, and many more. Any of these disabilities can lead to a unique set of problems, though many of the same daily tasks can be hindered by different impairments.

An individual with a physical disability may experience difficulty reaching and manipulating objects at various distances. People with impairments such as muscular atrophy or arthritis can have a limited range of motion, which may confine them to a narrow range of activities, or a lifestyle that requires caregivers. Assistive devices such as "reacher grippers" can alleviate some difficulties caused by these disabilities. More specifically, reacher grippers can increase an individual's independence by increasing their effective range of grasp. This allows them to carry out daily tasks such as retrieving objects from the ground, moving items from far distances, and more complex tasks that require grasping at range (Prieto, 2008).

Reacher grippers cater to both people with and without physical disabilities, but all of these devices have various issues when used by individuals with certain hand impairments. For instance, the vast majority of reacher grippers are operated by squeezing a trigger apparatus to open and close a set of claws. If an individual has arthritis in their back, they might use a reacher gripper to pick up items without bending over. However, if that individual also has arthritis in their hands, squeezing the trigger could be strenuous and painful. Many reacher grippers require a significant amount of strength to operate, versatile finger motion, and continuous force application from the user when grasping an object. These can all be problems for someone with reduced strength and control in their hands and wrists, and are areas in which current reacher grippers can be improved.

In order to more effectively accommodate users with these types of hand impairments, a device must be developed that improves upon the failings of commercially available reacher grippers. The ultimate objective is to increase the independence of the users. To do so, the device shall reduce the amount of dexterity, range of motion, and strength required to operate a reacher gripper. The process for creating this device will involve evaluating competing designs on their effectiveness at completing various tasks, designing and constructing an improved reacher gripper prototype, and evaluating the performance of said prototype with target users. The end result is a device that provides users with a safe, comfortable, and effective method of manipulating items at a distance in everyday tasks, allowing for a more independent lifestyle.

Chapter 2: Background

Reduced functionality in a person’s hand or wrist can have a number of causes. Among the most common are arthritis, muscular dysfunctions, and neurological dysfunctions. Users with these types of disabilities might also have a need to pick up objects that are beyond their reaching capability. A large selection of commercial products and novel designs have been developed to aid with manipulating objects outside of a person’s reach, though they can be less effective in the hands of a user with hand and wrist impairments. Various testing procedures can be used to evaluate a person’s need for devices like reacher grippers and how well reacher grippers perform their intended functions.

2.1: Hand and Wrist Impairments

Use of traditional reacher grippers is reliant upon the user’s ability to manipulate the device with their wrist and hand. Individuals that have problems with these sections of the arm will experience greater difficulty utilizing these devices. The following sections identify a few common types of disabilities related to hand and wrist control. Topics covered in these sections include definitions of these disabilities, symptoms of these disabilities, and how these disabilities affect an individual’s capabilities.

2.1.1: Arthritis

Osteoarthritis is one extremely common condition affecting hands and wrists. This condition occurs as the cartilage in a person’s joints degrades. In normal joints, cartilage covers surfaces of bones where they contact other bones. This covering provides a smooth sliding surface and also absorbs impacts. For an individual with osteoarthritis, the cartilage in certain joints breaks down, causing swelling, joint pain, and stiffness. The condition worsens over time as more cartilage is lost, until bone is contacting bone. Bones may develop spur growths as they degrade, and flecks of bone may chip off and float around in the joint, leading to more pain. Osteoarthritis can affect all joints, though it most commonly occurs in the knees, hips, lower back, neck, and finger joints (Fraser, 1999).

Osteoarthritis is the most common chronic joint condition, as it affects 27 million Americans. The condition occurs most commonly in individuals over the age of 65, and one in twelve individuals over 60 have osteoarthritis in their hands. Osteoarthritis can develop at any point in life, but old age, obesity, joint overuse, and genetics are all common risk factors (Fraser, 1999).

The pain and limited joint range that comes with osteoarthritis can severely limit a person's ability to perform everyday tasks and can reduce his or her independence. Activities such as walking, bending, lifting objects, and climbing can become difficult if the lower extremities are affected. If osteoarthritis is present in a person's hands, grasping objects and finely manipulating objects can also become a challenge. This includes a wide range of tasks such as typing, driving, opening containers, and sewing. Certain orthoses, often in the form of a glove, can be used to support and constrain the joints of the hand and wrist to reduce pain.

Next to osteoarthritis, rheumatoid arthritis is the second most common form of arthritis, and is the most common form of autoimmune arthritis (Osteoarthitis, 2014; Ruderman & Tambar, 2013). Like osteoarthritis, rheumatoid arthritis is a chronic disease that causes pain, swelling, and limited motion in the joints. However, rheumatoid arthritis occurs when an individual's immune system attacks his or her own joints. The exact cause for this malfunction of the immune system is unknown. Rheumatoid arthritis can affect any joint in the body, but most commonly affects the wrist, fingers, and feet. Over time, more joints may be affected than those at the initial onset of arthritis (Ruderman & Tambar, 2013).

Approximately 1.5 million Americans have rheumatoid arthritis, with about three times more women than men being affected. Similar to osteoarthritis, the disease can begin at any age, though it commonly occurs between 30 and 50. Men typically develop rheumatoid arthritis later than women (Ruderman & Tambar, 2013; Fraser, 1999).

As the immune system attacks the joints in rheumatoid arthritis, they can become loose and unstable, which limits their mobility and causes deformities. Fingers will bend with unnatural contours and may become locked into certain positions. Some common deformities include Boutonniere deformity, swan-neck deformity, hitchhiker's thumb, and trigger finger (Fraser, 1999; Apfelberg et al., 1978). Wrist deformities can also reduce grasping ability by constraining or loosening tendons (Apfelberg et al., 1978). The odd positioning of a person's digits and reduced strength caused by rheumatoid arthritis can add even greater difficulty to completing tasks that require hands, in addition to the limitations caused by stiffness and pain from other forms of arthritis. Orthoses such as specialized finger rings can be used to reposition a person's digits to a more normal shape and provide joint support.

2.1.2: Muscle Dysfunctions

Muscular atrophy is one of the more prevalent phenomena that can decrease muscle strength in the hands. It can be defined as a wasting or shrinking of any set of muscles. This decrease in muscle mass causes reduced strength. There are a wide variety of causes for muscular atrophy, but it is usually a result of muscle disuse, poor circulation, or malnutrition (Chris, 2015). If a person loses control of a set of muscles, from nerve damage for example, the unstimulated muscles will atrophy over time. Even if the person regains full control of these muscles, the atrophy will leave the affected area with a loss of movement and strength (Campellone, 2014).

One cause of atrophy is muscular dystrophy; a group of diseases in which muscles are damaged and weaken over time. Muscular dystrophy is exclusively a result of faulty genes that are responsible for the production of proteins in muscle formation. The diseases can occur at any stage of life. Muscular dystrophy is not typically just linked to hands and arms, but all muscles, and can result in the inability to walk, breathing problems, scoliosis, heart problems, and swallowing problems (Mayo Clinic Staff, 2014). Other causes of muscular atrophy include aging, injury, rheumatoid arthritis, and osteoarthritis (Campellone, 2014).

Tendonitis is another fairly common cause of impaired muscle function. It is an inflammation or degradation of tendons and other soft tissue that are connected to muscles and bone. Tendonitis usually occurs as a result of repeated, minor injuries to a tendon through an activity such as sports or manual labor, but can also be caused by a sudden and severe injury. Affected areas are most often the ankle, knee, hip, shoulder, elbow, and wrist. Tendonitis results in acute pain at the affected area and is worse during movement (Sheon, 2015). Weakness can also occur, although this is normally the result of a tendon actually tearing (Chris, 2015). The pain caused by tendonitis can result in reduced functionality of the affected area, similar to arthritis. However, tendonitis is almost always much more localized, meaning that an individual will not have as much difficulty performing a wide variety of everyday tasks. A person may recover from tendonitis fairly quickly, especially if treated at an early stage. The best method for treating tendonitis is to rest the affected area by avoiding heavy movement or movement that causes pain (Sheon, 2015).

2.1.3: Neurological Dysfunctions

Carpal tunnel syndrome is a loss of hand function that occurs from median nerve compression. The median nerve is responsible for movement and sensation in the hand. It passes through the forearm into the hand through a space in between bones called the carpal tunnel. When the median nerve is compressed, an individual can experience tingling or burning sensations from the hand up through the forearm, numbness in the hand, and a loss of control and strength in the hand (Biundo & Rush, 2013). Between 4 and 10 million Americans have carpal tunnel syndrome, and it often occurs in both hands (Lawrence et al., 2008; Padua et al., 2005). Due to the hand dysfunction caused by carpal tunnel syndrome, individuals can have trouble with everyday tasks such as writing, buttoning clothes, or grasping and moving heavy objects (Biundo & Rush, 2013; Apfelberg et al., 1978). This difficulty is only increased if both hands are affected. Certain positions of the wrist, such as flexing or extending, can exacerbate the symptoms. Carpal tunnel syndrome is caused by thyroid disease, wrist fractures, rheumatoid arthritis, and more. The claim is often made that the syndrome is caused by repetitive work activities such as typing, though this is still debated (Biundo & Rush, 2013). Orthoses that constrain the hand, similar to those used with arthritis, can be used to alleviate pain and help recovery.

Damage to the brachial plexus can also impede hand function. The brachial plexus is a group of nerves that runs from the brain through the neck and shoulder that is responsible for control and feeling in the shoulder, elbow, wrist, and hand. Damage to this group of nerves can disrupt function in any of the aforementioned areas. Damage may be caused by blunt or sharp force trauma, compression, or a variety of neurological diseases (“Brachial”, 2015). In general, brachial plexus disruption leads to stiffness, pain, loss of feeling and control, and muscle atrophy (“Nerve”, 2015). Most brachial plexus injuries are minor and will dissipate within a few weeks, though more serious injuries can cause permanent disability (“Brachial”, 2015).

The following are some specific types of brachial plexus damage: radial neuropathy, also known as squash palsy or Saturday night palsy, occurs when the radial nerve is damaged. This nerve controls finger, hand, and wrist movement. Thus, radial neuropathy may present itself as hand and wrist paralysis. Ulnar neuropathy occurs when the ulnar nerve, responsible for the control of forearm and hand muscles, is injured. Paralysis or weakness may be present in the hand and ring and pinkie fingers as a result of ulnar neuropathy. Median nerve palsy, not to be confused with carpal tunnel syndrome, is a result of damage to the median nerve. This can cause problems with sensation in the thumb, index, and middle finger. Thumb movement may be severely limited in what is known as ape hand deformity, and as a result, an individual will have great difficulty grasping objects ("Nerve", 2015).

2.2: Existing Solutions

Reacher grippers are tools used to minimize the difficulty of completing everyday tasks that involve extended reach. These tools typically contain a grabbing mechanism such as a claw, an actuating mechanism used to control the grabbing mechanism, and a long rod that connects the actuating mechanism to the grabbing mechanism.

The majority of reacher grippers use a claw-shaped design to grip objects, though some hold items with magnetic or adhesive tips (Chen et. al., 1998). Figure 1 shows a variation of the claw-shaped design. The claws are generally shaped in a way that allows them to close around objects of various sizes and shapes. A multitude of materials, surface patterns, and claw shapes are used to allow different types of contact between the claw and object being grasped.

Figure 1: Common Claw Design

Reacher grippers tend to vary the most in their actuation mechanisms. A pistol grip and trigger is the most common among these mechanisms, and uses leverage applied at the trigger to pull a cable that forces claws closed. A squeeze-type trigger is another popular mode of operation. Instead of having the trigger on a pivot, the whole trigger slides towards the user's palm. Like the pistol grip mechanism, this design puts the user's hand in a cylindrical grip position and allows the user to apply force with all four fingers. A third method of actuation opens and closes the gripper by sliding a guide up and down the length of the shaft. One hand is placed at the base of the rod and the other is placed on the slider. This two-handed grip allows for greater stability when using the reacher gripper, and reduces the weight on any one hand.

Additionally, some designs for reacher grippers add a locking feature that allows the claws to remain closed without continuous input from the user. This reduces stress on the user's hand throughout the operation of the device. These methods for designing reacher grippers have been used extensively in various commercially available reacher gripper devices, while more uncommon methods have been conceptualized in patents. Both commercial and patent designs are discussed in the following sections.

2.2.1: Commercially Available Devices

Commercially available reacher gripper devices tend to be designed very similarly. However, there are some differences in their designs to accommodate various users or price points to be competitive in the market. A wide range of these variations can be described through the Ettore Grip'n Grab, the Medline Reacher, and the HealthSmart GripLoc brands of reacher grippers.

2.2.1.1: Ettore Grip'n Grab

The Ettore Grip'n Grab (GnG) is representative of the reacher gripper market as a whole. With a price point at $15, this reacher gripper is within average market value for these assistive devices. It is operated by applying a force to the pistol grip trigger, which closes the claws on the end of the shaft shown in Figure 2. The grabbing force is transferred from the trigger to the claw via a cable that runs the length of the shaft. The handle and claws of the GnG are primarily made from plastic and rubberized material, while the shaft is made of aluminum. In total this device weighs 9.6- oz. (Amazon). While extending the user's reach by 3-ft, the moment felt at

Figure 2: Ettore Grip'n Grab (GnG)

the wrist from picking up objects is minimized due to the device's light weight. Additionally, this device adds a rotating function that allows the claws to be in either the vertical and horizontal positions.

This device is the best seller for reacher grippers on Amazon and has been reviewed by a large number of its users. Most reviews are positive citing this reacher gripper's ability to pick up heavier objects (5-lbs), to rotate 90°, and to grasp objects both small and large. However, the next most popular review topics included the product's poor durability and the difficulty users with arthritis had using the trigger. The GnG's low cost and overall effectiveness seemed to outweigh these negative points for many users, though it is important to note these difficulties common to reacher grippers.

2.2.1.2: Medline Reacher

The Medline reacher (MR) is another inexpensive reacher gripper. At $8 this reacher gripper provides an alternative to the common pistol grip with the full hand squeeze trigger as shown in Figure 3. This actuator is connected by a metal rod, as opposed to the cable in the GnG, which transfers the applied force to a linkage at the end of the shaft. The claw mechanism on this reacher gripper is in the form of a "scissor linkage" that pivots about a fixed point on the shaft.

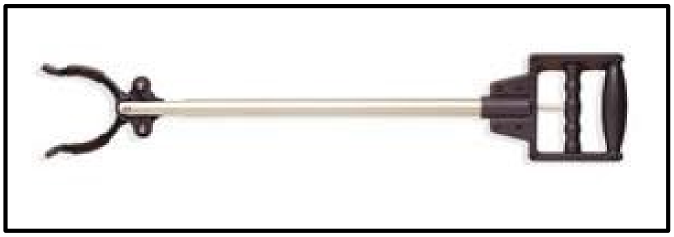


Figure 3: Medline Reacher (MR)

The MR is comprised of a significant number of plastic parts, with the exception of the aluminum shaft. This reacher gripper weighs 14-oz. and extends the user's reach by 31-in. Taking the ratio of device weight to device length, the GnG's weight to length ratio is more than 1.5 times better than the MR. Still, the MR is able to be used adequately without applying too much moment to the user's wrist.

Users of this device on (Amazon) appreciated the full hand grip for making it easier to keep the claws in the grasping position. Users also admired durable features such as the stiff metal rod that transferred force to the claws, as opposed to a thin cable used in products like the GnG. However, many customers expressed difficulty using this device because of the wrist and forearm strength required to hold objects in the claws' grasp. Additionally, the design of the MR uses two rubber attachments on the tip of the plastic claws to grip objects. Users found that when these pieces did not contact the target object, it was nearly impossible to retain grip.

2.2.1.3: HealthSmart GripLoc

A more expensive option for a reacher gripper is the HealthSmart GripLoc (HSGL). Costing $40, more than double the price of the GnG, this reacher gripper is aimed at arthritic clientele. This device, unlike the majority of reacher grippers, requires two hands to use as shown in Figure 4. The "power slide" technology in this device operates similarly to both the GnG and MR by transferring an applied force to the claws via an internal pulley system. However, this device has an additional locking mechanism activated by twisting the slider 90º clockwise or counterclockwise. This eliminates the need for continuous force input from the user while grasping an object.

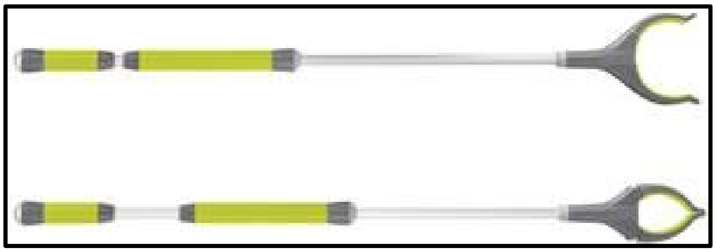


Figure 4: HealthSmart GripLoc (HSGL)

Similar to the previously mentioned reacher grippers, this device is made of plastic with the exception of the shaft. Combining a grip for users with arthritis and wider claws, this reacher gripper weighs 16-oz. and extends the user's reach by 3-ft. The HSGL has a comparable weight to length ratio to the MR. The specialized features of this device combined with its high price may dissuade users from purchasing it in favor of cheaper options, as this reacher gripper has very few reviews. Those that reviewed the device seemed to like the comfort of using the slider to grasp objects and then locking the claws into place to relieve some stress on their hands. At the same time, one reviewer mentioned that the actual claw material made it very difficult to grasp most objects.

2.2.2: Patents

Numerous patents have introduced new ways of executing tasks intended for reacher grippers by various methods. Among these include novel ways of actuating claws, locking the device in specific positions, extending the length of the gripper, and adding electromechanical operation controls.

2.2.2.1: Surgical Device with Double Jaw Actuation, US 5176699

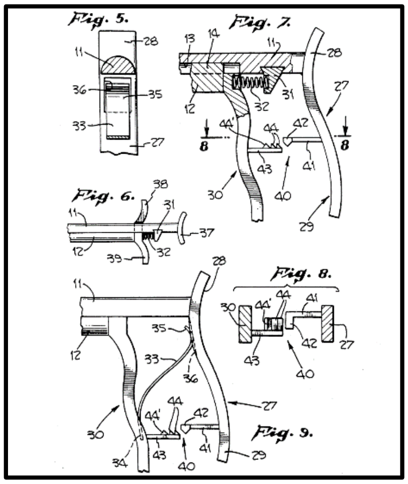


Figure 5: User Interface of Surgical Device with Double Jaw Actuation

This device is intended for use in a medical setting which requires both accuracy and precision during operation. The device's grabbing mechanism is common to typical reacher gripper devices. This surgical device opens and closes by running the upper and lower digits of the claw past each other. A grasp by the handle (30) can be pulled backward to draw the lower digit (57) the opposite end past the upper digit (63) as shown in Figure 6. The base of the digits is toothed (58, 62) so that as they slide past each other, they induce opposing rotating motions on the opposite digit, opening and closing the claw also seen in Figure 6. One advantage to this device is that it can be locked into place if the claw is closed far enough using a ratchet mechanism between the handle and trigger parts of the grasp (40).

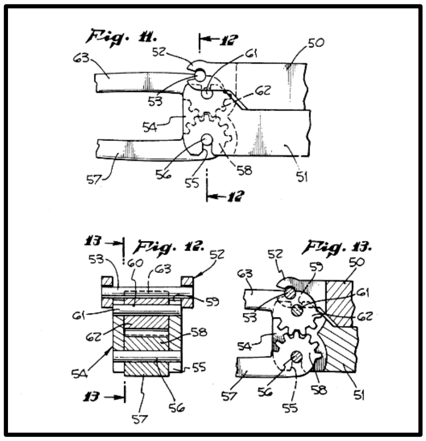


Figure 6: Claws of Surgical Device with Double Actuation Jaw

2.2.2.2: Lock-Type Gripping Device for Handicapped Persons, US 4374600

This device adds functionality to the standard reacher gripper by including a rotatable arm shown in Figure 7. Such an arm is useful for users sitting in wheelchairs that might need the extra mobility to reach around obstacles such as a high cabinet. Tasks such as these would otherwise be unachievable with standard reacher grippers. The claws are opened and closed by pulling a trigger (54) which tenses a cable (78) that runs the length of the device. The middle of the shaft is jointed so that the arm can be folded up and down, locking into specific angle positions on the index plate (72). The claw can still be used in these positions allowing more freedom for the user to grab objects. The locking mechanism on this gripper, as shown in Figure 8,

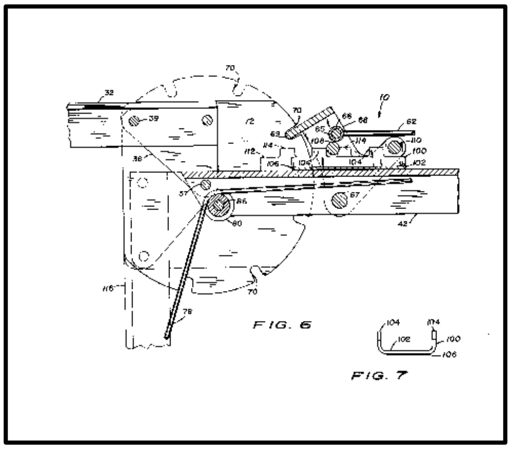


Figure 7: Locking Mechanism of Lock-Type Gripping Device for Handicapped Persons

allows the user to safely operate the device by both sliding a “U” shaped block and then depressing a button to ensure no accidental release of the device.

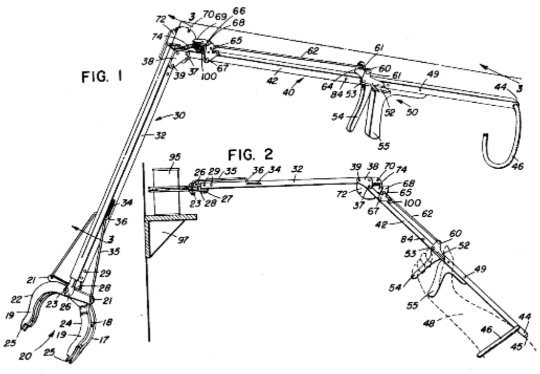


Figure 8: Shaft in bent variation of Lock-Type Gripping Device for Handicapped Persons

2.2.2.3: Handy Extending Grip, US 3112135

This reacher gripper device adds an extending capability through a scissor like mechanism that is operated through the use of one finger in a scissor-like motion as shown in Figure 9. The extension links (12) are connected to one another on a central axis through hinge pins (14). At any extension state (collapsed to fully-extended) the gripper mechanism is still functional. This is possible for two reasons. The first reason is that only the upper digit (20) is actuated in this device. The second is that this device is operated via a spool mechanism (26) which can be manually adjusted at each length to clamp the desired object. The spool itself is connected to the pincer by a wire.

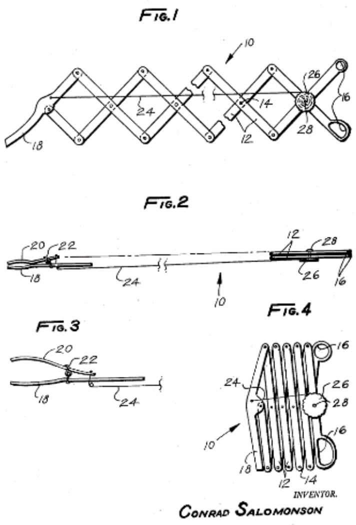


Figure 9: Extending capability of Handy Extending Grip

2.2.2.4: Grab Bot

This reacher gripper design received a provisional patent as part of a previous Major Qualifying Project completed in AY 2011 at Worcester Polytechnic Institute (Busteed & Rinaldi, 2011). This design, seen in Figure 10, made use of many features not fully utilized in previous designs, however, the most important additions were the electromechanical actuation of the claws and the increased arm support/ergonomic grip for users with physical disabilities. The electromechanical operation is controlled via a rocker switch placed at the location of the hand grip. This switch drives an electric motor which rotates a dual threaded rod that drives the two clamps together or away from each other depending on the user's input. This function both adds a way to keep the claws in positions along their clamping path as well as far more control of the claws than the common reacher grippers discussed in section 3.2.1. The other ergonomic aspects of this device also add to the successes of this design. By implementing a robust arm support, much of the stress normally applied at the wrist or forearm muscles is relieved by balancing the moments. Furthermore, a cylindrical handgrip was utilized to add further comfort to the user when operating the device.

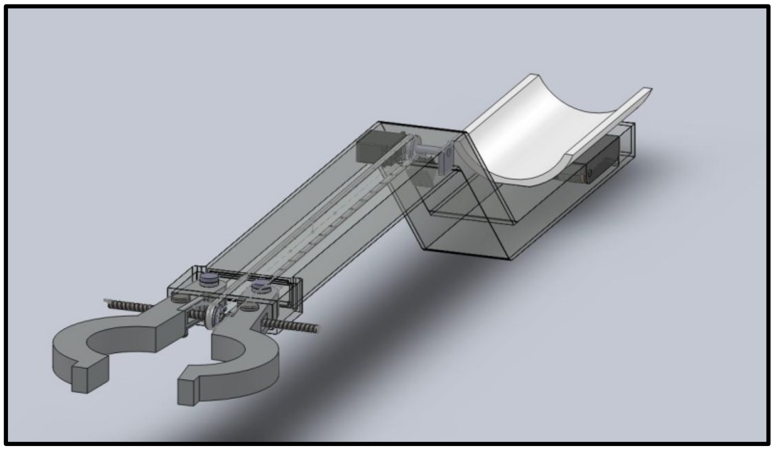


Figure 10: SolidWorks Model of Grab Bot, Previous MQP (Busteed & Rinaldi, 2011)

2.3: Evaluations

In order to design and build an effective device, the metrics for measuring the performance of users and devices must be evaluated. Using a set of metrics allows designers to make valid claims regarding performance and effectiveness of a device. Below are some qualitative and task-oriented evaluations. These were utilized to determine which aspects were most helpful in the development of a new reacher gripper.

2.3.1: Evaluating the Independence Level of a Person

A person’s functional independence level depends on their ability to perform activities of daily living. Activities of daily living (ADLs) are defined as the things people normally do in daily living, including any daily activity that’s performed for self-care such as feeding oneself, bathing, dressing, grooming, working, homemaking, and leisure (Medical Dictionary). These activities are considered necessary for living a healthy independent life. The ability or inability to perform ADLs can be used as a very practical measure of ability/disability in many disorders (Medical Dictionary).

To measure the independence level of a person with disabilities, clinicians recommend using self-administered evaluations. The DASH (Disabilities of the Arm, Shoulder, and Hand) is the most widely-accepted tool for measuring upper extremity disability. The Institute for Work & Health and the American Academy of Orthopedic Surgeons (AAOS) created the DASH by pooling together the items of several upper extremity questionnaires and filtering out any items which were too specific to any one disease or condition. Out of the 132 total items, 72% were relevant to the upper extremity as a whole. The DASH is a self-administered questionnaire that focuses on physical functions rather than specific conditions or afflicted parts of the body. It is a uniquely effective measure of upper extremity ability because it is not specific to any particular anatomic site or disease entity and only contains evaluation criteria that can be completed and understood by the patient with no in-depth medical knowledge or training (Hudak, 1996).

Subjects begin the DASH by rating their own ability to accomplish various daily activities pertaining to the upper body. Twenty-one activities are rated on a scale of 1 (no difficulty) to 5 (unable). Examples of these activities are as follows: ‘prepare a meal’, ‘carry a heavy object’, ‘change a lightbulb overhead’, etc. Subjects are not required to rate the difficulty of all twenty-one activities. Subjects then rate symptoms from a list on a scale of 1 (not severe at all) to 5 (extreme severity). These symptoms include pain, tingling, weakness, and stiffness in the arm, shoulder, or hand. Subjects proceed to an optional module of the test where they can rate any difficulties they may be having related to work or recreation involving their arms, shoulders, or hands. After completing the sections listed, the sum of the ratings of each questions are determined by the equation:

$$\left(\frac{Sum\ of\ n\ responses}{n} - 1\right) * 25$$

where *n* is the number of completed responses. The maximum achievable score is 100 and the minimum is zero. A score of 0-20 is considered normal, 20-40 indicates mild disability, 60-80 indicates severe disability. Any retests require a minimum difference of 15 points in order to be considered clinically important (Institute for Work & Health and AAOS).

A consistent theme throughout the research on disability evaluations is that they focus on the capabilities of individuals rather than their disabilities. This makes sense, as the treatments/assistive solutions for any particular score on the DASH are often overlapping. For example, two subjects who scored similarly on the DASH may be given identical treatments, regardless of their particular condition. The proper treatment for upper extremity disabilities is dependent on the individual's personal capabilities rather than the nature of their disease/condition.

2.3.2: Evaluating the effectiveness of a reaching device

The reacher gripper is a very popular form of assistive technology. Reacher grippers can improve the functional capabilities of individuals with disabilities by extending their range of reach. By doing this, users have less need to stretch or bend over, reducing possibility of further physical impairment (Chen, 1998).

In response to a survey where reacher gripper owners indicated a high rate of dissatisfaction with their devices, Chen, Mann, Tomita, and Burford set out to create a method of evaluating reacher grippers. They first began by creating a questionnaire about common tasks for which reacher grippers are most commonly used. This list of tasks was compiled from a Consumer Focus Group on Reachers at The WNY Independent Living Center. The team conducted phone interviews where they asked sixteen reacher gripper users over the age of 65 to rate the importance of the tasks on a scale of 1 (unimportant) to 3 (very important). The 8 tasks which were determined to be 'most important' were then used as test criteria to measure the effectiveness of 3 different reacher grippers.

Since the team could not test all the reacher grippers on the market, they decided to narrow their scope to 3 different reacher grippers, which were popular among users. Seven criteria for the "ideal" reacher gripper were identified by a focus group:

- Adjustable Length
- One-Hand Use
- Life-Time Guarantee
- Lock System for Grip
- Forearm or Wrist Support
- Lightweight
- Four-Finger Action Trigger

The team selected three reacher grippers which satisfied at least five of these criteria to evaluate using their new reacher evaluation method. The reacher grippers were evaluated based on the speed and accuracy with which the users could operate them. The overall user preference was also taken into account when completing the following tasks:

1. Put Cans into Cupboards
2. Take out Cans from Cupboards
3. Put Dishes into Cupboards
4. Take out Dishes from Cupboards
5. Pick up Remote Controls
6. Pick up a Newspaper from the Floor
7. Dressing, Pulling up Socks
8. Opening/Closing Drawers

Each task was timed to determine which reacher gripper allowed the user to complete the task in the shortest time. This was an unbiased and objective way of evaluating the user's proficiency with each reacher gripper. However, the speed of task completion was only different when picking up remote controls. Subjects in this study were also asked to make comments about what they perceived to be the best as well as their least favorite reacher gripper. Comments for individuals' "favorite" reacher grippers include:

- Lightweight
- Good Grasp
- Forearm Support
- Lock
- Easy to Use
- Easy to Squeeze
- Comfortable to Use
- Feel Secure
- Functional
- Sensitive Mouth
- Long
- Strong

Comments for individuals' "least favorite" reacher gripper include:

- Bad Grasp
- Complicated
- Uncomfortable to Use
- Unsecured
- Clumsy
- Heavy

- Difficult to Squeeze
- Too Long
- Not Strong
- Don’t like Forearm Support
- Too Short
- Bad Mouth
- Thick Handle
- Hard to Use
- Doesn’t Work Well
- No Forearm Support
- No Lock

These comments are important criteria to consider in the design of a reacher gripper. They all factor into the overall effectiveness of the device as a commercial product and an assistive device. Using the feedback from users in this study, a better and more effective reacher gripper may be designed.

2.3.3: Evaluations of Available Reacher Grippers

All four of the reacher gripper devices described in the previous sections were tested using the evaluation of reacher grippers, based on typical activities which would require their use (Chen et. al., 1998). Many of the evaluations were then compared to typical users’ reactions to the devices. The results from this testing are listed in Appendix F.

The GnG proved to perform precisely as many of its users explained through their reviews. The device’s light weight, ergonomic grip, and ability to rotate made it easy to use. However, the user needed to apply significant force on the trigger to maintain grip on objects throughout the tasks. The high amount of grip strength needed for this device would be problematic for users with arthritis or other ailments. Additionally, the geometry and material of its jaws made it effective at picking up most objects with thickness less than 4 in.

In testing the MR, results indicated that it supplied a far greater force than the GnG to objects when successfully positioned. However, it was harder to accurately position the claws to grab an object at distance. The device also required a large amount of forearm strength to lift heavier objects. While this device is specified for picking up items under 5-lbs, users may require a reacher gripper that can exceed this specification for more widespread use.

The HSGL, while intended for arthritic users proved to be the most limited commercial device throughout testing. While this device was more useful for picking up wider cylindrical objects, it was deficient at grasping the larger range of objects able to be picked up by both the GnG and MR. This was due to both the poor design of the extra-wide claws and the ineffectiveness of the locking mechanism. For instance, in the locked position the claws could be forced open with relative ease.

The Grab-Bot by far applied the greatest amount of gripping force out of all the grippers tested, meaning that it could pick up some heavier and slicker objects than the other grippers. However, it also performed worse than the other grippers in many aspects. The claws themselves were extremely thick and bulky, which made them difficult to maneuver into tight spaces when retrieving objects. The claws were shaped like half circles, which made picking up cylindrical objects that were smaller than the inner diameter of the claws very difficult. The speed of the claws was another great hindrance. It took eight seconds for the claws to go from fully open to fully closed. This made retrieving objects a time consuming process, especially if the object was not grasped correctly on the first try. Lastly the device was extremely heavy. At 4.1 pounds, it was difficult to wield, and required significant upper arm, hand, and wrist strength.

Chapter 3: Project Objective

There is a need to develop an assistive device for persons who have difficulty completing daily activities as a result of their limited reaching capabilities, hand and wrist strength, and hand control. A handheld electromechanical device that allows a user to grasp and manipulate objects in their area would augment the user's ability to complete tasks normally hindered by their disabilities. Such a device could improve the independence of the user and allow for a less restricted lifestyle, while alleviating added risk of injury during everyday tasks.

Chapter 4: Functional Specifications

The following chapter discusses the functional specifications considered in the design of the gripper device. These specifications were derived from observations made in preliminary evaluations of commercial reacher grippers and the Grab-Bot. The goal of functional specifications is to outline the typical usage and the actions which the device must be capable of performing/enduring. These specs are later translated to design specifications, which are engineering goals required to satisfy the intended functions of the device.

Functionality

1. The device is intended to allow the user to manipulate and relocate objects up to 3-ft away from the user's normal reach.
    a. This is the primary function of the device. Users will need extended reach.
2. This device must be able to accomplish tasks specified through established tests for reacher grippers in chapter 3 to evaluate level of independence in daily living situations
    a. This quantifies how well the device aids with daily tasks.
3. The device must be capable of holding objects that:
    1) Measure between 0.0039-in and 5-in in their smallest dimension
        a) In order for an object to be grasped, the object must fit between the claws of the gripper. (A 12-in x 12-in x 5-in object would be able to be picked up by grasping the faces which are only 5-in apart. However, if the object does not have any dimensions less than 5-in, the claws would be incapable of grasping it.)
    2) Weigh up to 10-lbs.
        a) We wish to give the user the greatest freedom in what they can manipulate. Manual competitor products are designed to pick up 5-lbs, but adding an electromechanical element should allow the device to pick up to 10-lbs.
    3) Have the form of any shape
        a) The shape of an object shouldn't be a limiting factor for the device.
4. The device must be able to function with droplets on its surface (i.e. equivalent to light to medium rainfall)

    a. We are intending this device to be used for daily functions, which at sometimes may take place outdoors with a possibility of rain or in a wet environment (kitchen or bath).

5. The device must be able to fully close from open position in under 4-sec.
    a. We would like the operation of the device to have a minimal effect on the user's time.

Convenience

6. The device, in its most compact configuration, must fit within a cylinder of 9-in diameter and 24-in length.
    a. In order for the device to be used at all times it must be able to be stored in a compact manner.
7. The device must weigh less than 4.1-lbs (weight of the previous MQP's device).
    a. To improve upon the previous design, the previous MQP is a good reference (Busteed & Rinaldi, 2011).
8. The device must be able to be donned and doffed with one hand in under 10-sec.
    a. This device is intended to be used periodically throughout the day, therefore the setup should have a minimal effect on the user's time.
9. The device must not require maintenance beyond replacing or recharging the power source.
    a. Competitive reacher grippers do not require maintenance from the users.
10. The device must operate independent of an external power source.
    a. Having to plug in a device when it is being used can limit where and when it is able to function.

Safety

11. The device's claws must not deflect more than 1/16-in perpendicular to their plane of motion under specified operating conditions.
    a. Since the claws only have two points of contact with the object, they must remain collinear in order to avoid creating a force couple on the object.

12. The device must be able to carry an object without continuous input from the user.
    a. The device should have some type of either locking mechanism or non-back drivable actuation.
13. The coefficient of friction between the claws and a glass object should be at least 0.44 (rubber on glass).
    a. In order to safely hold objects, the device should reduce the possibility of objects slipping from its grasp.
14. The device must not have any sharp points, protruding electrodes, or entangling moving parts upon which the user is likely to injure his/herself or others.
    a. No injuries should result from the use of the device.

Durability

15. The device must be able to properly function after a 3-ft drop onto ceramic tiled surface.
    a. Humans are prone to accidents; therefore, the device must be robust.
16. The device should be able to be used up to 75 times a day for a total lifespan of up to 2 years (approximately 55,000 uses).
    a. The MQP: "Grab-Bot: Reaching/Retrieving Aid" established that an average reacher gripper would be 75 times per day (Busteed & Rinaldi, 2011). The device should satisfy these conditions at a minimum.
17. The device must remain functional after the claws have been submerged in water up to 3-in
    a. Items may need to be retrieved from water.
18. The device must be able to operate within an ambient temperature range of 0˚-110˚F.
    a. The device should be able to operate in diverse environments to accommodate the largest number of users and uses.
19. The device's claws must be able to withstand temperatures up to 212˚F
    a. Items may need to be retrieved from boiling water.

Ergonomics

20. The device must keep user's wrist in a comfortable and anatomically neutral position (hand coplanar with forearm).
    a. Non-neutral wrist positions cause more muscle stress than neutral position.
21. The device handle must be between 4-in and 6-in long.
    a. This accounts for the average width of the human palm.
22. The device handle must be between 1-in and 1.5-in in diameter.
    a. This is recommended for maximum grip power (Patkin, 2001).
23. The device handle should use ergonomic geometry to prevent sliding of the hand.
    a. Using ergonomic geometry would provide a more secure and comfortable grip for the user.
24. The device must be designed to be operated by using the 'power grip'
    a. Makes use of stronger muscles in the hand so that the user can apply greater gripping force.
25. The device should require no more than 3.7-ft-lb of ulnar deviation torque from the user to operate.
    a. This maximum value is determined by the average maximum ulnar deviation strength of people over 70 years old, with a safety factor of 2 (Patkin, 2001).
        i. (8.36 lb-ft) *(1-0.22)/ (2) = 3.7 ft-lb
    b. Individuals with joint pain or muscle weakness will have difficulty utilizing the device if it places great stress on the joints.
26. The device should require no more than 16-lbf of grip strength for the user to operate.
    a. This maximum value is determined by the average maximum grip strength of a female rheumatoid arthritis patient (Patkin, 2001).
    b. For individuals with muscle weakness, the more strength required to operate the device, the more difficult it will be to use.
27. The device operation must not require excessive movement in the user's finger digits
    a. Individuals with joint pain, joint stiffness, or joint deformity may have a limited range of motion in the digits, and moving these joints may cause pain.
28. Typical wrist orthoses gloves should not impede the user's ability to use the device.

    a. The device should be comfortable and easily used with devices that the users may require. Wrist orthosis gloves will constrain some thumb movement, hold the hand in the handshake position, and add extra material between a user's palm and the device's handle.

Cost

29. The prototype of the device must be able to be manufactured using on campus machine shops and commercially available parts.
    a. This will be the fastest and least expensive method for constructing the device.
30. The device's manufacturing should minimize the need for sophisticated machining operations.
    a. These processes are expensive and time consuming.
31. The prototype of the device must cost no more than $495 to build
    a. The budget is limited.

Chapter 5: Preliminary designs

The following chapter presents the preliminary designs created during the design process. The designs are simple concepts which were later evaluated, narrowed down, and combined to form an overall design for the device. The preliminary designs in this section are separated into four distinct categories by function: Actuation, User Interface, Arm/wrist Support, and Claws. These components are defined as follows:

- **Actuation**: Any components involved in moving or rotating the claws which do not come into direct contact with the user (i.e. motor, linkages, springs, gears, threaded rods, etc.).
- **User Interface**: Any components which come into direct contact with the user during device operation.
- **Arm/wrist Support**: Any component that comes into contact with the user to cancel the moment about the user's wrist.
- **Claws**: The components which directly contact the object being grasped.

5.1: Preliminary Design 1 – Worm Gear with Dynamic Claw Energy Storage

This design, shown in Figure 11, applies the torque of the motor directly to the jaws of the gripper, rather than using a pulley like the Grab-Bot design. It also allows for a greater range of motion of the jaws for gripping large objects (90-deg should be achievable). An electric motor (1) turns a worm (2) which turns worm gears (3) that are rigidly attached to the jaws (6) of the gripper via countersunk machine screws (4). This design provides nonbackdrivability as well as consistent gripping force throughout the entire travel motion of the jaws. The jaws/worm gears rotate freely around a shoulder screw (5). The shoulder screw has very tight tolerances and will allow minimal side-to-side deflection of the jaws; especially if low-friction bushings are press-fitted into the worm gear/jaw. When

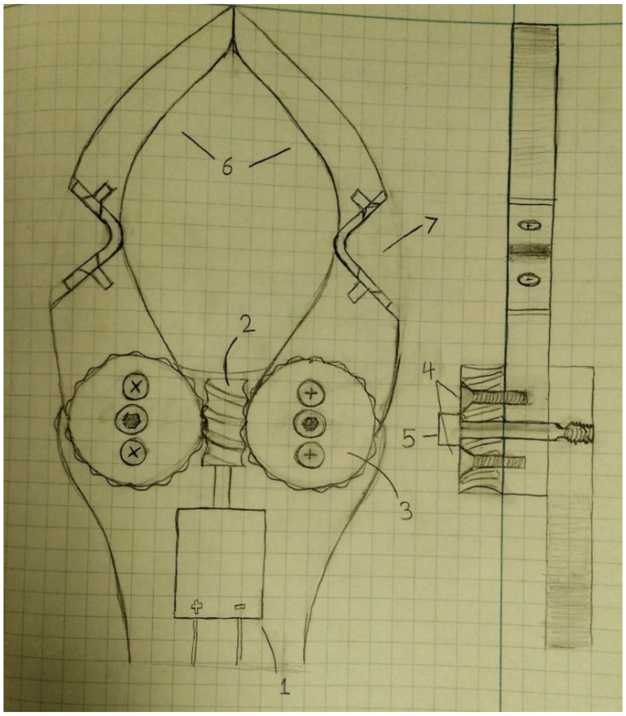


Figure 11: Worm Gear with Dynamic Claw Energy Storage

the jaws contact an object, the motor will keep turning and the L-shaped flat springs (7) will bend. Storing mechanical energy in the flat-springs allows the device to clamp down on an object. However, no energy is spent by motor to hold the object since the mechanism is non-backdrivable.

Ninety degrees of motion for each jaw allows gripping of large objects. Gear ratios must be adjusted in order to achieve desirable open/close speed of the jaws. Material for the jaws will have a high coefficient of friction and a small amount of compressible length so that the gripping surface can conform between the jaws.

5.2: Preliminary Design 2 – Scissor Linkage with Spring Energy Storage

Figure 12 displays a simplified layout of this design. The claws (1) are opened and closed by the movement of the scissor-like linkage (2). As part (3) is moved to the right, the claws close, and as it is moved to the left, the claws open. The pin joint (4) in the scissor link is secured to the shaft (5) outlined in the diagram. This shaft surrounds all components in the diagram except the claws and the middle joints of the linkage (6) as the linkage expands and collapses. Joint (4) must be very secure to ensure that the linkage does not deflect and leave the plane of the diagram. Part (3) is connected to part (7) via a spring (8). A motor near the handle (9) spins a threaded rod (10). Part (7) is threaded along the inside, and as the threaded rod spins, part (7) translates along the shaft. This causes displacement in the spring. If the claws are initially open, as part (7) translates towards the motor, part (3) is pulled along too, causing the claws to close. Once the claws are together or are grasping an object, part (3) no longer moves. As part (7) continues to translate, the spring is stretched, which applies clamping force at the claws.

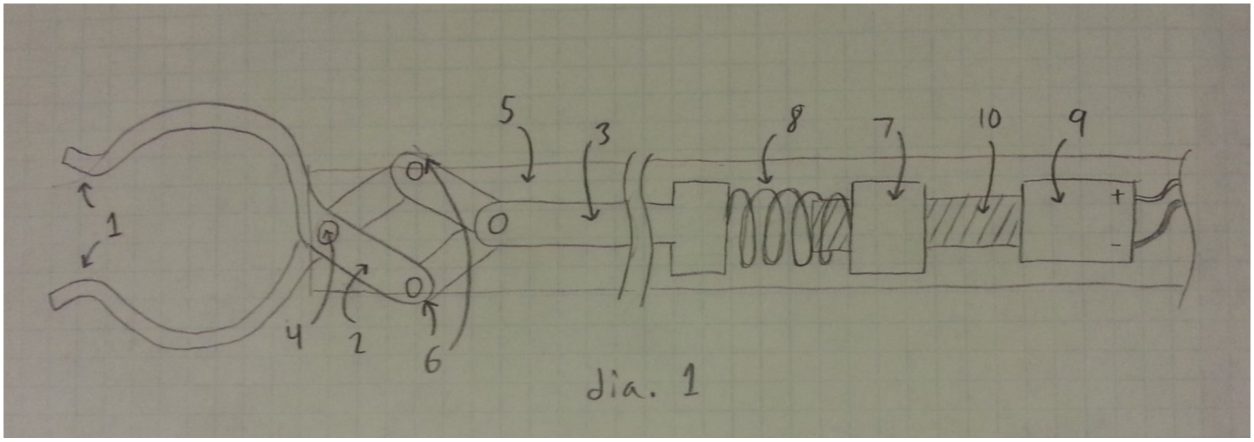


Figure 12: Full Scissor Linkage Gripper Design

Diagram 2 in Figure 13 contains a more accurate representation of how part (3) and part (7) fit together. Diagram 2 displays a cross-sectional area through the middle of part (3) along a plane through the axis of the shaft. Diagrams 3 and 4 show three-dimensional views of parts (3) and (7) respectively. Part (7) fits within part (3). As part (7) translates towards the claws, the spring retracts until it reaches its neutral length. At this point, part (7) contacts a shelf (11) within part (3). From here, part (7) pushes part (3) towards the claws without storing any energy in the spring. A sliding resistor (12) is fixed to the top of part (7). The tab of the resistor (13) is confined in a slot (14) on the top of part (3). As part (7) moves in and out of part (3), the resistance of the resistor changes. Because the clamping force at the claws is linearly proportional to the deflection of the spring, the resistance can be used to approximate the clamping force. The amount of clamping force could possibly be indicated by colored LEDs at the handle, facing the user. Different colored LEDs would correspond to different amounts of force.

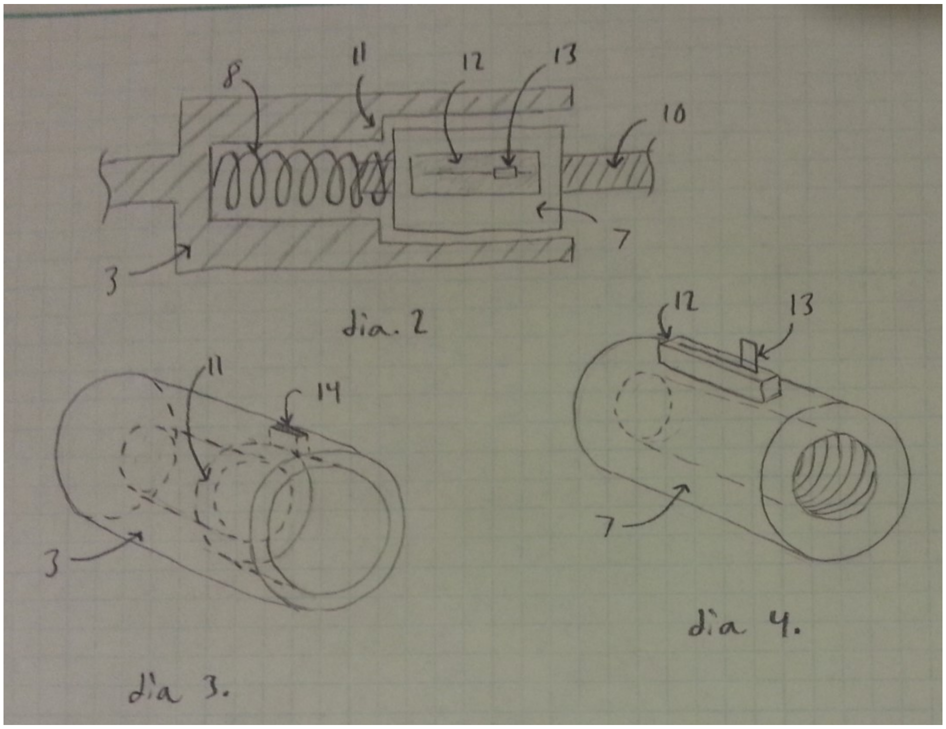


Figure 13: Scissor Linkage Design Components

5.3: Preliminary Design 3 – Compound Geared Mechanism

This design, shown in Figure 14, makes use of a gear set to actuate the claws on the reacher gripper. This design uses widely available and inexpensive pinion gears, a compound gear, and a link. The torque from the motor (1) is transferred to the first pinion gear (2) via a link (3). The driving pinion gear then transmits the torque to the larger of the two gears on the compound gear (4). The smaller of the two gears on the compound gear then interacts with a larger output pinion gear (5). When this gear rotates, the opposite pinion gear (6) will rotate in the opposite direction to open or close the claws. A type of gear train like the one being used is necessary to increase the difficulty of backdriving the device. This design also increases the mechanical advantage by increasing the gear ratio between the input and output gears at multiple stages. An important aspect of this design is securely mounting all of the gears to the frame while still allowing rotation. However, this may be accomplished through the use of lubricated bushings and shoulder screws which will both maintain the position of the gears while not adding friction, which would reduce the efficiency. Some difficulties with this design include the required geometry of the shaft needed to store all the components, the chance of gear backlash, and the non-limited rotation of the output pinion gear.

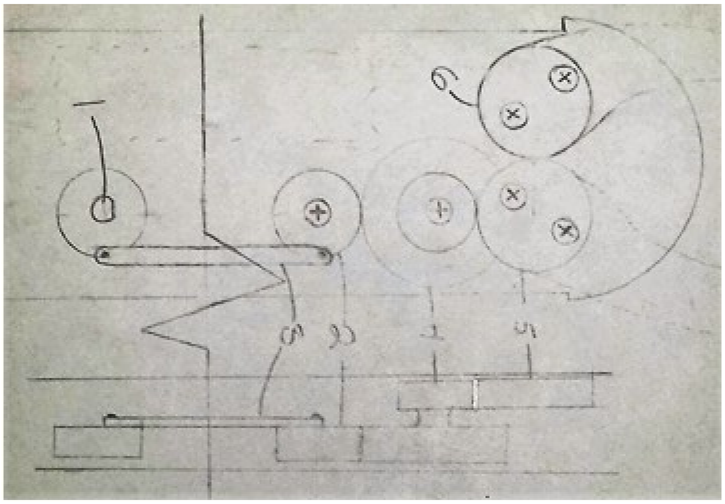


Figure 14: Compound Geared Mechanism

5.4: Preliminary Design 4 – Hilt and Rocker Switch

This design for the user interface features (Figure 15) an angled oversized handle for power grip. An oversized handle allows the user to position their hand in such a way that places the tip of their index finger directly on top of the rocker switch (shown on the front of the handle (1)). During normal operation, the user's fingertip rests directly in the center of the rocker switch, preventing them from accidentally activating the device. To operate the claws of the device, the user simply moves their finger up or down to activate the rocker switch.

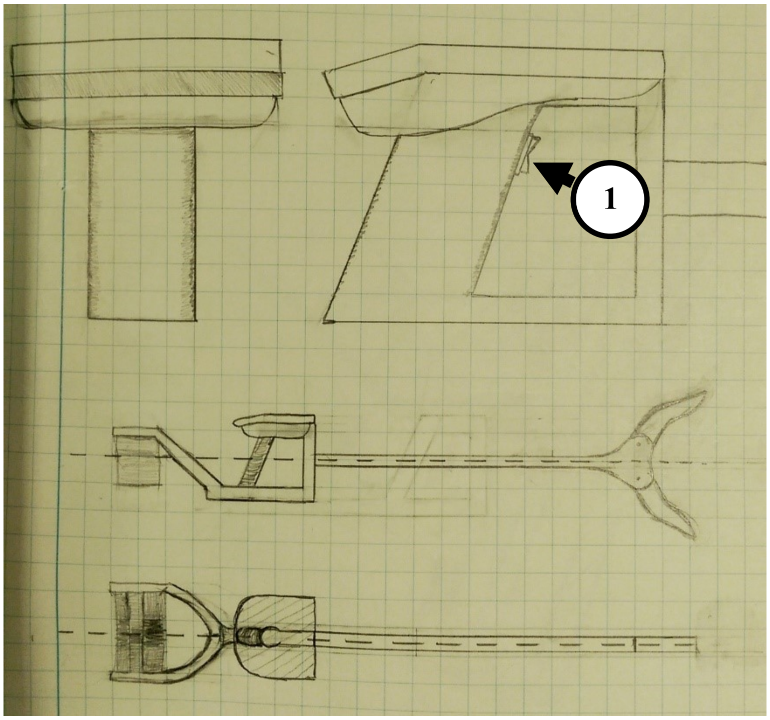


Figure 15: Hilt and Rocker Switch

The rocker switch, when pressed upward will close the jaws until they contact an object. The device will ‘know’ when to stop the motor by measuring changes in current draw by the motor, distance traveled by a spring, or force sensing. A second click upward will activate the motor again, causing it to turn a specified number of rotations, providing a bit more clamping force at the claws. A third click will do the same to further tighten the grip. To release the grip, the user presses the rocker switch downward, activating the motor until the claws reach their fully-open position.

This user interface also features a cushioned hilt at the top of the handle. When used in conjunction with a wrist/forearm support, the hilt can reduce the amount of force required from the top two fingers of the user to prevent the device from rotating downward out of the user’s hand.

Without a forearm support, the device naturally wants to rotate downward about the bottom of the user’s hand, requiring equal force input from the wrist and top two fingers of the user. When testing the previous MQP team’s device, the forearm support actually moves the point of the rotation back onto the forearm of the user, where the forearm support ends. By moving this point of rotation, the user’s fingers actually have to work harder. By placing a hilt on top and supporting the wrist/forearm/bottom of the hand simultaneously, the device can no longer fall out of the hand of the user.

Instead of a hilt, this design could use a small leather loop through which the user puts their hand. This kind of feature can be seen on Wii gaming system remotes or on digital cameras to prevent the user from accidentally dropping the device. These small leash-like loops are easily tightened using a small plastic slider.

5.5: Preliminary Design 5 – Bi-Directional Trigger

Diagram 1 in Figure 16 outlines the basics of this bi-directional trigger mechanism. To operate this device, users would place their palm and thumb around the handle portion (1). The fingers would wrap around the side of the handle, opposite the thumb, and pass through the loop (2). Users would grasp this device similarly to how they would grasp a lever action rifle. All four fingers could be used to both pull the loop towards the handle and push the loop away from the handle. This allows for a large amount of versatility in where the fingers are positioned. It also reduces the strength needed in any one finger to use the device. The loop pivots around a pin joint located inside of the device. A spring-loaded connector (4) is connected to the pivot. This connector allows the loop to snap into three distinct positions as defined by the contours in part (5). Having the loop in one of these three positions can control when the claw is opening, when it is at rest, and when it is closing. Signals to the motor can be controlled by electrical contact between the connector and the divots of part (5). The signals could also be controlled with a potentiometer at the pin joint. The pin joint, connector, and part (5) could be done away with entirely by connecting the loop directly to the end of a three-position switch. A user cannot firmly grasp this device without pulling the loop toward the handle. Moment and force cancellation at the wrist would be needed to ensure that this does not happen unintentionally. Alternatively, the loop could be reduced in size to fit just the top two fingers. The bottom two fingers would be free to squeeze the handle.

Diagram 2 illustrates an alternative design. The loop is connected to a slider (6) that translates along the shaft within a slot (7). The position of the slider could be determined by attaching it to a sliding resistor (8).

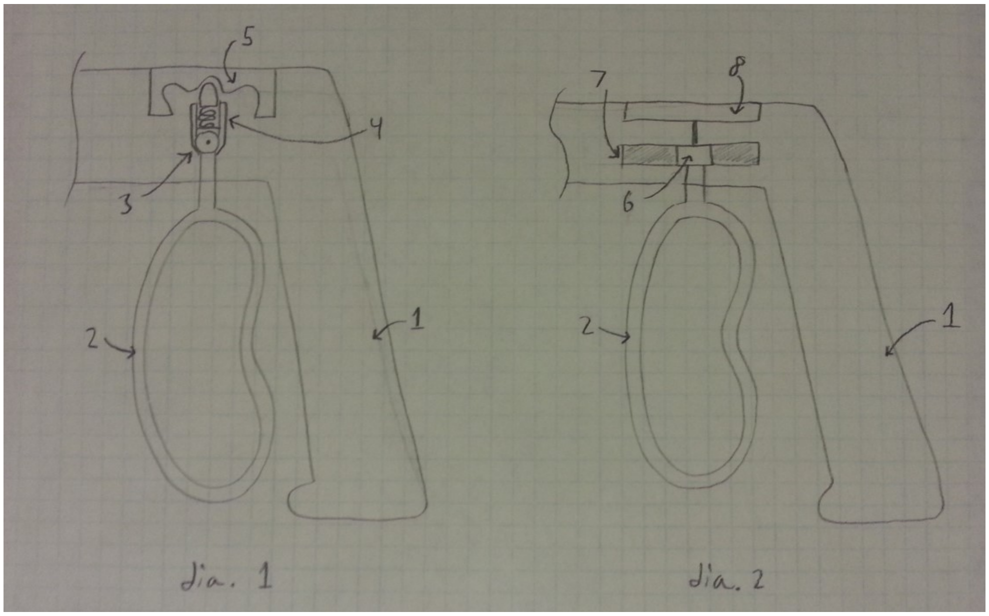


Figure 16: Bi-Directional Trigger

5.6: Preliminary Design 6 – Primer Switch

This design for the user interface (Figure 17) makes use of an ergonomic pistol or bike grip (1). Three buttons are located on the grip. The button placed at the thumb position is a primer button (2). This button does not allow the user to actuate the mechanism unless it is depressed. The button would have to register contact at switch found within the grip (3). When no pressure is applied a compression spring (4) will keep button 2 in its neutral position. If the primer is depressed, the user will have the opportunity to drive the claws forward using the button at the pointer finger location (5) or backward using the button at the middle finger location (6). Both buttons will act much like the primer in that they will contact a switch in the grip (7, 8) when depressed but will return to position by compression springs (9, 10).

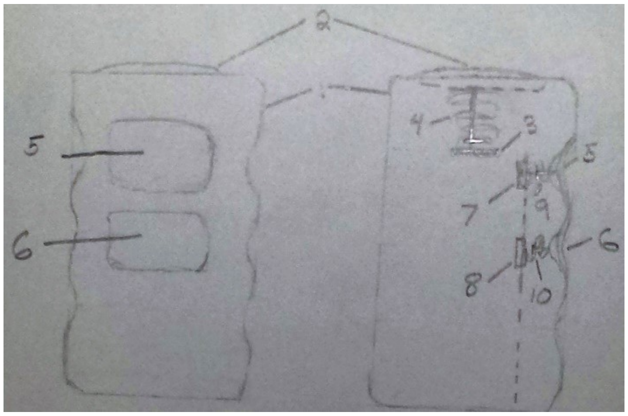


Figure 17: Primer Switch

This design will need to make use of programming to ensure the correct operation of the device at all times. In theory misuse of this design will be very difficult because the primer button is not in the natural position for the thumb, which would be on the side of the grip rather than the top. The difficulty with this setup is it may require some practice before a user can confidently operate the device. Another feature which may improve the interaction with the user would be a constant feedback system that will relay a light, digital readout, or intuitive analog gage that will notify the individual when certain thresholds of power are being applied to an object (i.e. none, contact, maximum).

5.7: Preliminary Design 7 – Adjustable Forearm/Wrist/Hand Support

This design, shown in Figure 18, features an adjustable wrist support for the device. A long screw (2) is placed in the handle (1) of the device. The wrist support (3) has a threaded hole down the center of it. The gap on the left side of the handle is a slot cut out of the back of the handle (1). The slot prevents the wrist support (3) from rotating, constraining the wrist support (3) to up and down motion only via the long screw (2). The user simply turns the screw head at the bottom of the handle until the wrist support (3) is raised to the perfect height for comfort.

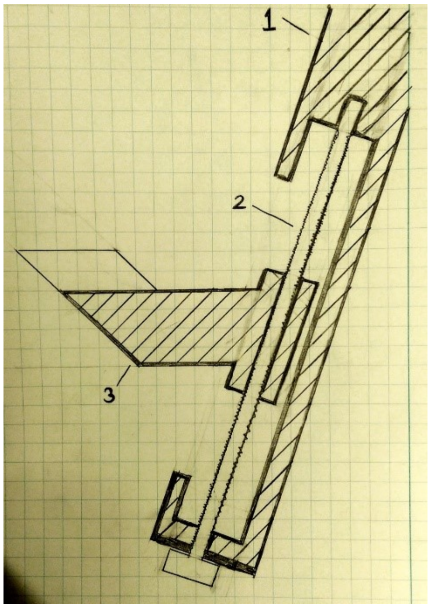


Figure 18: Adjustable Forearm/Wrist/Hand Support

The wrist support needs to be adjustable because users have different sized hands. In order to take as much strain off the user as possible, the device must fit their hands/wrist very well, keeping the wrist in a perfectly neutral position, as necessitated in the design specifications.

In order to eliminate the moment about the user’s wrist, the support runs along the bottom of the user’s hand, across the wrist, and about an inch onto the forearm.

5.8: Preliminary Design 8 – Articulated Arm Support

Diagram 1 in Figure 19 illustrates an arm support rest (1) and its attachment to a gripper handle (2). The arm support is in the shape of half a cylinder, in which a user rests their forearm. The support cancels moment at the wrist caused by the weight of the gripper and whatever is being grabbed. It does this by applying a normal force at the bottom of the arm. The cylindrical shape allows for this normal force to be applied even when the forearm is slightly rotated about its axis. The support is connected to the handle by two beams (3) (4) with a pin joint in between them. Diagram 2 shows this connection in greater detail. The beams are joined to each other via two bolts (5) and two lock nuts (6). This articulation is positioned directly below the wrist and serves to allow a user to move their wrist from side to side. This increases a user’s range of motion and maneuverability when using the device. One problem with this design is that as the hand becomes more perpendicular with the forearm, less moment is canceled by the arm support.

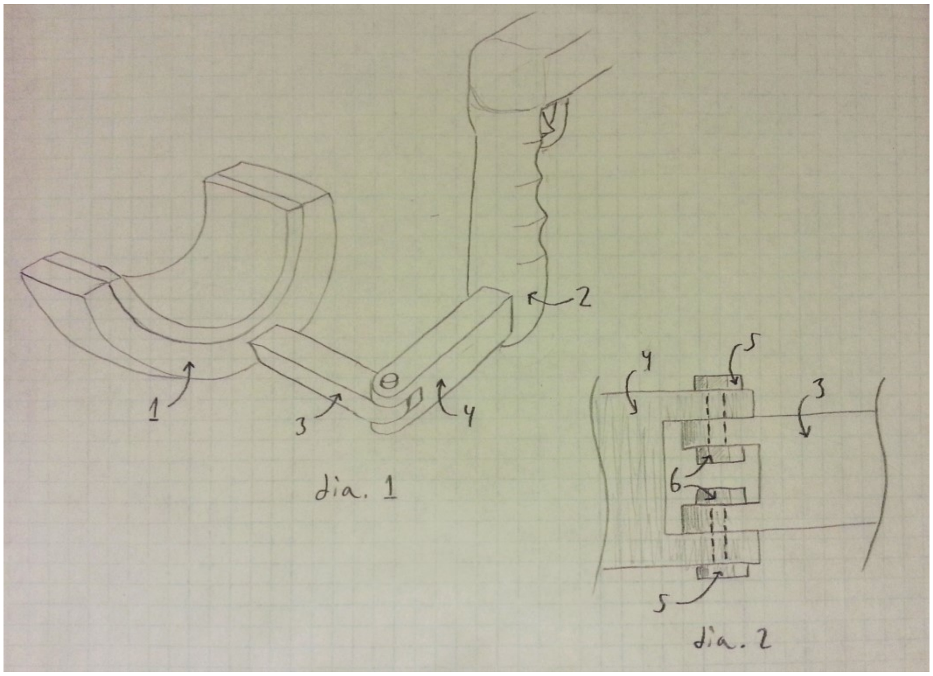


Figure 19: Articulated Arm Support

5.9: Preliminary Design 9 – Traditional Forearm Support

This design for a forearm support, shown in Figure 20, makes use of traditional supports in assistive devices for users with multiple sclerosis or cerebral palsy. The design consists of

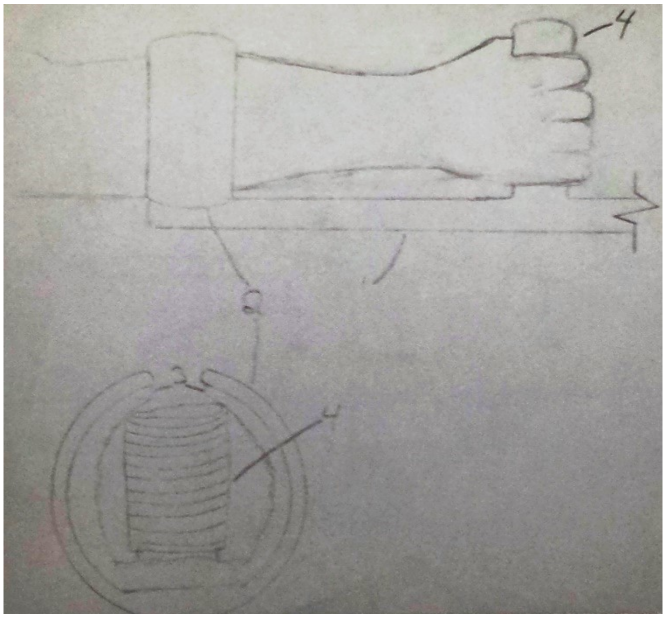


Figure 20: Traditional Forearm Support

three main parts. The first is the baton shaped metal shaft (1). The major function of this part is to add rigidity to the support so it will not deform. Attached to it is a rigid forearm support (2) which encompasses the forearm of the user. To make this more comfortable for the user a cushioned surface (3) is connected to the forearm support. An additional advantage of the cushioned surface is it allows the support to conform to users' various arm sizes. The third component of the support is the grip (4) which connects to the baton shaped shaft. The placement and orientation of this grip maintains an ergonomic power grip that can easily be adapted to include controls for the user interface. Another positive aspect of this design is that it maintains a straight extension from the arm through the device to the claws which will enable a larger, more controllable, range of motion for the user.

5.10: Preliminary Design 10 – Conforming Spring Claw

This claw, shown in Figure 21, was designed to provide optimum conformity to an object, therefore providing maximum possible surface area contact between the claws and the object being grasped. The claw has a solid gripping surface, but the other side has cutout geometry, allowing the claw to bend. The spaces cutout of the back of the claw allow the piece to bend, but prevents the part from bending too much. This part can be easily manufactured by 3D printing. If it is printed flat on the bed of the printer as show here, the fibers of the plastic

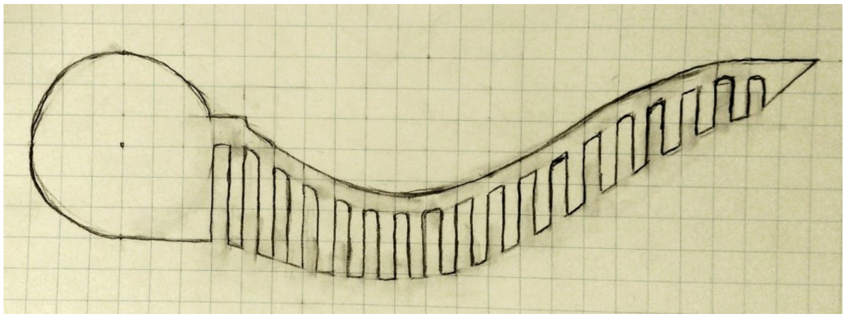


Figure 21: Conforming Spring Claw

filament will be put under tension when the part is in use, which will maximize the elasticity and yield strength of the part. For additional stiffness, a stiff metal band can be attached to the gripping surface of the claw. Another way to increase the stiffness would be to dip the part in polyurethane and let it dry, leaving a compliant polyurethane plate in each cutout space on the back of the claw. This claw design could also be used to store mechanical energy in the claws and is compatible with the actuation design that uses flat springs.

5.11: Preliminary Design 11 – Asymmetric Bent Claw

Figure 22 illustrates the claws both in a closed and an open position. The main bodies of the claws (1) are angled in such a way that most objects that fit inside of the main gap (2) will have four points of contact with the claw. The claws can be opened outwards about 35° from the closed position in order to have parallel gripping surfaces on either side of a large object. The tips of the claws (3) extend outward to provide a more maneuverable gripping area. A small divot in one of the claws provides a gap (4) useful for picking up small objects, such as pens, that would not be confined in the main claw gap. The inner surface of one claw is lined with a compliant foam (5). This could provide an increased coefficient of friction and more contact area between the claws and an object compared to contact with hard plastic or metal. The other claw is lined with teeth (6) that could be made from plastic or rubber. This surface geometry would also increase the grip between an object and the claws. Each of these linings could be applied to one claw, or one lining could be applied to both claws.

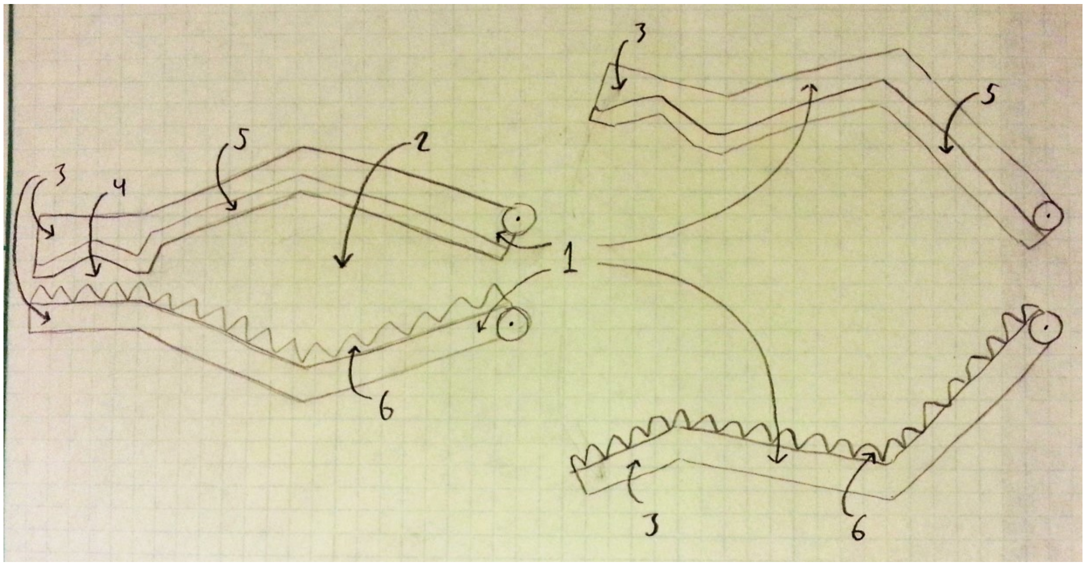


Figure 22: Asymmetric Bent Claw

5.12: Preliminary Design 12 – Three Digit Claw

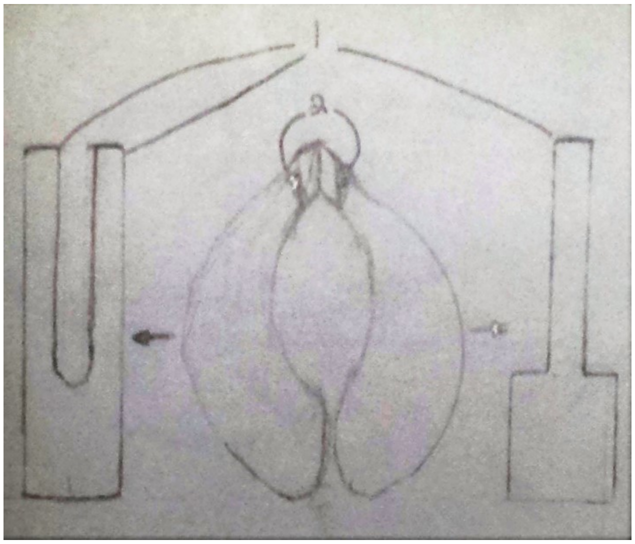


Figure 23: Three Digit Claw

This design for the claw, shown in Figure 23, makes use of three digits rather than the standard two digit claws. The movement of these claws is interoperable with virtually any actuation method used with a typical. The major advantage to these claws is the three points of contact (1) which will interface with the object trying to be manipulated. This feature will allow more control throughout the process because it will eliminate the possibility of the jaws deviating from their neutral plane. Another feature of this design is the ball or universal joints at the tips of the claw (2). This will allow all the forces being applied to the object to be parallel. The addition of a spring between the fingertip and the rest of the claw, not pictured in Figure 23, may improve the area of contact of the claw.

5.13: Preliminary Design 13 – Conforming Foam Zig Zag Claw

This claw design was inspired by the zig tech shoes made by Reebok and is shown in Figure 24. The claw structure (1) has a zig zag piece of foam polymer adhered to the bottom of it. The zig zag piece (2) is firm yet compliant, and its thin shape allows it to conform very well to objects. Free space is intentionally left between the claw structure (1) and the foam zig zag (2) to allow for maximum deflection and conformity.

The geometric profile of the claw is inspired by the claws of the Grip'n Grab, which seems to accommodate the shapes of many different objects very well. The S shape allows the ends of the claws to form a narrow pinching shape which is great for reaching into smaller spaces such as a cabinet.

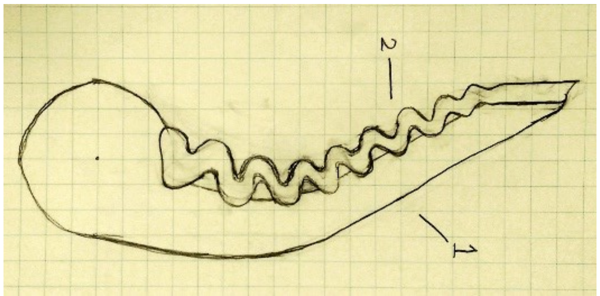


Figure 24: Conforming Foam Zig Zag Claw

Chapter 6: Final Design Selection

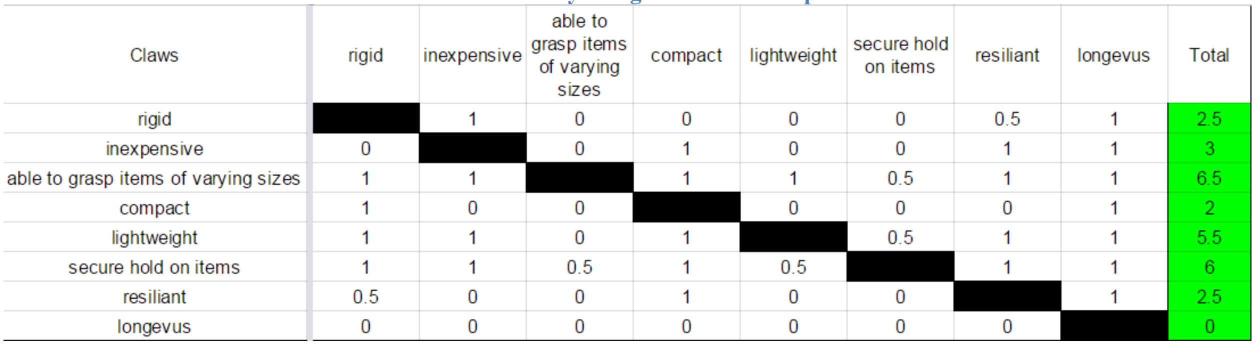
After all preliminary designs had been generated for different parts of the device, a final concept of the full device was needed which incorporated the best aspects from the preliminary designs. Metrics were devised to compare the preliminary designs against each other. Combinations of the best preliminary designs were generated to form full device concepts, and these were compared to select the best overall concept.

6.1: Component Attributes

Several preliminary designs were ideated for each individual component of the device. In the original plan for narrowing down the designs, all preliminary designs for an individual component were compared against each other. Lists of desirable attributes were recorded for each component. After, one preliminary design was selected for each component that best satisfied the listed attributes of that component. To determined which attributes should carry more weight when evaluating the designs, attributes were compared using a pairwise comparison chart.

In a pairwise comparison chart, all attributes are compared to each other one by one. If one attribute is deemed more important than the other, that attribute is given a score of 1, and the opposing attribute is given a score of 0. If two attributes are deemed to be of truly equal importance, they may both be given a 0.5. After all attributes have been compared, the scores of the attributes are totaled. The attributes with higher scores are deemed to be more important. The pairwise comparison chart for the preliminary designs of the claw components is shown below in Table 1. The pairwise comparison charts of the other components are found in Appendix A.

Table 1: Claw Preliminary Design Pairwise Comparison Chart



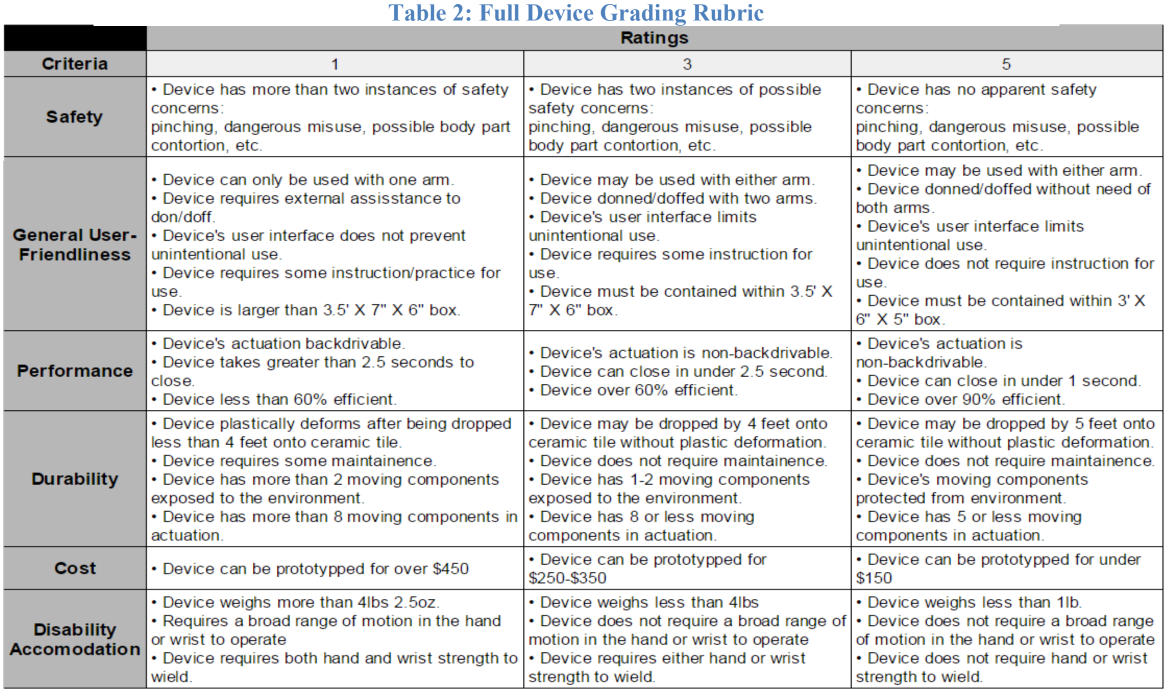
Claws	rigid	inexpensive	able to grasp items of varying sizes	compact	lightweight	secure hold on items	resiliant	longevus	Total
rigid		1	0	0	0	0	0.5	1	2.5
inexpensive	0		0	1	0	0	1	1	3
able to grasp items of varying sizes	1	1		1	1	0.5	1	1	6.5
compact	1	0	0		0	0	0	1	2
lightweight	1	1	0	1		0.5	1	1	5.5
secure hold on items	1	1	0.5	1	0.5		1	1	6
resiliant	0.5	0	0	1	0	0		1	2.5
longevus	0	0	0	0	0	0	0		0

As separate attributes were generated for each component to be used in these charts, a number of the attributes reoccurred across components. After some deliberation, the approach for selecting a final design was slightly modified. Preliminary designs were evaluated based on how well they served the final product as a whole. To select attributes for this process, observations were made on how well attributes scored in the pairwise comparisons for individual components, and which attributes reoccurred across multiple components. Reoccurring and high scoring attributes were selected to be used to evaluate the device as a whole.

6.2: Device Attributes

After all attributes were selected from the previous step, each was separated into six distinct categories that defined criteria for the device as a whole. This was done to facilitate grading the final designs. It was easier and more appropriate to evaluate a full device based on how well it met six criteria than it was to evaluate the device using a multitude of specific attributes that did not necessarily refer to the device as a single entity. Table 2 lists the attributes that define these six criteria. In order keep roughly the same number of attributes per criterion, some of the attributes listed were synthesized from multiple attributes.

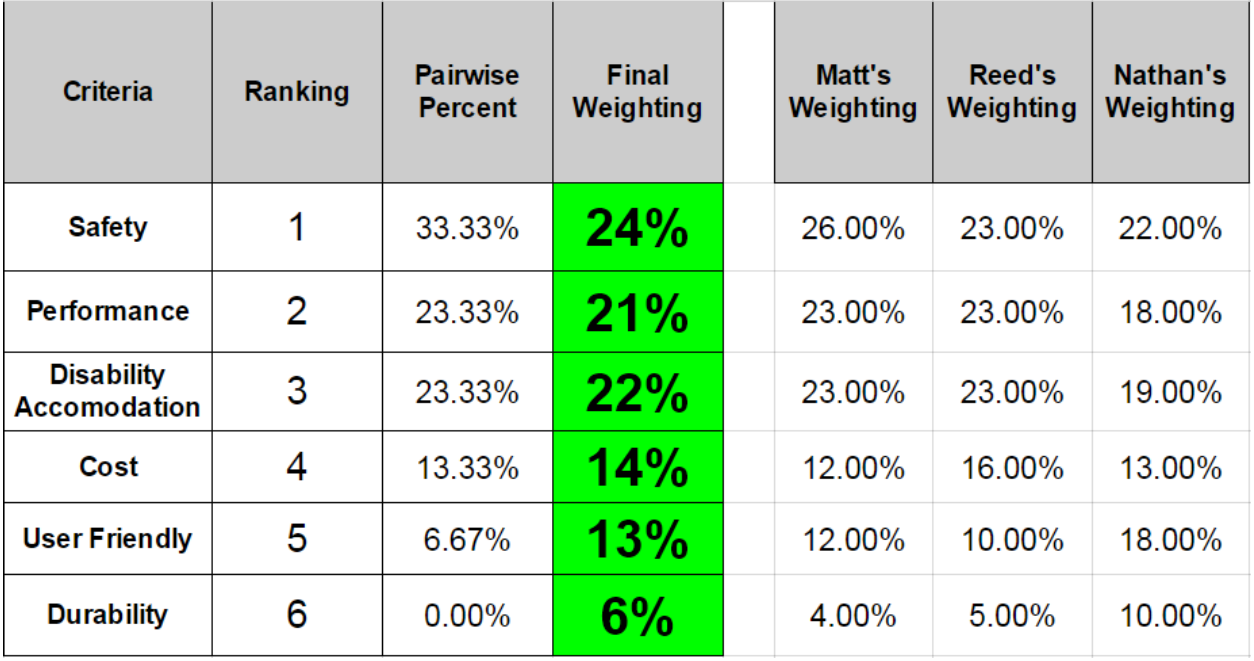
Table 2: Full Device Grading Rubric



	Ratings		
Criteria	1	3	5
Safety	• Device has more than two instances of safety concerns: pinching, dangerous misuse, possible body part contortion, etc.	• Device has two instances of possible safety concerns: pinching, dangerous misuse, possible body part contortion, etc.	• Device has no apparent safety concerns: pinching, dangerous misuse, possible body part contortion, etc.
General User-Friendliness	• Device can only be used with one arm. • Device requires external assisstance to don/doff. • Device's user interface does not prevent unintentional use. • Device requires some instruction/practice for use. • Device is larger than 3.5' X 7" X 6" box.	• Device may be used with either arm. • Device donned/doffed with two arms. • Device's user interface limits unintentional use. • Device requires some instruction for use. • Device must be contained within 3.5' X 7" X 6" box.	• Device may be used with either arm. • Device donned/doffed without need of both arms. • Device's user interface limits unintentional use. • Device does not require instruction for use. • Device must be contained within 3' X 6" X 5" box.
Performance	• Device's actuation backdrivable. • Device takes greater than 2.5 seconds to close. • Device less than 60% efficient.	• Device's actuation is non-backdrivable. • Device can close in under 2.5 second. • Device over 60% efficient.	• Device's actuation is non-backdrivable. • Device can close in under 1 second. • Device over 90% efficient.
Durability	• Device plastically deforms after being dropped less than 4 feet onto ceramic tile. • Device requires some maintainence. • Device has more than 2 moving components exposed to the environment. • Device has more than 8 moving components in actuation.	• Device may be dropped by 4 feet onto ceramic tile without plastic deformation. • Device does not require maintainence. • Device has 1-2 moving components exposed to the environment. • Device has 8 or less moving components in actuation.	• Device may be dropped by 5 feet onto ceramic tile without plastic deformation. • Device does not require maintainence. • Device's moving components protected from environment. • Device has 5 or less moving components in actuation.
Cost	• Device can be prototypped for over $450	• Device can be prototypped for $250-$350	• Device can be prototypped for under $150
Disability Accomodation	• Device weighs more than 4lbs 2.5oz. • Requires a broad range of motion in the hand or wrist to operate • Device requires both hand and wrist strength to wield.	• Device weighs less than 4lbs • Device does not require a broad range of motion in the hand or wrist to operate • Device requires either hand or wrist strength to wield.	• Device weighs less than 1lb. • Device does not require a broad range of motion in the hand or wrist to operate • Device does not require hand or wrist strength to wield.

To be able to grade the designs fairly, a rubric was developed for determining how well a design met each of the six criteria. The grading scale was from one to five for each criterion. The attributes were specifically designed for receiving a one, three, and five in each category. These attributes were based on the attributes used to define the six criteria. If the design failed to meet one of any of the attributes for a score (three or five), it could not receive that score or higher. If the design failed to meet at least half of the attributes for that score, it could not receive the next score down or higher (two or four). The cost and safety categories were an exception to this system. Cost was solely based on the price of the design. Safety was based on the number of safety concerns with the device. The grading rubric is shown in Table 3.

Table 3: Criteria Weightings



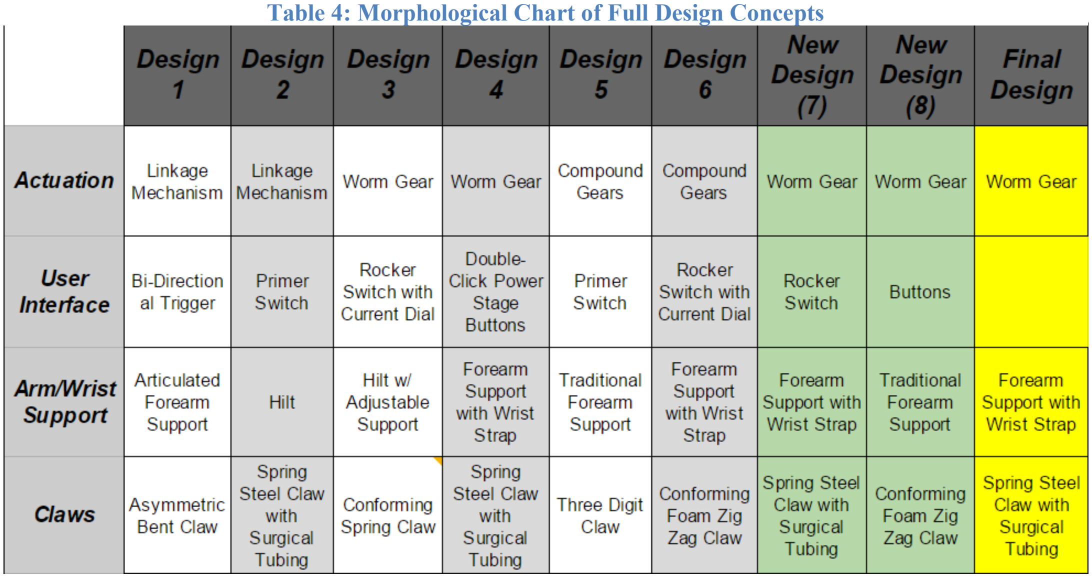
Criteria	Ranking	Pairwise Percent	Final Weighting	Matt's Weighting	Reed's Weighting	Nathan's Weighting
Safety	1	33.33%	**24%**	26.00%	23.00%	22.00%
Performance	2	23.33%	**21%**	23.00%	23.00%	18.00%
Disability Accomodation	3	23.33%	**22%**	23.00%	23.00%	19.00%
Cost	4	13.33%	**14%**	12.00%	16.00%	13.00%
User Friendly	5	6.67%	**13%**	12.00%	10.00%	18.00%
Durability	6	0.00%	**6%**	4.00%	5.00%	10.00%

Each criterion received a weighting as well. The importance of each criterion was ranked using a pairwise comparison chart. These results identified which criteria were more important than others, but did not necessarily reflect the weight of one criterion versus another. For example, the pairwise comparison chart could only discern that safety was more important than the other criteria, but if it was felt that safety was at least two times as important as the next criterion, this is not reflected in the pairwise comparison results. Therefore, using the pairwise results as guidance, specific weight values were assigned to each criterion as a percentage. The weights of all the criteria totaled to 100%. Each team member weighted the criteria individually, and the average of these values was used as the final weight for the criteria. These weights would be applied to the grading of each criterion in a later step to determine a final score for the preliminary designs. Table 3 contains the results from this weighting process. The pairwise comparison of the criteria may be found in Appendix A.

6.3: Design Selection

The next step was to create concepts of the full device that could be evaluated. Using a morphological chart (Table 4), six complete concepts were generated for the full device. The concepts were comprised of one preliminary design for each component. That is, one design for the actuation mechanism, one for the user interface, one the arm and wrist support, and one for the claws. The morphological chart was used to generate different combinations of the component designs. Designs were combined in a manner in which components would complement each other when placed into a whole device.

Table 4: Morphological Chart of Full Design Concepts



	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6	New Design (7)	New Design (8)	Final Design
Actuation	Linkage Mechanism	Linkage Mechanism	Worm Gear	Worm Gear	Compound Gears	Compound Gears	Worm Gear	Worm Gear	Worm Gear
User Interface	Bi-Directional Trigger	Primer Switch	Rocker Switch with Current Dial	Double-Click Power Stage Buttons	Primer Switch	Rocker Switch with Current Dial	Rocker Switch	Buttons	
Arm/Wrist Support	Articulated Forearm Support	Hilt	Hilt w/ Adjustable Support	Forearm Support with Wrist Strap	Traditional Forearm Support	Forearm Support with Wrist Strap	Forearm Support with Wrist Strap	Traditional Forearm Support	Forearm Support with Wrist Strap
Claws	Asymmetric Bent Claw	Spring Steel Claw with Surgical Tubing	Conforming Spring Claw	Spring Steel Claw with Surgical Tubing	Three Digit Claw	Conforming Foam Zig Zag Claw	Spring Steel Claw with Surgical Tubing	Conforming Foam Zig Zag Claw	Spring Steel Claw with Surgical Tubing

Once the concepts were generated, they were graded using a rubric, and their scores were weighted to give each concept a final score. Some initial calculations were needed to evaluate the performance of the designs. These calculations mostly involved actuation speed and efficiency. These calculations can be found in Appendix A. The concepts all scored roughly the same for safety, and given the high weight given to that criterion, the devices were compared both with and without the safety score. The score table is located in Appendix A.

At the end of scoring, the results were scrutinized to determine why some designs scored poorly and why others scored well. This information was used to create two more concepts that would ideally score better than the previous concepts. These designs are highlighted in green on the morphological chart of full device concepts, Table 4. The additional concepts were then graded and did in fact score better. Of these two, the highest scoring one was chosen to comprise the final design, highlighted in yellow. A selection for the user interface is left out of the final design selection. This was because it was deemed that the differences between control schemes that used buttons or a rocker switch were insignificant compared to the logic that would be used to control the claw itself. The implementation of the control system is further discussed in the Electrical Analysis Section.

6.4: Final Design

Once the final combination of functions was determined the next step was to conceptualize a full design of the device. This task was completed using preliminary design sketches as references in order to model the device using Creo and SolidWorks. The final design may be seen in Figure 25. The design may be further broken into subassemblies based on the intended motion of the parts including translation, rotation, or fixation. Subassemblies include rotation of the head (1), claw coupler (2), driveshaft (3) (not visible), arm/wrist support (4), front casing (5), and back casing (6).

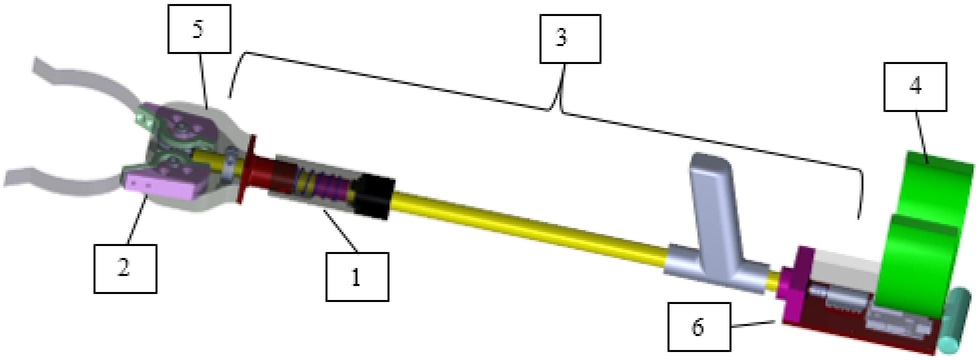


Figure 25: Full Design as Modeled in Creo

6.4.1: Claw Coupler

The function of the claw coupler subassembly is to both secure the claws to the device while simultaneously allowing rotation of the claws via the worm and worm gear interaction. The full subassembly may be seen in the exploded view in Figure 26. The claw coupler is constructed using five unique components. The only part which is currently sold is the worm gear. The worm gear, within the full assembly is positioned on an axle exactly half the radius of its pitch circle away from the worm's pitch circle. Two identical disks then sandwich the gear by being placed in the gear's reliefs on the top and bottom. After creating two identically flush surfaces, both the coupler and coupler clamp are placed over the combination of parts. A secured subassembly which is able to clamp the spring steel claws is eventually achieved by inserting screws which fix the components to each other. The claw may then be inserted in the slot between the coupler and coupler clamp, and secured via two screws.

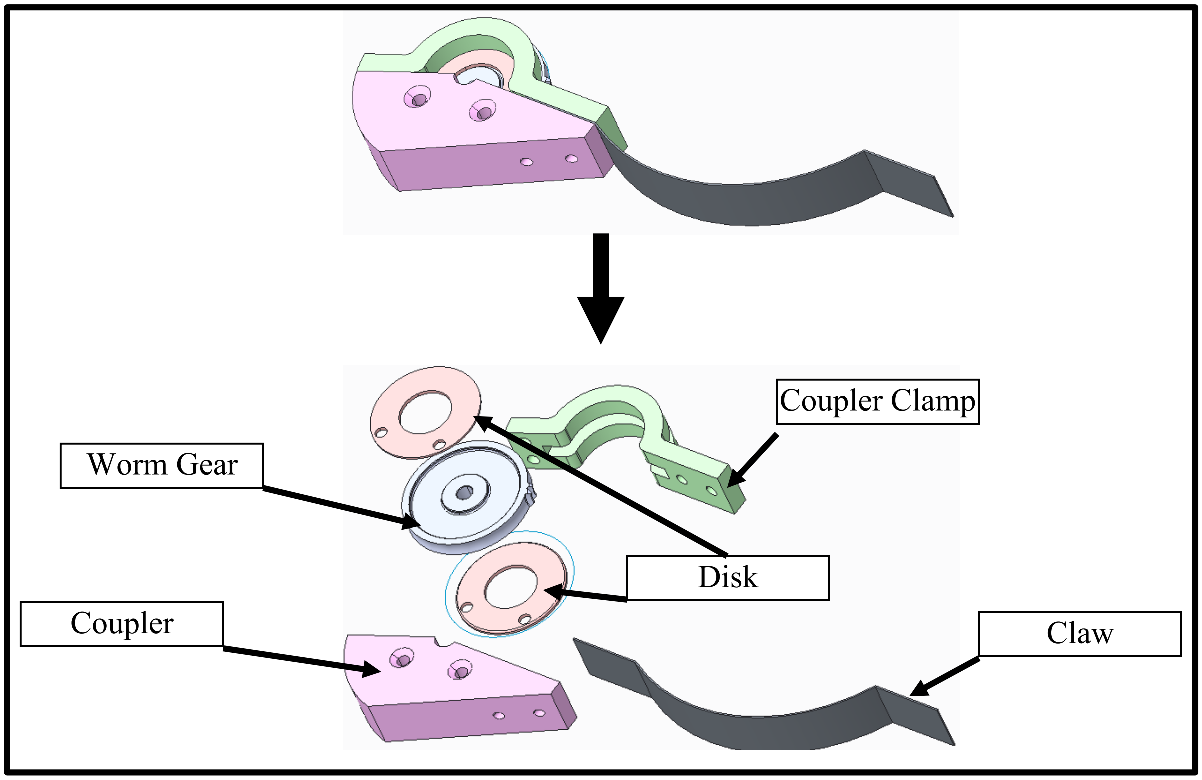


Figure 26: Exploded View of Claw Coupler

6.4.2: Driveshaft

The driveshaft subassembly applies the torque to the output gears and actuates the claws to grasp objects. Figure 27 shows the subassembly and its five unique components. The motor which supplies the torque is placed near the back of the device where the user controls are located. It is mounted via its accompanying mounting bracket which secures it to the rear casing bottom. To transfer the rotation from the motor shaft to the driveshaft, a coupling hub subassembly is placed in contact with both components. The coupling hub is constructed of two stepped components which become fixed on their respective shafts and are then sandwiched to an equally stepped nylon disk. It is important to note that this particular shaft coupler only transfers torques and does not resist axial forces which may be produced from the worm. For this reason, flanged-thrust bearings are press-fit to the driveshaft component on each end to resist forces that would disrupt normal operation. After the second thrust bearing, a worm gear is press fit onto the driveshaft.

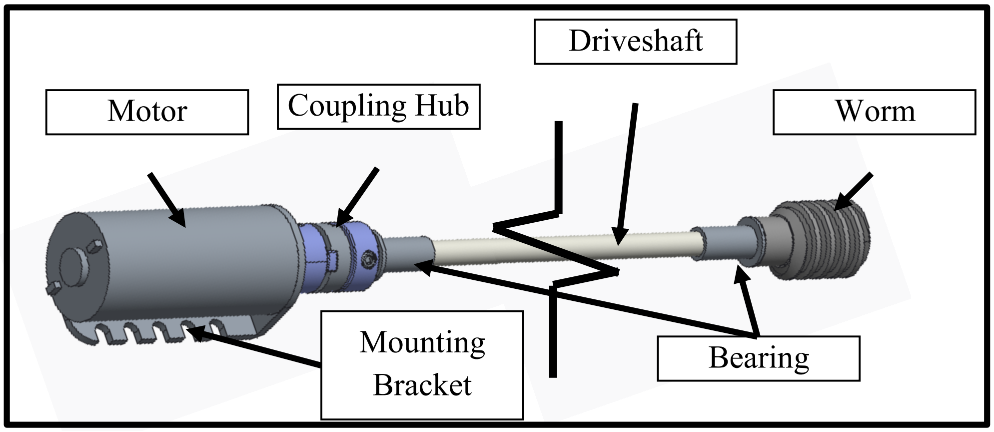


Figure 27: Driveshaft Subassembly

The zeroth order prototype of the actuation mechanism was built using LEGOs and may be seen in Figure 28. The dual worm gear setup functioned as intended. It was determined that the gear ratio between the worm and the gears seemed to be suitable for a gripper. By visual inspection, the gear ratio was about 1:12. The gears were confirmed to be non-backdrivable. The plastic LEGO worm was able to turn the gears almost effortlessly without any lubrication. This helped confirm the purchase of plastic gears instead of metal.

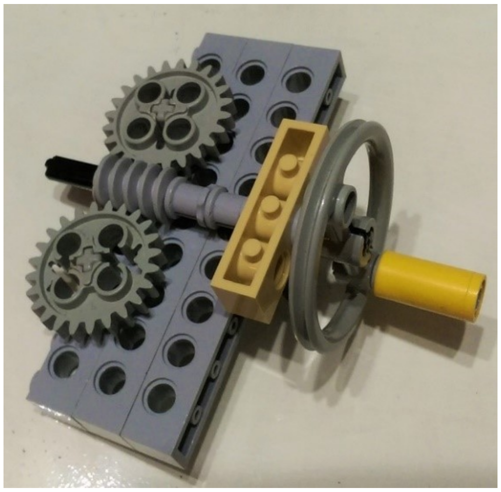


Figure 28: Zeroth-Order Prototype of Worm Gear Mechanism

6.4.3: Rotation of the Head

The rotation of the head as achieved with seven total components. Figure 29 shows a cross-sectioned balloon diagram of the subassembly whereas Figure 30 shows an isometric representation.

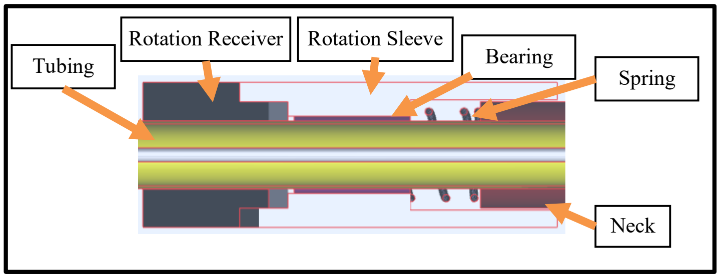


Figure 29: Cross-Section of Rotation Subassembly

The tubing is hollow polycarbonate tubing with a circular cross-section and is used to house the driveshaft. It also connects both casings in the device. The rotation receiver is a fixed component with two tiers of steps used to physically secure the position of the head as well as limit its rotation about the tubing to 90-deg. The rotation sleeve is the male component to the stepped-receiver. This component fixes the orientation (horizontal or vertical) of the front casing to the same as itself via a slot system which will be further defined later in this section. This allows the head to be in the same orientation as the sleeve. A bearing and compression spring are placed within the cavity of the rotation sleeve, between the front casing and tubing. The bearing ensures smooth translation of the rotation sleeve about the tubing whereas the spring is used to return the rotation sleeve back to its secured position after being manipulated by the user. The neck component is fixed to the front casing at the head of the device and has two holes which are in line with the slot found on the rotation sleeve. Pegs are placed in these holes, after all components are assembled on the tubing, to create a peg and slot connection.

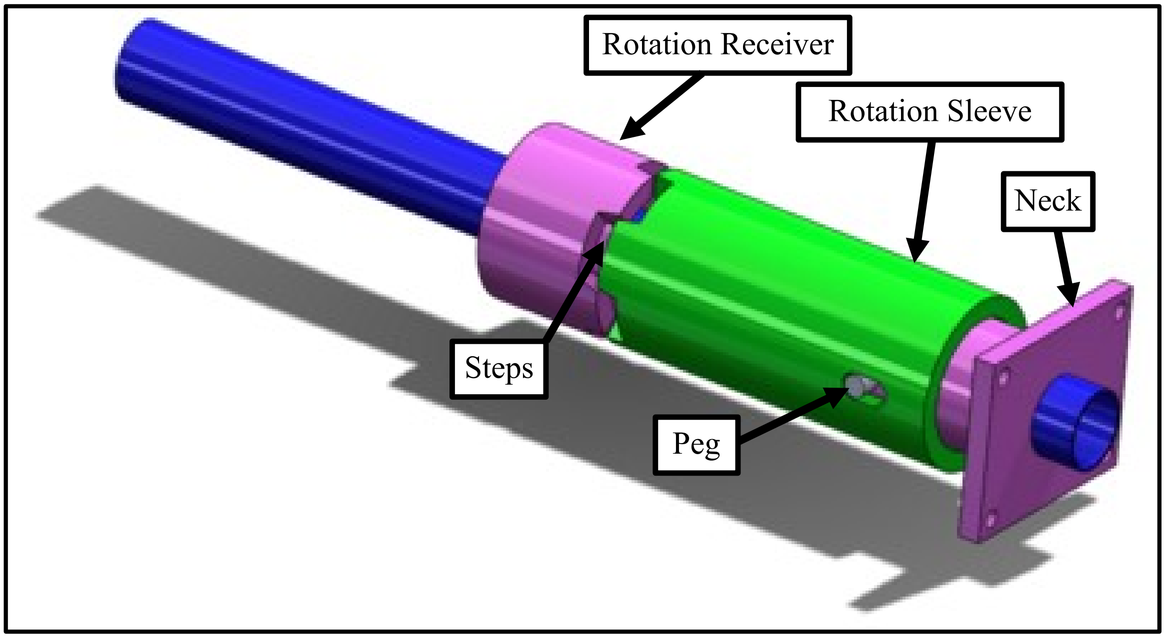


Figure 30: Possible Configuration of Rotation Component

The zeroth order prototype of the rotation mechanism was built using scrap PVC pipe and masking tape (Figure 31). The notches cut into the PVC pipe fit together well and locked into place snugly. No peculiar observations were made as the prototype functioned as intended.

Figure 31: Zeroth-Order Prototype of Rotation Mechanism

6.4.4: Arm/Wrist Support

To negate the forces and moments applied to the user's hand and wrist the device has an arm support (1) and a wrist support (2) to ensure maximum comfort shown in Figure 32. The arm support is made of a molded thermoplastic to conform to the geometry of a forearm. It is then secured at the back of the rear casing top at an optimal distance from the grip. Furthermore, a padded foam insert is applied to the inside of the plastic. This configuration serves as mechanical stop to prevent the user's arm from pivoting at the grip by imposing at least two additional points of contact.

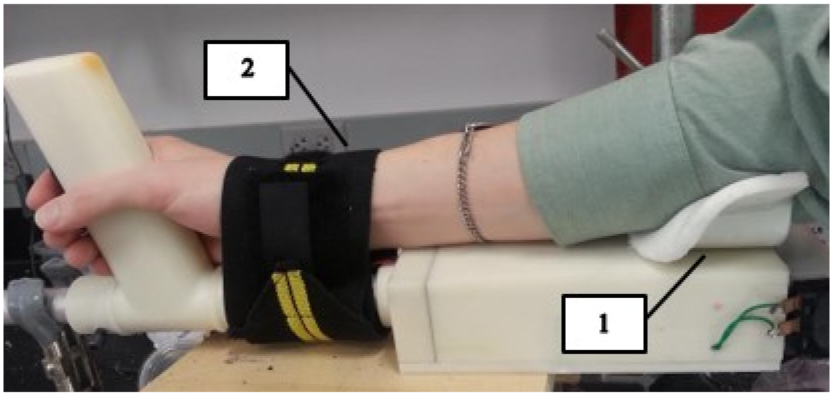


Figure 32: Arm and Wrist Support with User

The wrist support's purpose is to allow the user to wield the device without the specific requirement of high grip strength. It accomplishes this feat by wrapping around the operator's wrist, via a semi-elastic strap, and affixing the gripper to the individual's forearm. While this method does not eliminate the force at the wrist, in combination with the arm support, it transfers the entirety of the forces felt at the wrist or hand onto the user's arm. This is essential because persons with hand disabilities or elderly individuals will be able to manipulate the device more easily than those which require constant application of grip strength to counteract the weight of the device and the object being grasped.

6.4.5: Casing

The casing comprises a multitude of components on each end of the device and can be seen in its entirety in Figure 33. The primary functions of the casing are to protect the components from the environment and establish sufficient strength to support loads acting upon the device. At the head of the device, the shaft collar allows the front casing subassembly to rotate by resisting axial translation and allowing rotation about its axis. Following roughly 30-in of tubing, the rear casing secures the tube via a three-part case consisting of the rear casing wall, rear casing bottom, and rear casing top. The tubing is fixed within the rear casing wall. The rear casing bottom is the area where the electrical components and motor mounting bracket are secured. The rear casing top is then placed into the correct orientation and all three components are fastened to each other. The battery is to be secured at the rear of the device.

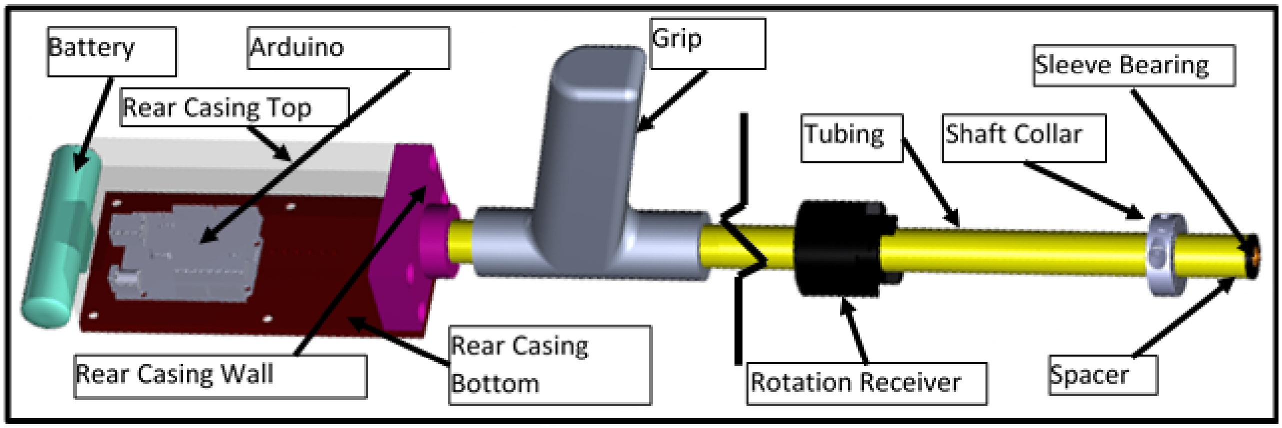


Figure 33: Casing Subassembly

6.4.6: Front Casing

The location of the claws and their desired range of motion rely on the front casing show in Figure 34. Two custom printed casings are designed to achieve both tasks. Additionally, this casing also defines the length of the driveshaft and tubing by containing a cavity where a collar is being placed. This collar, as explained earlier, restricts the translation of the front casing. The two halves of the front casing are secured by fasteners. Furthermore, the neck acts as another securing method and is placed along the tubing. As explained earlier, pegs are inserted into the neck which will translate along a slot in the rotation subassembly. These components allow the head to rotate as one unit, independent of the tubing. Ball and sleeve bearings are also introduced to this assembly to resist forces acting on the worm gears and driveshaft, respectively.

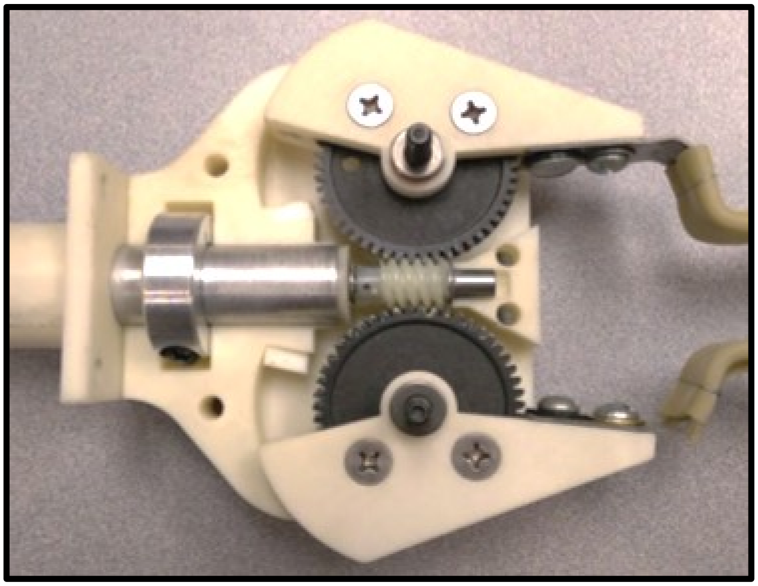


Figure 34: Front Casing Subassembly

6.4.7: Final Design Bill of Materials

The final design consists of parts which can be purchased from McMaster-Carr, Grainger, SDP/SI, and The Home Depot. Those which cannot be purchased were rapid prototyped using the 3D printers at Worcester Polytechnic Institute. Parts were rapid prototyped on a Dimension SST 1200es system using low density ABS material. This 3D Printer is capable of printing within a tolerance of +/- 0.006-in and creates layers 0.01-in thick. For the scope of this project, these are acceptable limitations. The bill of materials may be seen in Figure 35.

Part Name	Quantity	Material	Weight/Unit	Subassembly	Supplier	Part #
SHAFT COUPLING HUB	2	ALUMINUM	.000 lb	DRIVESHAFT	McMaster	59985K1
DISK	1	NYLON	.001 lb	DRIVESHAFT	McMaster	59985K91
DRIVESHAFT	1	303 STAINLESS STEEL	.212 lb	DRIVESHAFT	McMaster	16-Mar
THRUST BEARING	4	STAINLESS STEEL	.038 lb	FRONT CASING	McMaster	6655K33
SLEEVE BEARING	3	OIL-EMBEDDED STEEL	N/A	CASING & FRONT CASING	McMaster	6627K402
MOTOR	1	N/A	.095 lb	DRIVESHAFT	Pololu	1163
MOUNTING BRACKET	1	ALUMINUM	.009 lb	CASING	Pololu	1138
WORM	1	NYLON	.005 lb	DRIVESHAFT	SDP/SI	A 1M 5-Y24
WORM GEAR	2	NYLON	.055 lb	CLAW COUPLER	SDP/SI	A 1T 6-Y245008
ARDUINO UNO	1	CIRCUIT BOARD	.055 lb	CASING	Arduino	DEV-11021
ROCKER SWITCH	1	ABS	N/A	CASING	Grainger	29FG30
7.4V BATTERY	1	LI-ION	.156 lb	CASING	AA PPC	CU-J702
MOTOR DRIVER	1	CIRCUIT BOARD	.014 lb	CASING	Pololu	1451
TUBING	1	6061 ALUMINUM	.256 lb	CASING	McMaster	9056K72
COMPRESSION SPRING	1	STEEL MUSIC WIRE	.012 lb	ROTATION	McMaster	9657K407
COLLAR	1	ALUMINUM	.075 lb	CASING	McMaster	6157K17
SLEEVE BEARING (ROTATION MECH)	1	BRONZE	.080 lb	ROTATION	McMaster	6381K557
CLAW	1	1095 STEEL	.09 lb	CLAW COUPLER	McMaster	9043K46
SURGICAL TUBING	1	LATEX RUBBER	.025 lb	CLAW COUPLER	McMaster	5234K64
SET SCREW	1	STAINLESS STEEL	.015 lb	FRONT CASING	McMaster	92313A537
REAR CASING BOTTOM	1	ABS	.021 lb	CASING		
REAR CASING TOP	1	ABS	.055 lb	CASING		
REAR CASING WALL	1	ABS	.079 lb	CASING		
SLEEVE BEARING SPACER	2	ABS	.001 lb	CASING		
FRONT CASE BOTTOM	1	ABS	.145 lb	FRONT CASING		
ROTATION RECEIVER	1	ABS	.065 lb	CASING		
ROTATION SLEEVE	1	ABS	.115 lb	ROTATION		
FRONT CASE TOP	1	ABS	.145 lb	FRONT CASING		
NECK	1	ABS	.053 lb	FRONT CASING		
COUPLER CLAMP	2	ABS	.025 lb	CLAW COUPLER		
LEFT CLAW COUPLER	1	ABS	.045 lb	CLAW COUPLER		
RIGHT CLAW COUPLER	1	ABS	.045 lb	CLAW COUPLER		
1/4-20 x 1" Countersunk	12	Steel	.015 lb	N/A		
1/4-20 x 2.5" BOLT	2	STEEL	N/A	FRONT CASING		
1/4-20 NYLON INSERT NUT	2	STEEL	N/A	FRONT CASING		
GRIP	1	ABS	N/A	CASING		

Figure 35: Bill of Materials

Chapter 7: Engineering Analysis and Design

Before confidence may be placed that the design will satisfy the customers' needs assurances must be made that it can withstand the forces applied via picking up objects and maneuvering them. Additionally, the forces or moments applied to the user cannot exceed the requirements. This analysis was completed only after visual representations of components and the forces or moments applied were developed. Free body diagrams and their respective assumptions may be found in their entirety in Appendix B. Furthermore, various materials were selected that could accommodate the operational loads of the device. Once structural integrity of the parts was confirmed through stress analysis, the required motor, power supply, and electrical components were selected.

7.1: Kinematic Analysis and Motor Selection

In order to find an appropriate motor to drive the claws, torque and speed analysis needed to be conducted. Initially, it was assumed that the claws would be picking up objects no heavier than 5-lbs. The most torque would need to be supplied by the motor when the claws were grasping an object at their tips, due to the large lever arm from the gear shaft to the claw tip. If the claws were covered with surgical tubing, the smallest coefficient of friction between the claws and a grasped object would be equivalent to the coefficient of friction between rubber and glass, 0.45. The length of the claws was 5-in, and the gear ratio of the worm gear was 25. The efficiency of worm gears is usually 0.80, so this was used as the efficiency value. Based on these assumptions, the required motor torque was calculated as 9-oz*in in order to hold a 5-lb object while being held with the claws gripping in a horizontal position, with the device held steady in a horizontal plane. The calculations are found in Appendix B.

One of the other functional specifications was that the claws would be able to open and close in under 4-sec. Based on a gear ratio of 25 and the fact that each claw is designed to open 30°, the motor would need to rotate 13.1 revolutions in less than 4-sec. It would not be difficult to find a motor that could spin at least this fast. The calculations for this speed are found in Appendix C.

Once these values were calculated, a motor needed to be found to match. The motor would ideally be as light and small as possible to reduce the weight and profile of the device. The motor selected was a Pololu 6 Volt, 73:1 gear ratio motor seen in Figure 36.

Figure 36: Pololu 73:1 Metal Gear Motor 20Dx42L mm

The maximum torque provided by this motor is 60-oz*in. This yields a safety factor of 6.7 for picking up 5-lb objects, which is useful, as more torque is needed to secure objects that are being swung. The motor's maximum speed is 180-rpm. While the motor is opening and closing the claws, it is very close to unloaded, and thus close to maximum speed. This means that the claws go from fully open to fully closed in about 0.69-sec. The motor weighs 43-g and measures 20-mm in diameter. This means that it can easily fit into the device housing and will not add excessive weight.

7.2: Motor Control Logic

The main principle behind the operation of the gripper is that the claws will stop closing automatically when they apply a specified amount of force. This force is regulated using code uploaded to a control board on the gripper. The torque of the motor is proportional to the pushback force applied at the claws. Motor torque is also proportional to the electric current that the motor draws. Therefore, the force applied at the claws can be determined by measuring the current draw. Greater current draw means more force applied at the claws. The claws of the device are made of flexible spring steel. If the claws are closing around an object, they will deflect as they apply more force. Once the motor meets the prescribed current limit, it will stop moving. The claws are non-backdrivable, so once the motor stops, the claws will remain deflected and apply force to the grasped object.

The user controls the operation of the claws using a three position rocker switch in the gripper handle. This switch has two control schemes which can be toggled using another switch. The first control scheme is the main control scheme. Setting the switch to the bottom position sets the claws to open until they contact the edge of the claw casing and stop. The middle position sets the claws to close until they apply a light gripping force to an object, about 3-lb. This is for grasping delicate objects. The top switch position has the claws close until they apply a strong force, about 6-lb. This is for grasping heavier objects. The second control scheme replaces the middle switch function with immediately stopping the motor. This allows the user to manually set the position of the claws. The bottom position opens, the middle position stops, and the top position closes. The maximum force limits were retained in order to prevent users from stalling the motor.

To control the motor, an Arduino Uno is used, which runs a unique code. The program controls the motor through a state machine and interrupt service routines as seen in Figure 37. The program starts with a setup phase that assigns modes to pins and other processes. Immediately after, the program enters a continuous loop, running the same code over and over again. The main body of this loop is a three case state machine. Every time the loop is run, a group of code in one of the three states, or cases, is selected to execute. These states correspond to the position of the switch. The first case tells the motor to open until it hits the casing, the second tells the motor to close until a small force is applied, and the third case tells the motor to close until a large force is applied. In each case, the Arduino reads the current being drawn by the motor. If the current is below a specified value, the motor continues driving. If the motor draws current above a specified value, the motor is stopped until the state changes. The specified current values can be adjusted in the program to change the amount of force the claws apply, allowing it be calibrated easily.

In the setup phase of the program, the program checks the position of the mode-toggle switch. If the switch is in the default position, the state machine executes as described above. If the switch is in the other position, the middle switch state, State 2, is altered so that the motor is set to stop regardless of the motor current reading. This means that the motor will immediately stop in the middle switch position. To change control schemes, the mode-toggle switch must be flipped and the control board must be reset by turning off and on the power.

Interrupts are used to change states. Interrupts are small sections of code that execute instantaneously regardless of what else is happening in the main code. The three position rocker switch is connected to two input pins in the Arduino control board. These pins are set to have pull-up resistors which means they are set to a default state of HIGH unless they are grounded through the switch. When the switch is moved, one of the two pins will go from HIGH to LOW or vice versa. When the switch is in the middle position, both pins are HIGH. When the switch is in the up position, the first pin is set to LOW while the second remains HIGH. When the switch is in the down position, the second is set to LOW while the first pin remains HIGH. Depending on which pin changes state, a certain interrupt will be triggered. These interrupts tell the program to change to the appropriate state based on the switch position. Using interrupts in this manner ensures that the state is changed as quickly as possible. Figure 37 provides a flowchart of the basic logic behind the state machine.

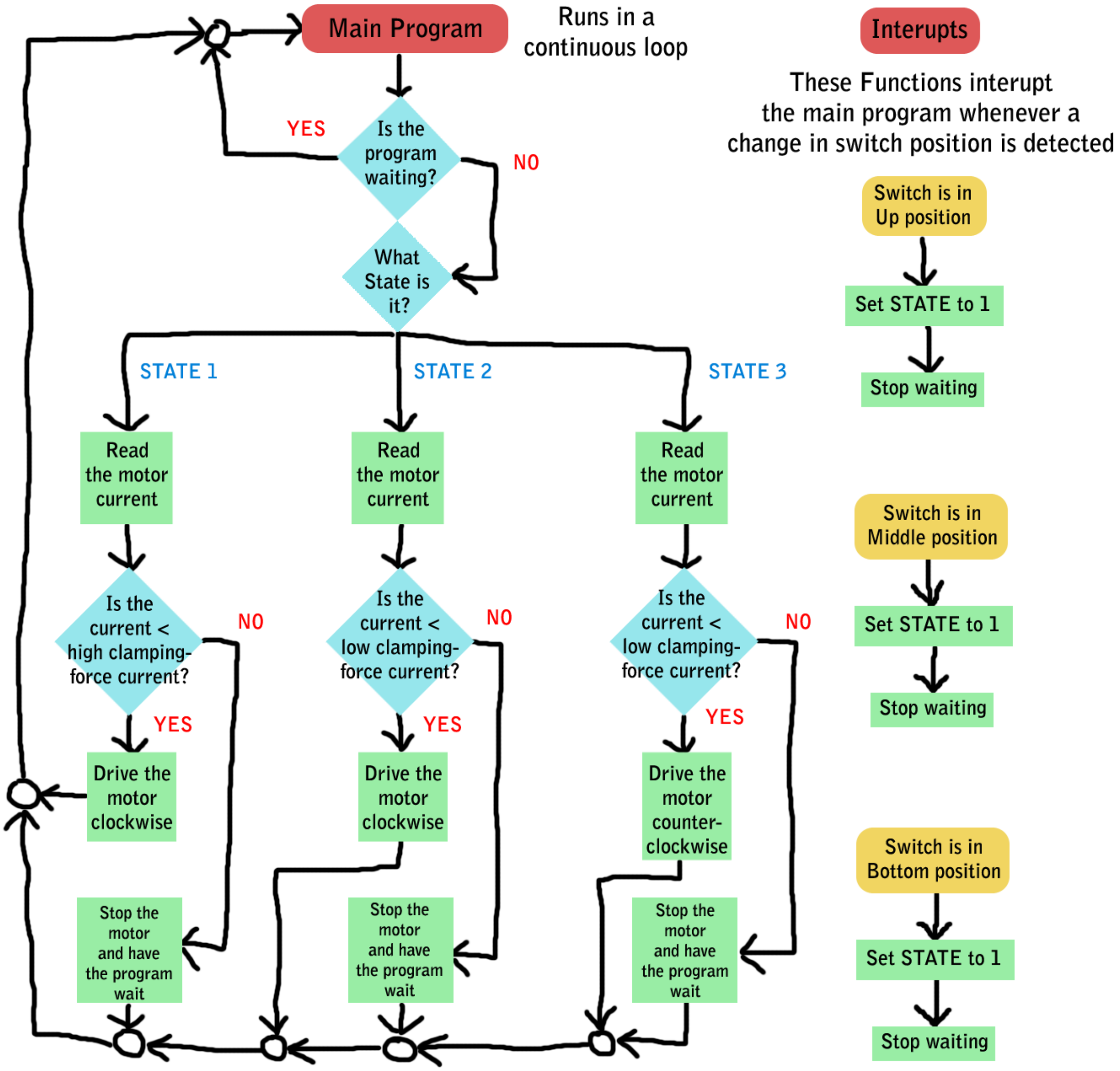


Figure 37: State Machine Logic

As one would expect, a number of problems were encountered with how the code was implemented, which had to be addressed. For example, switches have a tendency to bounce a signal when they change position, meaning that interrupts would trigger tens of times in an instant when it was only supposed to trigger once. To fix this, a debunking script was added to the interrupts.

Another notable problem involved the fact that interrupts for Arduino can be set to trigger based on whether the received signal rises (LOW to HIGH), falls (HIGH to LOW), or simply changes (either rises or falls). Setting different interrupts to trigger during a rising or falling signal would allow the program to immediately set the state machine case to the proper case, as it can differentiate between the switch moving into the top position and moving out of the top position. However, due to unknown reasons, the Arduino was only triggering interrupts during a change in signal, meaning an interrupt would be triggered both if the switch moved into a position or out of a position. To solve this problem, the program had to be altered so that the proper interrupt function was selected based on the previous state of the state machine. For instance, when the switch is flipped from the middle position to the top position, the interrupt for the top position is triggered. In the interrupt, the program checks the previous state, which was state 2. It then knows the switch is in the top position and then sets the current state to state 3. When the switch is flipped back to the middle position, the interrupt for the top position is triggered again. The program checks the previous state, which was 3. It knows the switch is in the middle position and sets the current state to 2.

A third problem that required attention was related to motor inrush current. When motors move from a stopped position, there is a large spike in current often many times the current they draw when stalled. The program uses current to detect how much force the claws are applying. This means that the motor would begin to spin, the program would sense that its current draw was above a specified limit and stop the motor immediately. To solve this, a delay was added to each case in the state machine. After the motor changes direction or goes from stopped to start, the program waits 500ms before checking the current.

7.3: Control System Components

The entire control system is composed of a handful of electrical components. Figure 38 provides a wiring diagram for the component connections. The system can be explained by going over each component individually.

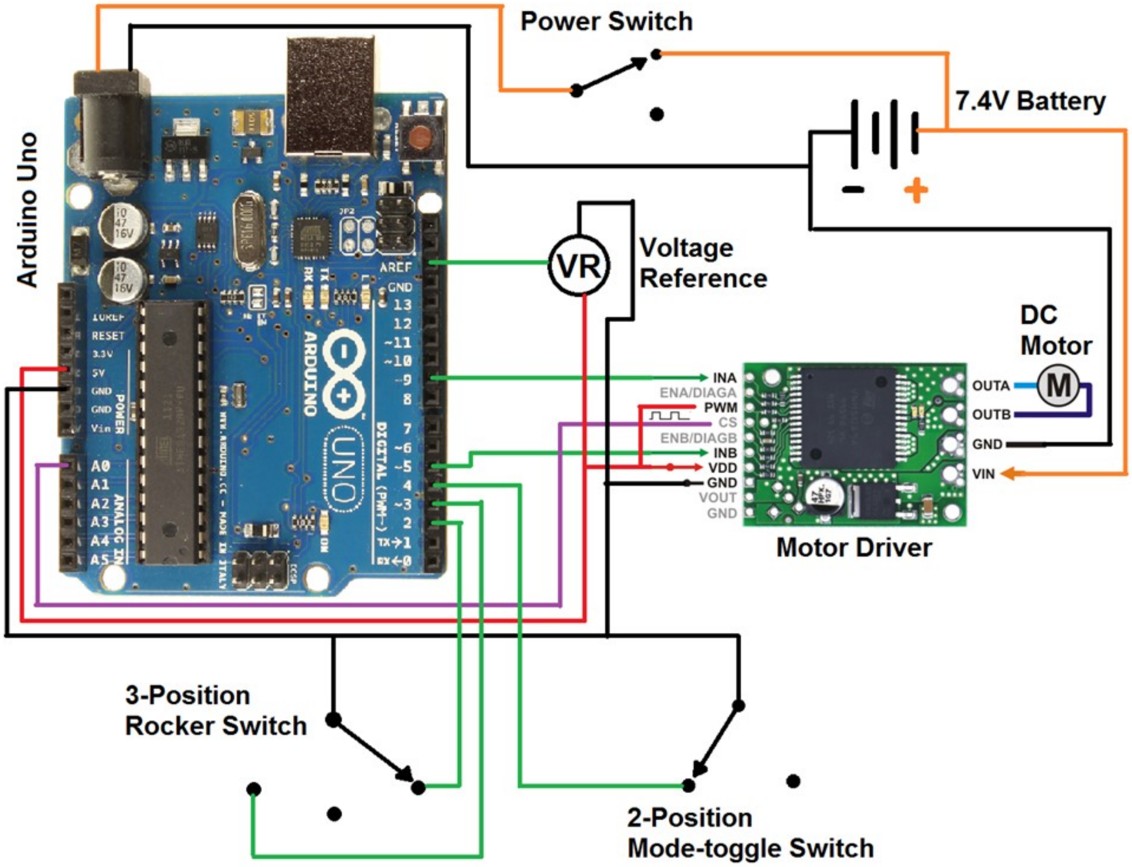


Figure 38: Control System Wiring Diagram

Arduino Control Board

The Arduino Uno is the main component of the control system. It executes the code by reading and outputting signals to and from other electrical components. It also supplies a 5 Volt line to power some of the other electrical components.

Motor Driver

The Pololu VNH5019 motor driver allows the Arduino to interface with the motor. The Arduino uses two pins to send signals to the motor driver dictating what it wants the motor to do. The motor driver then interprets those signals, takes power from the battery, and supplies it to the motor to give the proper speed and direction. The driver also sends a signal to the Arduino corresponding to the amount of current drawn by the motor. The Arduino can also send a PWM signal to the driver, which dictates how fast the motor should be going. However, there was some difficulty sending a signal to the board that would have the motor spin fast enough, so the

PWM pin on the board was set to a constant 5-V. This means that the motor spins at max speed whenever it is spinning at all.

Voltage Reference

As mentioned before, the motor driver sends a voltage to the Arduino that is proportional to the current the motor is drawing. The Arduino reads this as an analog signal. This analog signal must be compared with a reference voltage to be assigned a value between 0 and 1024. This value can be used in the program to set a value for the maximum allowable current. However, the driver only outputs about 140-mV for every 1-A of current the motor draws, and the motor draws a maximum of 3.3-A. The internal reference voltage of the Arduino is not precise enough to be able to interpret the signal from the driver accurately. To solve this problem, an external reference voltage was used. This electrical component outputs a steady 1.25-V to be used as the reference for the analog signal.

Battery

The battery supplies power for the Arduino and the motor. The Arduino Uno requires a minimum of 7-V to function properly, so a 7.4-V, 1400-mAh battery was selected. At 2.5-oz, 4-in long, and 0.87-in in diameter, it is relatively small and lightweight. Most importantly, it is rechargeable. Assuming that the motor draws an average of 1-A while it is running, and the Arduino has negligible current draw, the motor should be able to run for 1.4 hours continuously before needing to recharge.

Motor

Most of the specifics of the motor have been discussed in a previous section. However, an important aspect of the motor is that it is rated for 6-V. Both the Arduino and the motor run off of the same power supply, yet the Arduino requires a minimum of 7-V to function properly. To avoid supplying an overvoltage to the motor, the battery voltage would need to be stepped down from 7.4-V to 6-V. Unfortunately, this cannot be done by simply adding a resistor in series with the battery, as the current drawn by the motor varies. Adding a resistor in series would supply the motor with an inconsistent voltage. Therefore, it was determined that overvoltaging the motor would be the best solution. By using the 7.4-V battery, the motor is overvoltaged by 23%. Overvoltaging a motor will decrease its lifespan, but for the first-order prototype, this should be acceptable.

Switches

There are three switches in the system. The first is a three-position rocker switch embedded in the gripper's handle. This switch lets the user control the motor. Moving the switch to different positions grounds corresponding pull-up pins on the Arduino, which let the program position the switch. The second switch is a two-position switch that sets how the three positions of the rocker switch correspond to the motor's behavior. The switch can be put into two different positions for two different control schemes that were described in an earlier section. The third switch is the power switch. This two-position switch cuts the power to the Arduino and can be used to reset the system.

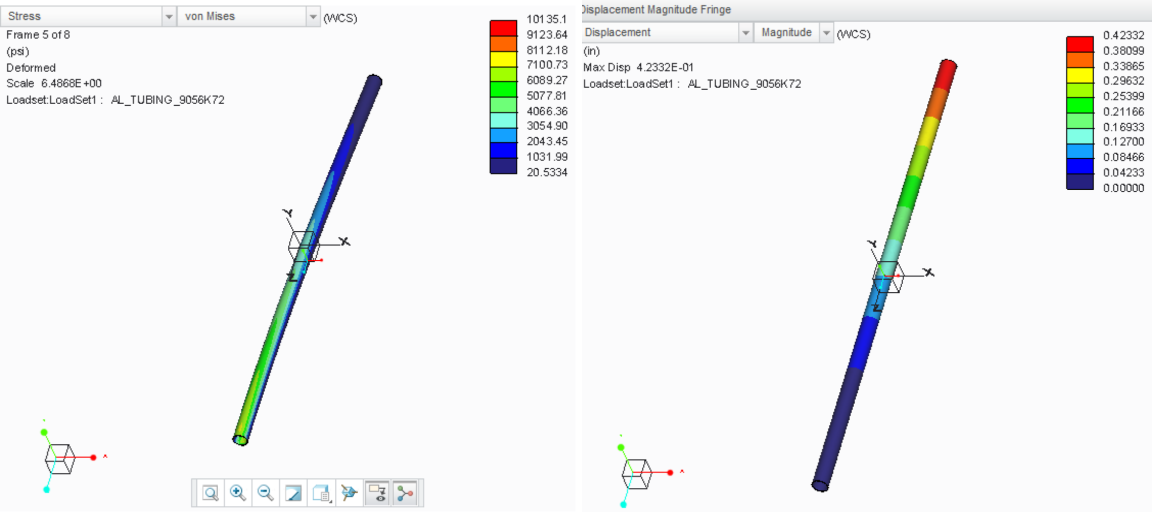
7.4: Deflection Analysis

For the device to function properly all parts, identified as critical, cannot deflect more than a tolerable distance. In the following subsections, each of these parts will be further scrutinized to assure their functionality in the design.

7.4.1: Tubing

The tubing of the device cannot bend more than ½-in because it holds the driveshaft; if the driveshaft bends more than this it would risk gear separation. MathCAD was used to determine the deflection at the end of the tubing given an object at the claws weighing 5-lb, 29-in length (from handle), and variable tube cross-sections. The moment of inertia was calculated first, followed by deflection and bending stress. The driveshaft was neglected from the analysis because it has such a small moment of inertia compared to the tubing. For the selected tubing (OD: 7/8"; ID: 0.805") of aluminum, the max deflection was 0.498-in, bending stress safety factor of 4.9, and a weight of 0.265-lb.

These findings were further validated using the CAD modeling software Creo Parametric 3.0. The analyses shown in Figure 39 were evaluated by applying fixed constraints to the rear face of the aluminum tubing. The full weight of the object was directed downward on the front face of the tubing as a distributed load. From these constraints a maximum stress was observed at the critical section on the top of the tubing near the rear face of roughly 8,000-psi, much lower than the yield strength of the material. Furthermore, similarly to the calculations, a maximum displacement of 0.42-in at the front face of the tubing when a loading of 5.7-lbf was applied was found. These results validate the choice of selecting this tubing.


Stress von Mises (WCS)
Frame 5 of 8
(psi)
Deformed
Scale 6.4868E+00
Loadset:LoadSet1 : AL_TUBING_9056K72

Displacement Magnitude Fringe
Displacement Magnitude (WCS)
(in)
Max Disp 4.2332E-01
Loadset:LoadSet1 : AL_TUBING_9056K72

Figure 39: Bending Stress and Deflection of Al Tubing as Simulated Using Creo

7.4.2: Spring Steel Claws

The claws of the device should bend no more than 0.125-in in order to give the motor enough lag time to measure the current required to stop before the motor stalls. Too much deflection would diminish the possible clamping force, while too little deflection could damage the motor. Calculations which may be found in Appendix E utilized MathCAD to determine the proper thickness of the claws to obtain a deflection at the end of the claws given the following constraints: swinging object weighing 3-lbs (which was measured through testing to generate 5.7-lbf while swinging the device up and down); 5.25-in in length (unsupported); 0.875-in wide; variable thickness. The deflection horizontally was determined to be 0.125-in and 0.002-in vertically. A bending stress safety factor of 2.3 was observed. With these parameters, the total weight of the claws is 0.106-lbs.

These findings were further validated using the CAD modeling software Creo Parametric 3.0. The analyses shown in Figure 40 were obtained by applying fixed constraints to surfaces denoted within the figure by blue stars (due to the orientation of the image, the opposite face of flat section denoted is not displayed, but was also fixed). The x and y components of the applied force were then placed at the tip of the claw as shown in Figure 40. From these constraints a maximum stress at the critical section at the first "bend" of the claws was found to be well under the yield stress for the spring steel. Furthermore, similarly to the calculations, a maximum displacement of 0.13-in, mostly in the horizontal direction, was observed at the face where the loading was applied. These results validate the choice of selecting claws of this thickness and geometry.

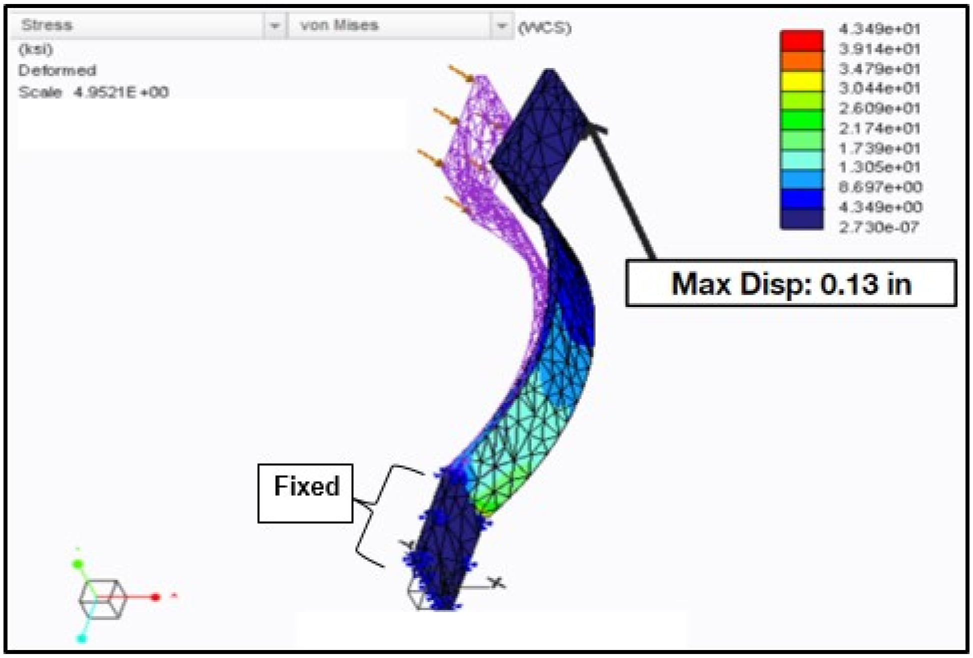
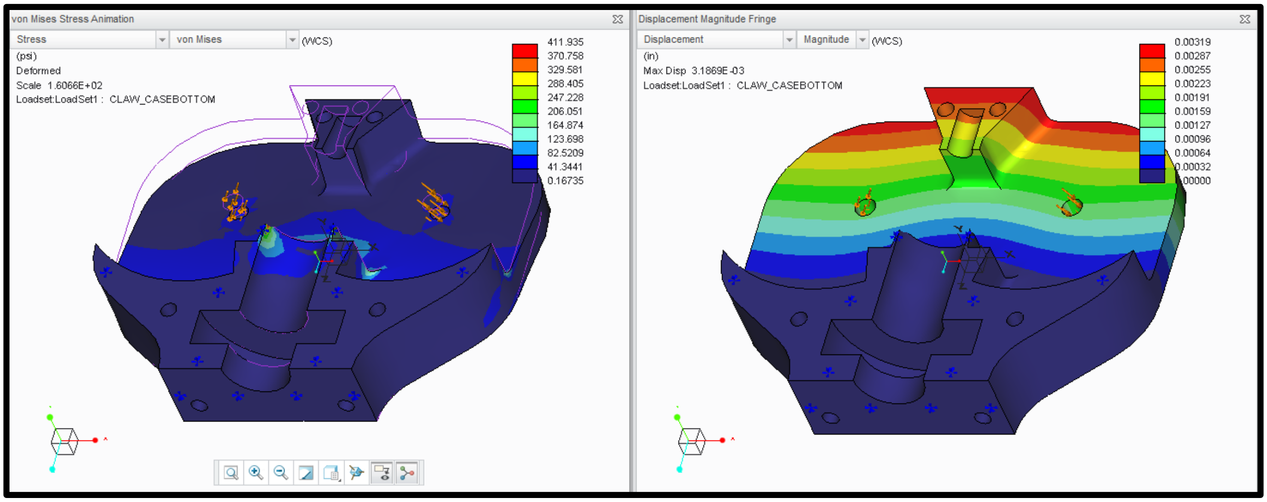


Figure 40: Bending Stress and Deflection of Spring Steel Claws as Simulated Using Creo

7.4.3: Front Casing

Free body diagrams and preliminary analyses indicated that the only other component which would need to be validated to withstand operating conditions was the front casing. The casing's critical sections had to be designed to resist fracturing which would cause the device to either break or improperly function. However, simple analyses of this complex geometry did not provide adequate findings to use as evidence of validating parameters. Therefore, Creo Software was used to identify the maximum stresses and deflection to determine if the design met its requirements.

The front casing, in the worst case scenario, is subject to two forces (3.3-lbf in the negative x-direction as shown by the red line in Figure 41 and 6-lbf in the negative y-direction as shown by the green line in Figure 41) applied at the surface where the worm gears' axles connect to the front casing. The results of this study can be seen in Figure 41. It was assumed that the surfaces displayed in the figure with small blue stars were constrained. The maximum stress on this ABS casing was under 400-psi, well within a tolerable range of stress for the material. Moreover, the static analysis also demonstrated the minimal deflection observed in this casing, less than 0.01-in.



von Mises Stress Animation
Stress | von Mises | (WCS)
(psi)
Deformed
Scale 1.6066E+02
Loadset:LoadSet1 : CLAW_CASEBOTTOM

Displacement Magnitude Fringe
Displacement | Magnitude | (WCS)
(in)
Max Disp 3.1869E-03
Loadset:LoadSet1 : CLAW_CASEBOTTOM

Figure 41: Bending Stress and Deflection of Front Casing as Simulated Using Creo

Chapter 8: Manufacturing

The following chapter is an overview of the manufacturing steps involved in creating the first-order prototype of the gripper device. This stage of the project entails extensive trial and error in order to get the device working properly. For clarity, the assembly steps of the prototype are presented first, then specific issues with the device are in the following sub-section. After completing the troubleshooting process, the device able to be assembled from start to finish according to the assembly instructions. The manufacturing stage of the project is necessary before the device's design could be evaluated under real-life conditions.

8.1: Assembling the Prototype

Once all parts and materials were acquired, the following procedure was followed to assemble the device:

1. Slide worm onto drive shaft until the screw holes line up with the grooved section of the shaft. Tighten set screws with Allen key.
2. Press flanged sleeve bearings into 3D printed 'sleeve bearing spacers', shown in Figure 42.

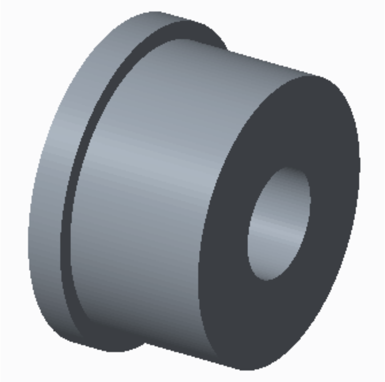


Figure 42: Model of Sleeve Bearing Spacer

3. Press 'sleeve bearing spacers' into either end of the aluminum tubing until the flange meets the end of the tubing.
4. Lubricate drive shaft and sleeve bearings with white lithium grease.
5. Insert shaft into tubing through one of the sleeve bearings. Hold tubing and shaft vertical, worm-side facing up while rotating the shaft with your fingers to locate the shaft through the second sleeve bearing.
6. Slide rotation 'receiver' onto tubing, shown in Figure 43. Tighten set screw until secure.

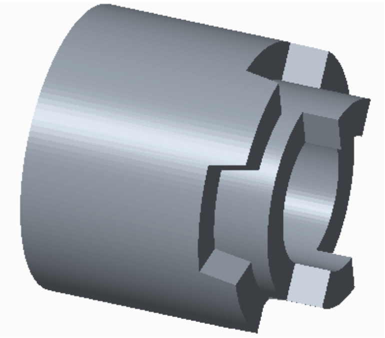


Figure 43: Model of Rotation Receiver

7. Slide rotation ‘sleeve’, shown in Figure 44, onto tubing.

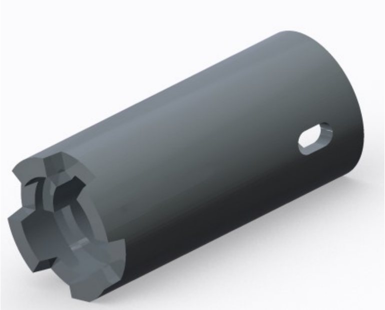


Figure 44: Model of Rotation Sleeve

8. Slide compression spring onto tubing.
9. Slide ‘rotation casing’, shown in Figure 45, onto tubing.

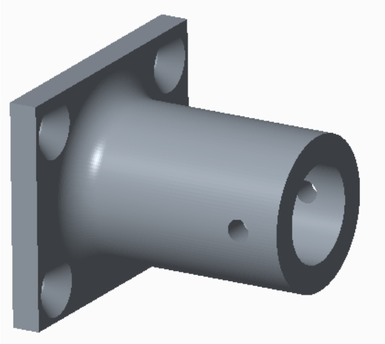


Figure 45: Model of Rotation Casing

10. Pre-load spring and turn set screws into either side of the ‘rotation casing’. Do not tighten against tubing to allow head to rotate.
11. Slide shaft collar over tubing.
12. Fit sleeve bearing onto shaft, flange against the front of the worm.
13. Fit ‘front casing bottom’ onto tubing. Locate shaft collar into the designated cutout in the ‘front casing bottom’ and move tubing forward until the worm fits snugly between both sleeve bearings. Tighten shaft collar.
14. Insert ¼-20 bolts up through bottom of ‘front casing bottom’.
15. Assemble left and right claw assembly.
    a. Fit ‘claw coupler’, shown in Figure 46, onto the side of the gear.

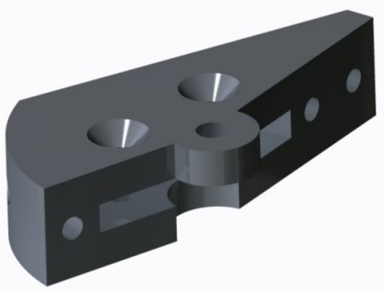


Figure 46: Model of Claw Coupler

   b. Attach 'spring steel claw' to 'claw coupler' with two ¼-20 screws.
   c. Attach surgical tubing to 'spring steel claw' by wrapping segments of florist wire over it and twisting them until tight. Trim excess florist wire with wire cutters.

16. Slide thrust bearings and claw assemblies onto bolts.
17. Place 'front casing top' over bolts and fasten with nuts.
18. Fasten 'rotation casing' to front casing with screws.
19. Slide 'grip', shown in Figure 47, onto tubing.

Figure 47: Model of Grip

20. Slide 'rear casing wall' onto tubing until flush with 'sleeve bearing spacer'.
21. Attach motor and motor bracket to 'rear casing bottom' with screws.
22. Attach shaft coupling hub to drive shaft. Tighten set screw.
23. Attach shaft coupling hub to motor shaft. Tighten set screw.
24. Attach bread board and motor driver to 'rear casing bottom'.
25. Connect wires (see wiring diagram).
26. Fasten 'rear casing top' to device with screws.

8.2: Troubleshooting the Prototype

While the device was designed to function properly, some issues did arise in the manufacturing phase that required action.

8.2.1: Motor Misalignment

After assembling the rear casing, the motor shaft was aligned slightly above the drive shaft. The shaft coupler which was purchased is designed to compensate for slightly misaligned shafts, however it still caused some problems. The misalignment caused the two shafts to push away from each other and the motor to wobble on its bracket, ultimately loosening the set screws holding the shaft coupling hubs in place. We were able to improve the shaft alignment by shaving down the plastic surface which the motor bracket was attached and bending the bracket slightly. The shafts are now only slightly misaligned and do not cause any noticeable issues.

Additionally, the motor shaft is a bit smaller than the hole of the shaft coupling hub. When the set screw of the shaft coupling hub was tightened down on the motor shaft, the shaft was forced into a non-concentric position in relation to the hub. Because the shaft coupling hub was not concentric with the motor shaft, the hub wobbled during operation, forcing the hubs apart and making the motor work harder to overcome the friction of the sliding shaft coupling parts.

To resolve the wobbling problem, the size of the motor shaft had to be increased by a small amount. A single piece of duct tape on the round side of the motor shaft prove to be the best solution. The flat part of the motor shaft, where the set screw presses onto, was left bare so that the set screw of the shaft coupling hub would have enough friction to stay in place.

8.2.2: Gear Misalignment

The holes of the front casing which locate the gears in relation to the worm were too close to each other, making it impossible to fit the top of the casing over the bolts. It is uncertain whether this was due to human or 3D printing error. This problem was initially solved by boring out the holes in the outward direction with a Dremel multi-tool. After this modification, the gears were able to mesh properly without binding. However, to align the gears properly, the ends of the bolts had to be delicately maneuvered into place each time the front casing was opened and closed. External star-shaped lock washers were used to ‘bite’ into the casing and prevent the bolts from drifting outward away from the worm.

This solution worked while rotating the drive shaft by hand. However, when the motor was attached to the shaft, it would only run for a short time before the separation forces from the worm-gear interaction forced the bolts out of alignment. The final solution to this issue was to reset the gears to their proper locations, measure the distance between the centers bolts, and fabricate a thin plate which would locate the bolt heads at the proper distance. A thin piece of polycarbonate sheet was cut into a rectangular piece which had two 1/4-in holes 2.26-in apart drilled into it. These plates were placed on top and bottom of the casing, over the previous bolt holes. Not only do they keep the gears in perfect alignment, but they also seem to distribute the compressive force of the bolts across the surface of the casing, eliminating the need for the two screws at the front of the front casing.

8.2.3: Insufficient Space in Rear Casing

When modeling the rear casing of the device, the power plug for the Arduino as well as the driver for the motor were overlooked. To make room for these components, the back wall of the rear casing was cut out and a new extension was fabricated out of polycarbonate.

8.2.4: Electrical Issues

The device tends to misbehave when the wires are moved into certain orientations. Since the casing is so small on the inside, the wires have to be compressed in order to attach the top of the rear casing. When the wires are moved it sometimes causes the Arduino to get stuck in an undesirable state where the motor moves continuously without responding to any input by the user via the rocker switch. The frequency of these mishaps was reduced by replacing certain wires that may have been damaged and securing wires to the bread board with tape.

8.2.5: Design for Assembly

The rear casing could have been planned out bit better. At first it was thought that the motor and all other electronics should be mounted on the rear casing panel so work could be easily completed. However, since a bread board is being used, it is only necessary to have access from the top. The layout of the casing had already been determined when it was realized that a switch to toggle control modes was needed alongside a power switch. The switches were therefore mounted on the same surface as the rest of the electrical devices. This was the only possible way to link the shaft couplings before closing the rear casing. In hindsight the motor should have been mounted on one half of the casing and electronics on the other. This was able to be worked around for the prototype, but should be addressed in later versions. Additionally, no place was designated for the battery, which ended up being zip-tied next to the grip of the device.

8.2.6: Fastening Fixed Components

Fastening 3D printed parts was a recurring issue as set screw holes were not accounted for in many of the CAD models. It was then necessary to drill holes into low-density parts which had very limited material for the screws to secure themselves. Many of the holes which were drilled became damaged over time and required a lot of reworking to fix, resulting in wasted time and effort when the holes could have been printed from the beginning and made the proper way.

8.2.7: Claw Geometry

The shape of the claws had to be changed in order bring the middle of the claws together more when closed. Adding two 90-deg bends to the base of each claw makes them more suitable for grasping objects in the desired range of size.

8.2.8: Shaft Coupler/Worm

During operation, the shaft coupler hub and worm kept loosening and moving with respect to the drive shaft due to the high torque of the motor and the axial forces due to the worm-gear setup. To secure these components a Dremel multi-tool was used to grind flat surfaces on to the drive shaft where the components attached so the set screws could sit better on the shaft and would be less likely to loosen.

8.2.9: Front Casing Weight Reduction

After assembling the device, it was heavier in the front than expected and required substantial muscle strength just to wield the device. In order to reduce the moment at the wrist caused by the weight in the front, the front casing was taken apart and all components were weighed individually. The claw coupler clamp pieces were not serving any function at all since the claw couplers fit so snugly over the gears, but were contributing significantly to the weight. By removing these pieces completely and using smaller screws in the couplers and smaller washers on the top of the casing the total weight of the front casing was reduced by 15%.

Chapter 9: Evaluating the Prototype

In order to create a viable product, the reacher-gripper must satisfy some basic requirements. At the initial stage, it must succeed at meeting the functional specifications which are intertwined with the measurement of success. In order to accomplish this, protocol must be developed to measure those specifications which can be measured. Additionally, outside observations and opinions on the device must be included to establish a consensus on what was accomplished and where the product may be improved.

9.1: Functional Requirement Evaluation

To evaluate the functional requirements various measurements were conducted and experiments performed to evaluate the device performance in comparison to the design specifications. The following specifications required physical measurements which may be gathered through the use of rulers, scales, and stopwatches:

1. The device must extend user's reach by 3-ft.
2. The device must hold objects up to 10-lbs in weight. *
3. The device must be able to fully close (from open position) in under 4-sec.
4. The device must weigh less than 4.5-lbs (previous MQP).
5. The device must fit within a cylinder of 9-in diameter and 24-in length.
6. The device must be able to be donned and doffed in under 10-sec.

Additional specifications were measured during use of the device:

7. The device can hold objects whose smallest dimension is between 0.0039-in. and 5-in.
8. The device's claws must not deflect more than 1/16-in perpendicular to their plane of motion under specified operating conditions.
9. The device should require no more than 3.7-ft-lb of ulnar deviation torque from the user to operate.
10. The device should require no more than 16-lbf of grip strength for the user to operate.

The majority of these metrics were found to be accurate measures of requirements the device must satisfy, however after progressing through the test process some specifications were found to not accurately reflect the success of the device. These findings will be discussed further in the results and conclusions section of this report.

Additionally, to verify the theoretical analysis of forces experienced by the user and the potential grip force applied to objects, a test protocol was developed to validate the results using fixtures, digital force gages, and Logger Pro software. The first tests were conducted to determine the forces experienced by the user. Figure 48 the setup of the experiment conducted in Olin Laboratory at WPI.

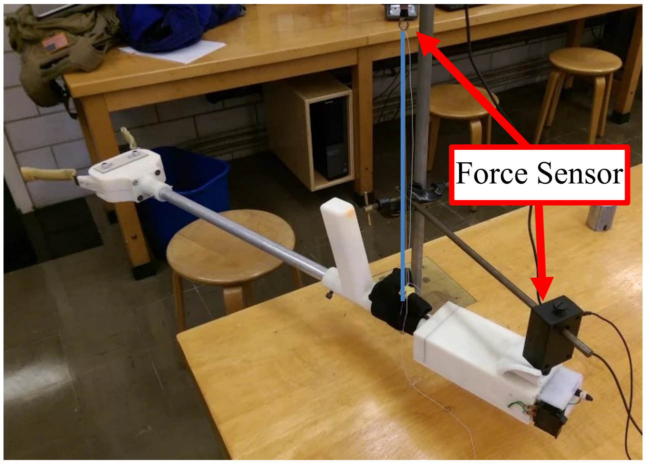


Figure 48: Test Setup for Forces Experienced by User

The Logger Pro software allowed for real-time analysis of the forces experienced at the location of the wrist and the forearm. This analysis was accurately measured by using two force sensors at the designated location. The sensor located at the wrist used a thin string to connect the device to the sensor to measure the vertical force induced on the user. To measure the vertical force on the user's arm, a bumper sensor was used on the support. Both loadings, unloaded and 2.5-lbs object being grasped by the claws were analyzed and their results recorded.

Another important measurement which needed to be identified was the actual force the device was capable of exerting. Figure 49 shows how this metric was evaluated. Utilizing a force gage, spring, string, and fixturing the force being applied by the claws was measured by actuating the device and recording the reading displayed through software. A spring placed at the gage allowed the force being applied by the claws to be transferred throughout the claw's closing motion. This test was conducted three times to generate the most accurate output. Throughout this test, the device was kept stationary on a fixture to isolate the motion of the claw. The results of this test may be found in the results and conclusions section.

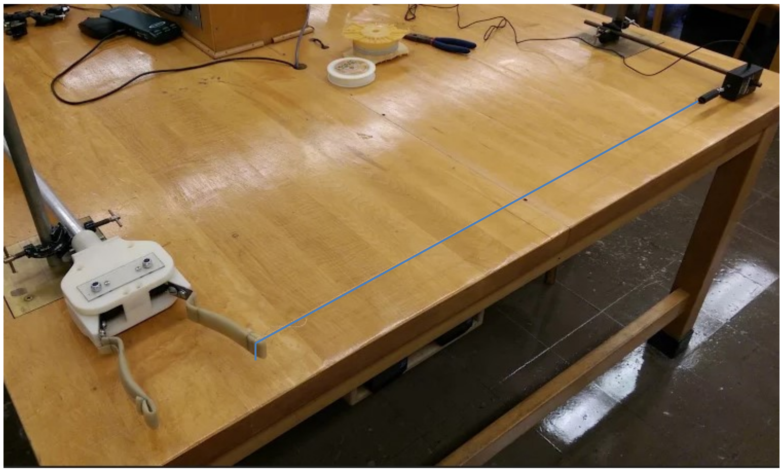


Figure 49: Test Setup to Measure Force Output at Claws

9.2: Functional Testing Results

Results from functional testing indicated that the device satisfied the vast majority of the requirements laid out in functional specifications. However, as mentioned earlier, some requirements were found to be incongruent with the needs of the final device. The requirement that the device extend the user's reach by 3-ft wasn't entirely accurate to the industry standard extension length. Once this fact was understood the group decided to manufacture the device to extend the user's reach by 32-in, a more accurate reflection of competitive devices. Another specification that was determined to be unfounded was the requirement that the device pick up objects weighing up to 10-lbs. This value was derived from both the MQP completed in 2011 which stated 8-lbs as the goal, in addition to commercial grippers' typically published maximum threshold of 5-lbs (Busteed & Rinaldi, 2011). While these devices may be capable of maintaining their structural integrity at this weight, users are typically incapable of lifting objects weighing more than 3-lbs at that distance. When tested the device was found to successfully hold up to 4-lbs, which exceeded this new limit. Lastly, the packaging specification of being able to fit within a 9-in diameter cylinder that is 24-in long is no longer needed as an articulating arm design that could fold was no longer being pursued. Therefore, to limit the length of the device to 24-in would not allow for approximately 3-ft of extension.

Some specifications were designed to limit the hindrance on the user's time or effort to operate. The device was found to close in under 1-sec (mean = 0.75-sec) when recorded using a stopwatch. This finding far exceeds the parameter of closing in under 4-sec, however it also demonstrates that the user can operate the device at close to the same speed as a mechanical alternative. Another specification that was intended to limit the time requirement on the users was the ability to don and doff the device in under 10-sec. When analyzed it was found that the device took an average of 4-sec to don and the same amount of time to doff, well under the proposed limit. The overall device weight was determined to be a total of 1-lb less than the previous reacher gripper MQP (Busteed & Rinaldi, 2011), weighing in at 3.5-lbs. Although this is still a large amount of weight for the user to wield, the design incorporated a method of mitigating the perceived weight at the wrist, thereby requiring minimal grip strength to operate. This design also eliminates the need for ulnar deviation because the wrist and forearm are essentially fixed to the rear casing.

The last requirement was the breadth of items that the device could grasp. During background testing the commercial grippers were unable to pick up objects such as paper, on the smaller end, and wider objects such as peanut butter jars, on the larger end. The specification was therefore to be able to pick up objects from .039-in to 5-in, width of paper and peanut butter jar, respectively. The design that was manufactured successfully picked up paper and has the ability to grip objects up to 7.9-in.

In addition to testing for functional specifications, evaluations to identify key results that may impact the usefulness of the assistive device were developed. As described in the testing chapter experiments were devised to test different forces that may be applied to user’s along with the grip force the claws can apply. The loads at the user’s forearm and wrist were found to be approximately 4-lbf and 8-lbf under no loading, respectively. With a 2.5-lbs loading the forces are 9-lbf and 14-lbf for the forearm and wrist, respectively. These results show the large increase in strength needed at the user's wrist given an increased load experienced by the user at different loads. After constructing a fixture to evaluate the clamping force, the device was determined to be capable of applying 8-N of force to an object. While this value is slightly below the theoretical calculation of 12-N, this still seems to be acceptable due to the control logic in the device. The experiment tested the force applied by one claw, however the device can only detect the current draw. Since the controller cannot detect any difference between one claw being loaded and both claws being loaded, the closing motion may have been terminated prematurely.

9.3: User Evaluations

In order to determine whether the device was viable as a commercial product, it needed to be tested with prospective users. User feedback would provide invaluable insight about the strengths and weaknesses of the device by those who would purchase it. Specifically, it would be useful to know how much effort it required to manipulate objects with the device, how easy it was to understand how to use the device, how comfortable it was to use the device, and perhaps most importantly, if users would be willing to purchase a device similar to this prototype. These evaluations, along with other feedback, would help determine what improvements would be needed to turn this device into a marketable item.

The intended user group for this device is individuals in need of a way to extend their reach, and who have impairments in their arms and hands. As mentioned previously, these types of individuals are likely to be the elderly living independently or perhaps in some sort of assisted living. This user group was selected as the primary test population. Younger and more able-bodied participants were sought out to be testing participants as well, since it was easier to access these types of participants, and doing so would provide a greater number of samples in the testing. Additionally, these users might have different perspectives on the device and provide alternative types of feedback that may not have been received otherwise.

In order to find elderly participants, staff at The Village at Willow Crossings Retirement Community in Mansfield, Massachusetts were contacted. After they expressed interest in aiding the project team, they were sent an overview of the proposed testing. A similar proposal was also sent to the Institutional Review Board at WPI. The proposals were approved by both parties, and an invitation was extended to conduct evaluations at Willow Crossings. Individuals who are living independently and those in need of assisted living both attend Willow Crossings. Here, there are various activities in which seniors can participate, and the testing was promoted as one such activity. Unfortunately, none of the seniors living independently were able to participate in the testing, so results were limited to those in assisted living. To recruit younger participants, friends and acquaintances at Worcester Polytechnic were contacted and asked to participate in the evaluations.

The device evaluation consisted of two trials. The first trial was for evaluating a common reacher gripper, the Grip ‘n Grab, and the second trial was for evaluating the prototype, the Grab Bot II. A common reacher gripper was used in the first trial to serve as a comparison for the device to determine its ability to compete with what was available on the market. The Grip ‘n Grab was chosen as it had the most conventional design for a reacher gripper, and it scored the highest during the preliminary evaluations of commercial grippers.

The evaluation trials were conducted following the reading of an informed consent form to the participant. This form is included in Appendix D. After the participant had understood and signed the consent form, the evaluation of the two devices commenced. The participant was asked for their age, and what type of impairments they have in their arms, if any. These responses were recorded on a form by one of the investigators. This response form is located in Appendix D. The response form was accompanied by a script used by an investigator for the duration of the trials, found in Appendix D.

At the start of each trial, the participant was given either the Grip 'n Grab or the Grab Bot II, along with a brief verbal explanation of how to operate it and a demonstration by one of the investigators. They were then allowed to practice using the device. When the participant was given the Grab Bot II, they were instructed to strap themselves into the device, though they were allowed to ask for assistance with putting it on if needed.

During the trials, the participant was asked to retrieve four different objects using the device and place them on a table top. There was a light object on the ground, a heavy object on the ground, a light object on a raised surface such as a cabinet, and a heavy object on a raised surface. Due to the various times and locations of the testing, the items and placement of those items was not consistent for all tests. However, certain aspects remained constant. The light objects weighed between 0.2-lbs and 0.5-lbs, and were items such as television remotes and empty cups. Heavy objects weighed between 1.3-lbs and 2.0-lbs, and were items such as containers of liquid and shoes. The surface upon which objects were deposited was about 36in from the ground. The raised surface from which objects were retrieved was about 60in from the ground. If the participant felt uneasy standing for the duration of the testing, they were allowed to sit in a chair, and the raised surface was changed to about 48in above the ground. After the participant had retrieved an object, they were asked to rate the difficulty of retrieving that object from 5 (easy) to 1 (hard). The scale of difficulty was presented to them visually as well as verbally. The scales used for these ratings are found in Appendix D. It would have been more informative if more trials could have been conducted with a greater number of commercial reacher-grippers and a variety of items, but this greater amount of activity may have been too much of a strain on some elderly participants.

At the end of the trials, the participant was asked a series of questions about their thoughts on the device they had just used. These questions included: how comfortable was the device to use, how easy was it to understand how to use, what did the participant like about the device, and what did the participant not like about the device. Additional questions were asked for the Grab Bot II. These included: how easy was it to take the device on and off, what would the participant use this device for, what improvements they would make to the device, and how much would they pay for the device. Once the participant had answered these questions, their part in the evaluation was over. The next step was to evaluate the results.

9.4: User Testing Results

This section discusses the results of the user-based testing. The responses of the Willow Crossings residents are compared to those of the WPI students for both the Grip ’n Grab trials and the motorized gripper trials. Results from this research contains both quantitative and qualitative responses. Figure 50 compares how the two device were evaluated by the two user groups. It displays a sum of all questions rated 1 to 5, with 1 being an unfavorable performance, and 5 being a favorable performance. The data are composed of the rankings of task performance difficulty for all four tasks, comfort, ease of donning and doffing, and intuitiveness. The Grip ‘n Grab received higher ratings among both user groups than the motorized gripper. This is likely because the Grip ‘n Grab is a well-refined commercial product while the motorized gripper is a first-order prototype. The motorized gripper had closer ratings to the Grip ‘n Grab among WPI students than Willow Crossings residents. It was likely rated much higher with the student group because they are younger and more able-bodied than the users at Willow Crossings. The motorized gripper is much heavier than the Grip 'n Grab so it is not surprising that elderly users would have trouble operating it.

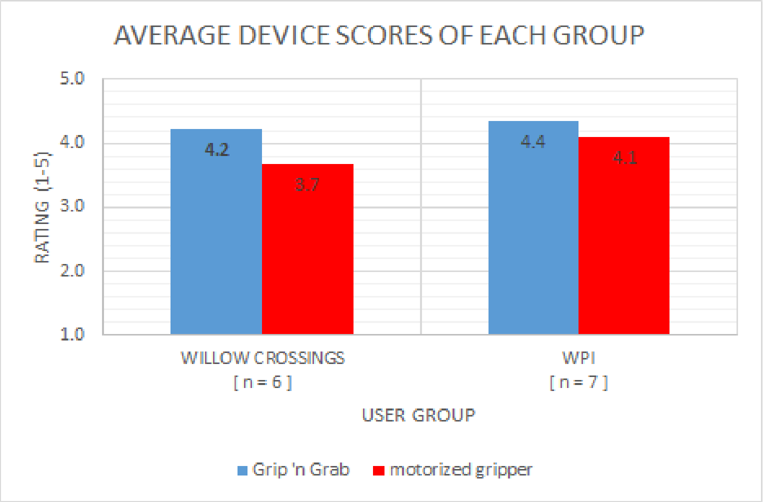


Figure 50: Average Device Ratings for Each User Group

Figure 51 compares the averages for the task easiness ratings for all four tasks. The averages for each individual task can be found in Appendix D. The motorized gripper scored slightly worse than the Grip 'n Grab among both user groups. Both user groups rated the Grip 'n Grab at the same level of difficulty, but WPI students found the motorized gripper more easy to use than the Willow Crossings residents by a score of 0.2. This is likely due to the fact that the motorized gripper weighed 2.9lb more than the Grip 'n Grab, which would have made less of a difference to the able bodied students. The highest difference in averages for the motorized gripper versus the Grip 'n Grab in terms of difficulty was 0.3.

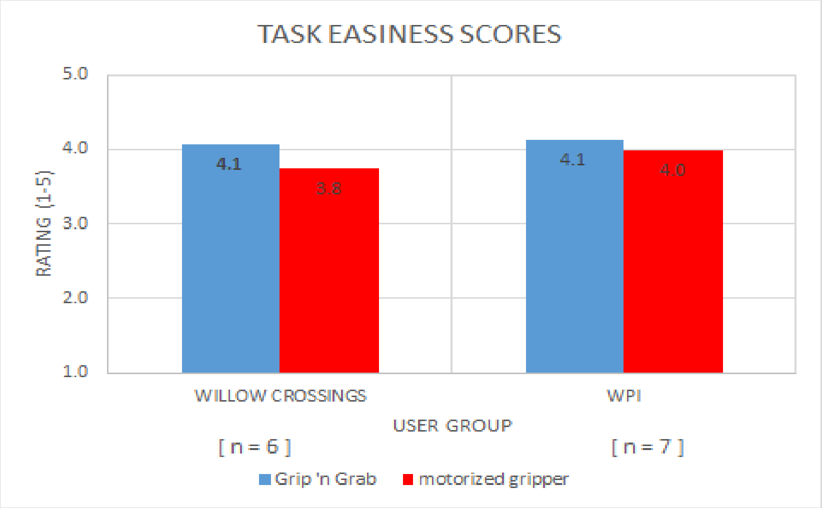


Figure 51: Ease of Completing Tasks

Figure 52 depicts how comfortable users were when operating the devices. For Willow Crossings residents, the Grip 'n Grab was rated higher than the motorized gripper. This was the opposite for WPI students, though the discrepancy was not as high. WPI students rated the comfort of the motorized gripper a score of 1.2 higher than the Willow Crossings residents, and rated the Grip 'n Grab a score of 0.5 lower than the Willow Crossing residents. It is easy to believe that the Willow Crossing residents would find the motorized gripper less comfortable, as it is heavier and more restrictive, but it is unclear what the WPI students found to be more comfortable in the motorized gripper.

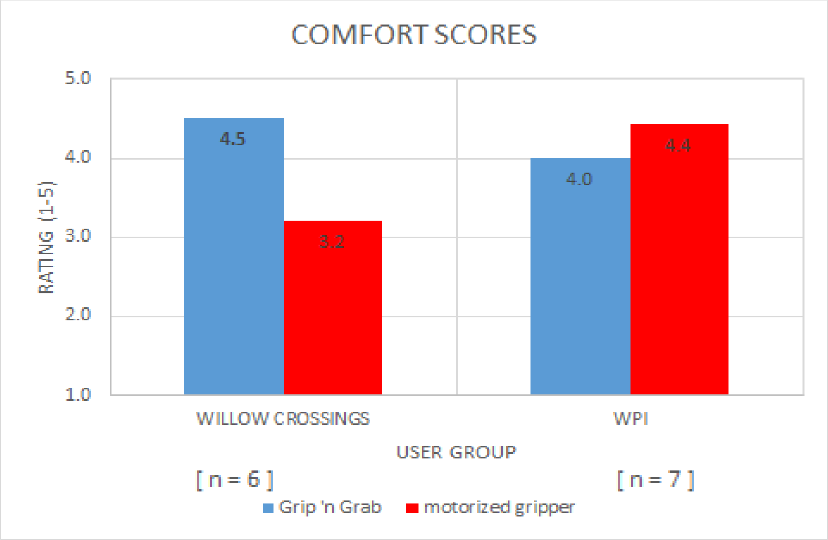


Figure 52: User Comfort Level

Figure 53 shows the results pertaining to the difficulty of putting on and taking off the motorized gripper. This criterion did not apply to the Grip ‘n Grab, Willow Crossings residents rated the motorized gripper a score of 0.9 lower than the WPI students. This can likely be attributed to the fact that the elderly participants had less hand strength and dexterity than the WPI students, which would make strapping and unstrapping the Velcro wrist support more difficult.

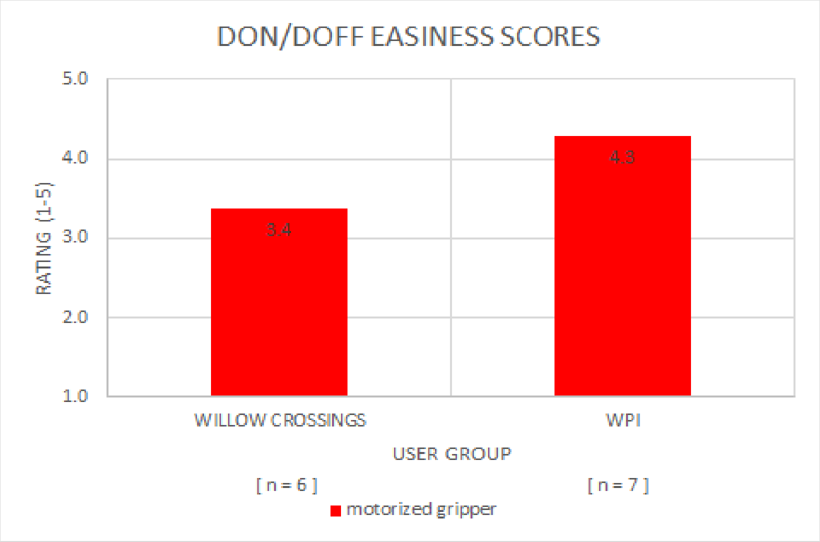


Figure 53: Ease of Donning/Doffing Device

Figure 54 displays how easily comprehensible users found the gripping devices. Both groups stated that the Grip ‘n Grab was easier to understand than the motorized gripper. The differences between each group's ratings of the devices are relatively small, and likely not significant due to the small sample size of participants.

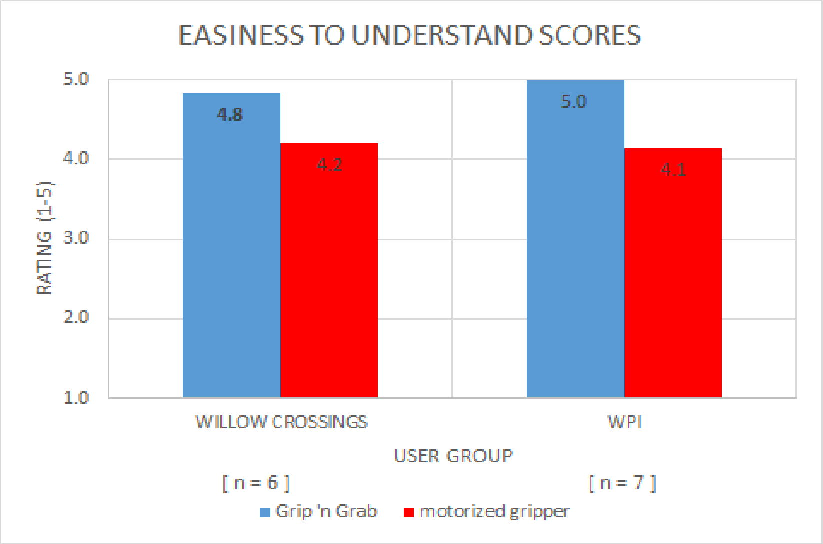


Figure 54: Intuitiveness of Device

Users were asked how much they would expect to pay for a device like the motorized gripper if it were a fully realized commercial product. Both young and old participants had similar response ranges as seen in Figure 55, with a total minimum of $20 and a maximum of $100. There was no apparent mode for a sample this small, though such a value would be useful for determining a reasonable market price.

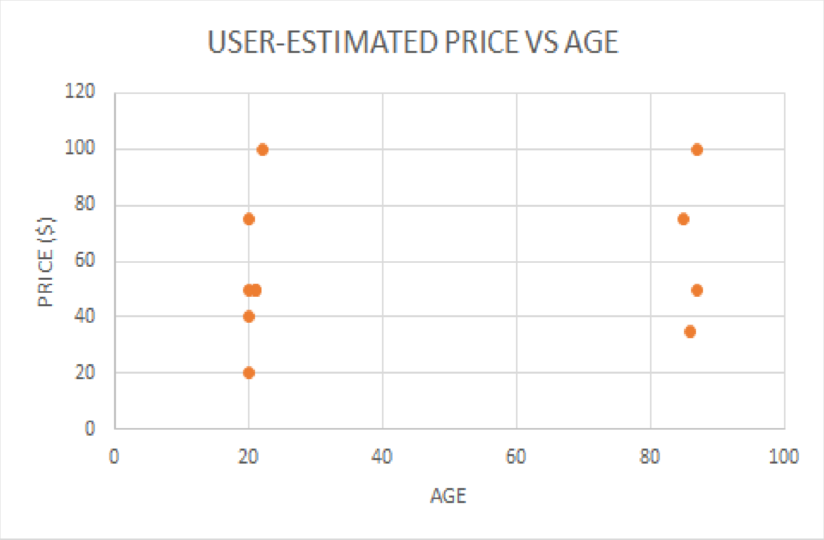


Figure 55: User Estimations for Price

9.5: Favorable Aspects of Device

Users of the motorized gripper reported that they liked the following features of the device:

- Longer claws
- Automatic
- Can grab large objects
- Controls are simple
- Grasp is more secure
- Better at grabbing unorthodox objects
- Less hand strength required

Most frequently users (n=6) mentioned that the claw geometry of the motorized gripper provided an advantage in picking up objects over the Grip ‘n Grab. The rest of the responses were unique.

9.6: Unfavorable Aspects of Device

Users of the motorized gripper reported that they disliked the following features of the device:

- Heavy (n=5)
- Awkward angles
- Clumsy
- Not working properly (control malfunction) (n=4)
- Hard to control

The most common critique among the responses was that the device weighed too much. The second most common critique related to the improper function of the device’s controls. The remaining responses had to do with the ergonomics and controllability of the device.

9.7: User-Suggested Improvements to be Made to Device

Users of the motorized gripper gave the following suggestions for improving the device:

- Move the weight backward
- Make buttons easier to push
- Change control scheme (n=4): make middle button stop
- Make back support more secure
- Design better gripping geometry for the claws (n=2)
- Implement an extendable shaft
- Give it the ability to bring objects closer to you

The most common suggestion was to improve the improperly functioning controls. The second most common response was to improve the claw geometry, which contrasts interestingly with the large number of positive response towards that aspect of the design.

9.8: Additional Comments from User Testing

- Users indicated a possible need for adjustable length reacher gripper.
- Most users used a second hand while using the Grip ‘n Grab
- Switch was difficult to use / understand
- Some users believed gripper had a second functionality as a cane
- Clients with prior experience using a reacher gripper indicated that their device was only able to be used 50-60 times before breaking
- Users indicated primary use in the kitchen

Chapter 10: Conclusions and Recommendations

A device was successfully developed that allowed users with reduced hand and wrist functionality to grasp and manipulate objects at a distance. Users with impairments such as arthritis were able to manipulate objects less than 2lb from various heights. The device also greatly improved upon the design developed by the previous MQP (Busteed & Rinaldi, 2011). The device was able to fully open and close in under 1 second and weighs 3.5 lbs. This is 87.5% less time and 15% lighter than its predecessor. Additionally, the device has force-sensing abilities which prevent the device's claws from crushing objects in its grasp or over-torqueing the motor.

Individuals that used the device found it to be advantageous in a number of ways. The device was found to be about as easy to utilize as a commercial gripper for retrieving a variety of common objects. Some users found that the claw design of the device was more useful for picking up larger and more irregularly shaped objects. Additionally, users appreciated the fact that less hand strength was required to operate the device than normal grippers.

There were a number of areas for improvement related to the device. In almost all user evaluations, the device was rated more poorly than the commercial gripper. One of the most notable complaints about the device was its high weight. Users noted that this aspect made the device unwieldy and difficult to use. Another issue with the device was the frequency of minor electronic malfunctions in the control interface. This was the result of a number of factor that could not be fully addressed in the time allotted. This flaw is not intrinsic to the design of our device, but simply our implementation of it.

Despite the flaws with the device, the device has marketable value due to its novelty. The most unique aspects of the design are the non-backdrivable actuation and clamping spring steel claws. This means there is no actuation force needed to maintain a grasp on an object, and no need for the user to engage any locking mechanisms. There are currently no grippers on the market with non-backdrivable claws or with a form of energy storage similar to our design. Users have stated that they would be willing to pay $50 to $100 for the device. If the drawbacks of the device are addressed, it could be sold as a commercial product.

10.1: Recommendations for Future Work

If future work were to progress on this project, there would be specific avenues in which effort should be focused. Specifically, reducing the weight of the fully assembled device, improving the assembly process, altering the types of bearings utilized, utilizing more flexible claw material, and optimizing the rotation mechanism for individuals with reduced hand strength would be advantageous.

10.1.1: Weight Reduction

One of the heavier parts in the front casing of the device was the shaft collar. At the time of purchase, its weight was not considered. However, when the device was picked up it was a bit heavier than expected and the solid aluminum shaft collar stuck out as a major contributor. This part could have easily been 3D-printed out of ABS and functioned properly without adding much weight.

10.1.2: Bearing Decisions in the Front Casing

The thrust ball bearings used above and below the claws in the front casing were very tall, requiring a larger front casing than originally intended. A flanged sleeve bearing should have been used instead as they are rated for even more axial force than the thrust ball bearings and require almost a 1/4-in less space. With these bearings, head casing height may have been reduced by about a 1/2-in.

10.1.3: Spring-Steel Selection

The spring steel selected for the claws was heavier in hand than expected. It would have been better to use thinner spring steel because it would be lighter and more flexible. The flexibility of the claws is essential for the operation of the device because it provides a cushion for the Arduino to sense changes in current and allows the device to clamp down on objects quickly.

10.1.4: Rotation Mechanism

The compression spring of the rotation mechanism is a little too stiff for the user to compress. The springs were only available in certain sizes and range of stiffness. The size of the shaft and rotation mechanism components necessitated a spring constant of 10-lbf/in when a spring constant of 7-lbf/in was more desirable.

10.1.5: Reduction in Front Casing Size and Weight

Since the operation of the device only requires using a 30-deg section of the gears, the rest of the gears could be cut off in order to reduce packaging size and weight. New claw couplers could be made to fit onto the gears. If mass-produced, the spring-steel claws could be fastened directly onto the gears without any need for separate coupler parts.

When purchasing the gears, the option to get them with or without brass inserts was available. The former was chosen without realizing how much weight they would add to the device. At the time the decision was made, it was not yet decided whether the gears would mount on fixed or rotating shafts and wanted to keep options open.

10.1.6: Fastener Sizing

All 3D printed parts of the device are over-sized for their required function. While the outer dimensions were necessitated by functional requirements and average human proportions, the wall thicknesses were primarily dictated by hardware size since the screws fastened directly into the walls. However, the ‘proper’ way to fasten 3D printed parts is to create separate bosses for screw holes instead of fastening them directly into the walls of the parts, which was realized later. This makes sense because most mass-produced parts have separate cylindrical bosses for screws.

While dimensioning the parts, calipers were used in order to visualize how large or small each part would be. However, the big mistake was in choosing ¼-20 screws to be the standard hardware size for the device. The device should have been designed with these screws in hand, so that a sense for how large and heavy they were may have been realized. Since the means to factor hardware into a stress analysis were not available, we ended up overlooking this area. In hindsight hardware one, two, or three sizes smaller may have been sufficient and would have cut down on the overall weight of the device.

10.1.7: Scaling Production

To produce a viable product to market there are some very specific changes that need to be made in regards to materials, processes, and actual design. As the current model only represents a prototype and proof of concept, a production version requires further work. In the interest of time available to undertake an MQP, WPI’s rapid prototyping services to generate components with minimal lead time. If a full-scale production line were to be created for this reacher gripper, an investment in tooling to create injection molded parts would be made.

Injection molded parts would be desirable due to their low cost, comparable strength to the prototype, and minimal time to produce. The only major cost associated with this option would be to create custom tooling in order to mold the following parts: rear casing bottom, rear casing top, rear casing wall, front case bottom, front case top, neck, coupler clamp, claw couplers, and grip.

In addition to designing the tooling, the design of certain parts should be revisited with respect to fastening. A method of fastening which would allow for easier assembly, along with reduction in parts and weight, would be to design snap fits into the device rather than screws. By utilizing the plastics' tensile strength and geometry to secure parts to each other a reduction of at least 0.25-lbs may be realized. Considering the device weighs under 3.5-lbs, this is a significant margin for a simple and cost-effective fix. Furthermore, if this product were to be assembled on an assembly line, this alteration would minimize the instructions and movements required by workers. Moreover, this would reduce the cost required to assemble.

Regarding the parts which were purchased at base price, if a company intended to sell a viable product they would have to reduce this cost. The most likely route that would accommodate such a solution would be to identify a quality supplier that could provide bulk quantities at reduced price. Unfortunately, this may require a prolonged contract with the supplier that would require further research into estimated sales. This step is essential to ensure inventory does not outweigh the market.

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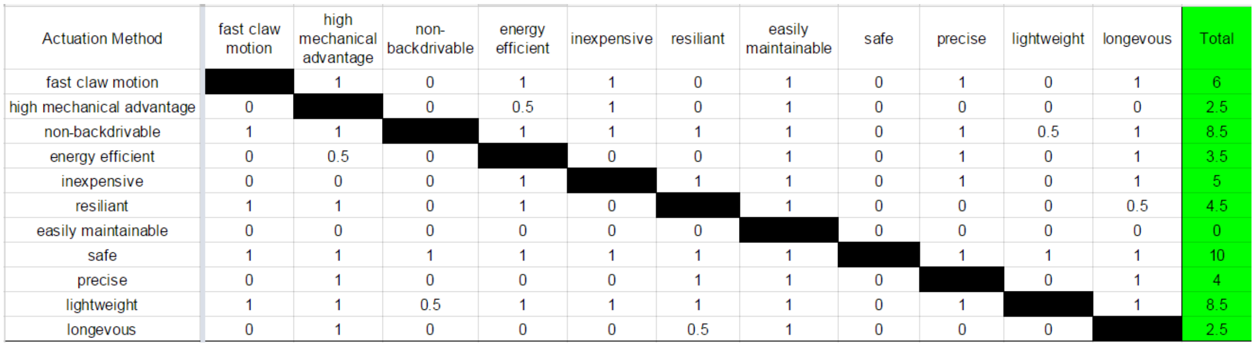
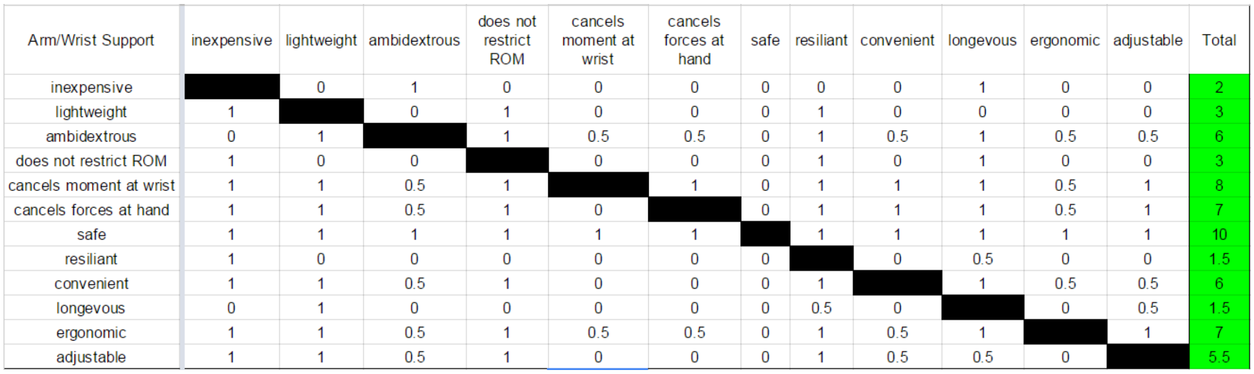
Appendix A: Design Selection



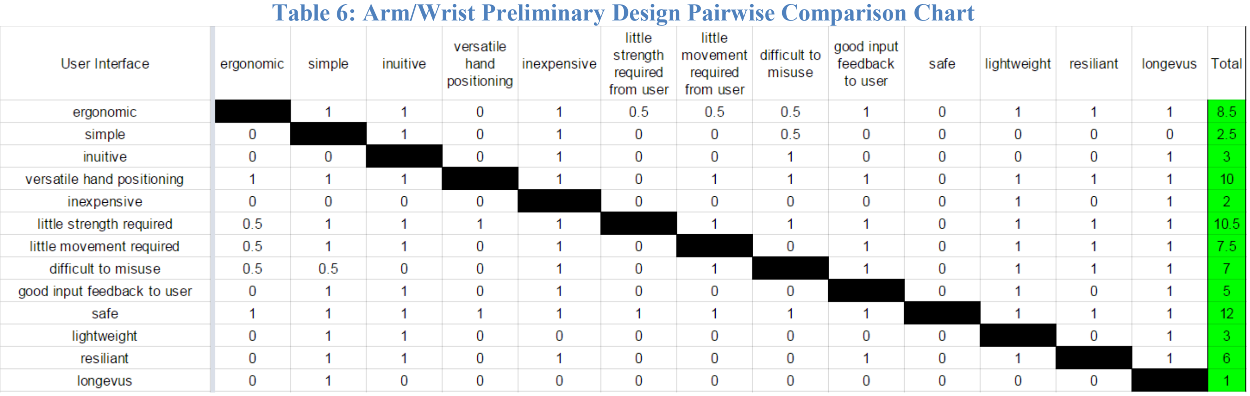
Actuation Method	fast claw motion	high mechanical advantage	non-backdrivable	energy efficient	inexpensive	resiliant	easily maintainable	safe	precise	lightweight	longevous	Total
fast claw motion	■	1	0	1	1	0	1	0	1	0	1	6
high mechanical advantage	0	■	0	0.5	1	0	1	0	0	0	0	2.5
non-backdrivable	1	1	■	1	1	1	1	0	1	0.5	1	8.5
energy efficient	0	0.5	0	■	0	0	1	0	1	0	1	3.5
inexpensive	0	0	0	1	■	1	1	0	1	0	1	5
resiliant	1	1	0	1	0	■	1	0	0	0	0.5	4.5
easily maintainable	0	0	0	0	0	0	■	0	0	0	0	0
safe	1	1	1	1	1	1	1	■	1	1	1	10
precise	0	1	0	0	0	1	1	0	■	0	1	4
lightweight	1	1	0.5	1	1	1	1	0	1	■	1	8.5
longevous	0	1	0	0	0	0.5	1	0	0	0	■	2.5

Table 5: Actuation Method Preliminary Design Pairwise Comparison Chart



Arm/Wrist Support	inexpensive	lightweight	ambidextrous	does not restrict ROM	cancels moment at wrist	cancels forces at hand	safe	resiliant	convenient	longevous	ergonomic	adjustable	Total
inexpensive	■	0	1	0	0	0	0	0	0	1	0	0	2
lightweight	1	■	0	1	0	0	0	1	0	0	0	0	3
ambidextrous	0	1	■	1	0.5	0.5	0	1	0.5	1	0.5	0.5	6
does not restrict ROM	1	0	0	■	0	0	0	1	0	1	0	0	3
cancels moment at wrist	1	1	0.5	1	■	1	0	1	1	1	0.5	1	8
cancels forces at hand	1	1	0.5	1	0	■	0	1	1	1	0.5	1	7
safe	1	1	1	1	1	1	■	1	1	1	1	1	10
resiliant	1	0	0	0	0	0	0	■	0	0.5	0	0	1.5
convenient	1	1	0.5	1	0	0	0	1	■	1	0.5	0.5	6
longevous	0	1	0	0	0	0	0	0.5	0	■	0	0.5	1.5
ergonomic	1	1	0.5	1	0.5	0.5	0	1	0.5	1	■	1	7
adjustable	1	1	0.5	1	0	0	0	1	0.5	0.5	0	■	5.5

Table 6: Arm/Wrist Preliminary Design Pairwise Comparison Chart

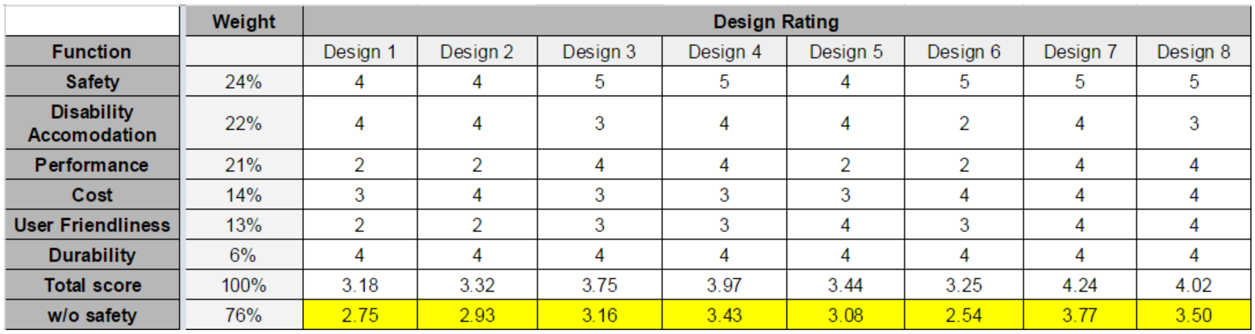


User Interface	ergonomic	simple	inuitive	versatile hand positioning	inexpensive	little strength required from user	little movement required from user	difficult to misuse	good input feedback to user	safe	lightweight	resiliant	longevus	Total
ergonomic	■	1	1	0	1	0.5	0.5	0.5	1	0	1	1	1	8.5
simple	0	■	1	0	1	0	0	0.5	0	0	0	0	0	2.5
inuitive	0	0	■	0	1	0	0	1	0	0	0	0	1	3
versatile hand positioning	1	1	1	■	1	0	1	1	1	0	1	1	1	10
inexpensive	0	0	0	0	■	0	0	0	0	0	1	0	1	2
little strength required	0.5	1	1	1	1	■	1	1	1	0	1	1	1	10.5
little movement required	0.5	1	1	0	1	0	■	0	1	0	1	1	1	7.5
difficult to misuse	0.5	0.5	0	0	1	0	1	■	1	0	1	1	1	7
good input feedback to user	0	1	1	0	1	0	0	0	■	0	1	0	1	5
safe	1	1	1	1	1	1	1	1	1	■	1	1	1	12
lightweight	0	1	1	0	0	0	0	0	0	0	■	0	1	3
resiliant	0	1	1	0	1	0	0	0	1	0	1	■	1	6
longevus	0	1	0	0	0	0	0	0	0	0	0	0	■	1

Table 7: User Interface Preliminary Design Pairwise Comparison Chart

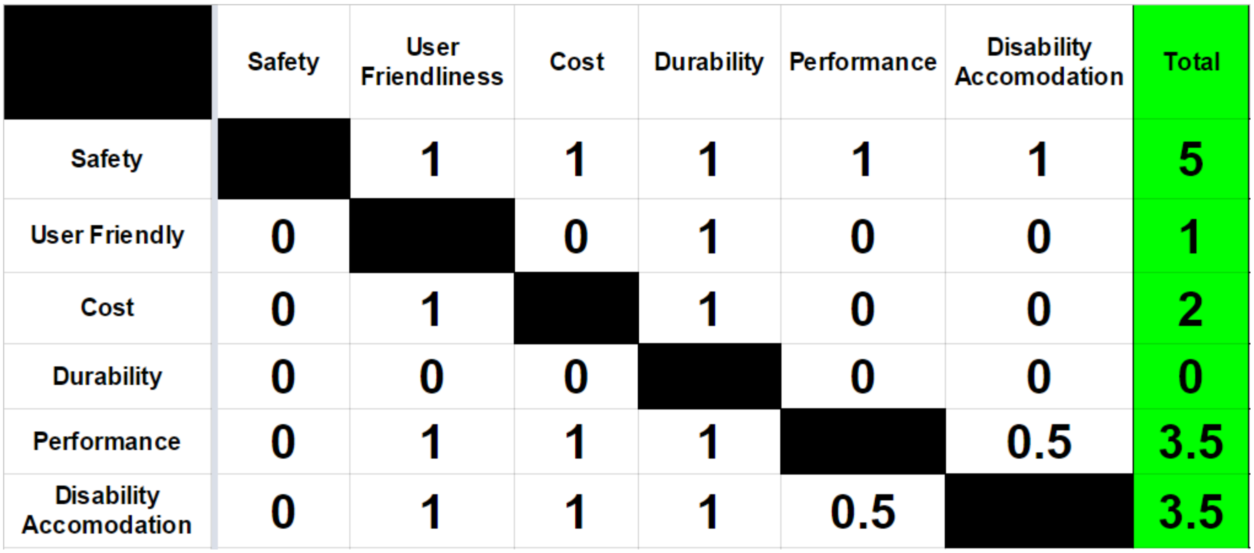
Safety	User Friendliness (Convenience)	Cost	Durability	Performance	Disability Accommodation
user protected from pinching	ambidextrous		resilient	non-backdrivable	ergonomics
limited foreseeable dangerous misuse (over powered claws)	easy don/doff		longevous	fast claw motion	lightweight
cannot contrort the body in a harmful way	difficult to misuse		maintainability	energy efficiency	non-restrictive
	inuitive		internal components protected from damage	ability to secruely grasp items of various sizes	cancels moments/forces at hand/wrist
	compact				

Table 8: Attributes Used to Define Device Criterions



	Weight	Design Rating							
Function		Design 1	Design 2	Design 3	Design 4	Design 5	Design 6	Design 7	Design 8
Safety	24%	4	4	5	5	4	5	5	5
Disability Accomodation	22%	4	4	3	4	4	2	4	3
Performance	21%	2	2	4	4	2	2	4	4
Cost	14%	3	4	3	3	3	4	4	4
User Friendliness	13%	2	2	3	3	4	3	4	4
Durability	6%	4	4	4	4	4	4	4	4
Total score	100%	3.18	3.32	3.75	3.97	3.44	3.25	4.24	4.02
w/o safety	76%	2.75	2.93	3.16	3.43	3.08	2.54	3.77	3.50

Table 10: Final Design Scoring



	Safety	User Friendliness	Cost	Durability	Performance	Disability Accomodation	Total
Safety		1	1	1	1	1	5
User Friendly	0		0	1	0	0	1
Cost	0	1		1	0	0	2
Durability	0	0	0		0	0	0
Performance	0	1	1	1		0.5	3.5
Disability Accomodation	0	1	1	1	0.5		3.5

Table 9: Full Preliminary Design Criteria Pairwise Comparison Chart

Appendix B: Free Body Diagrams

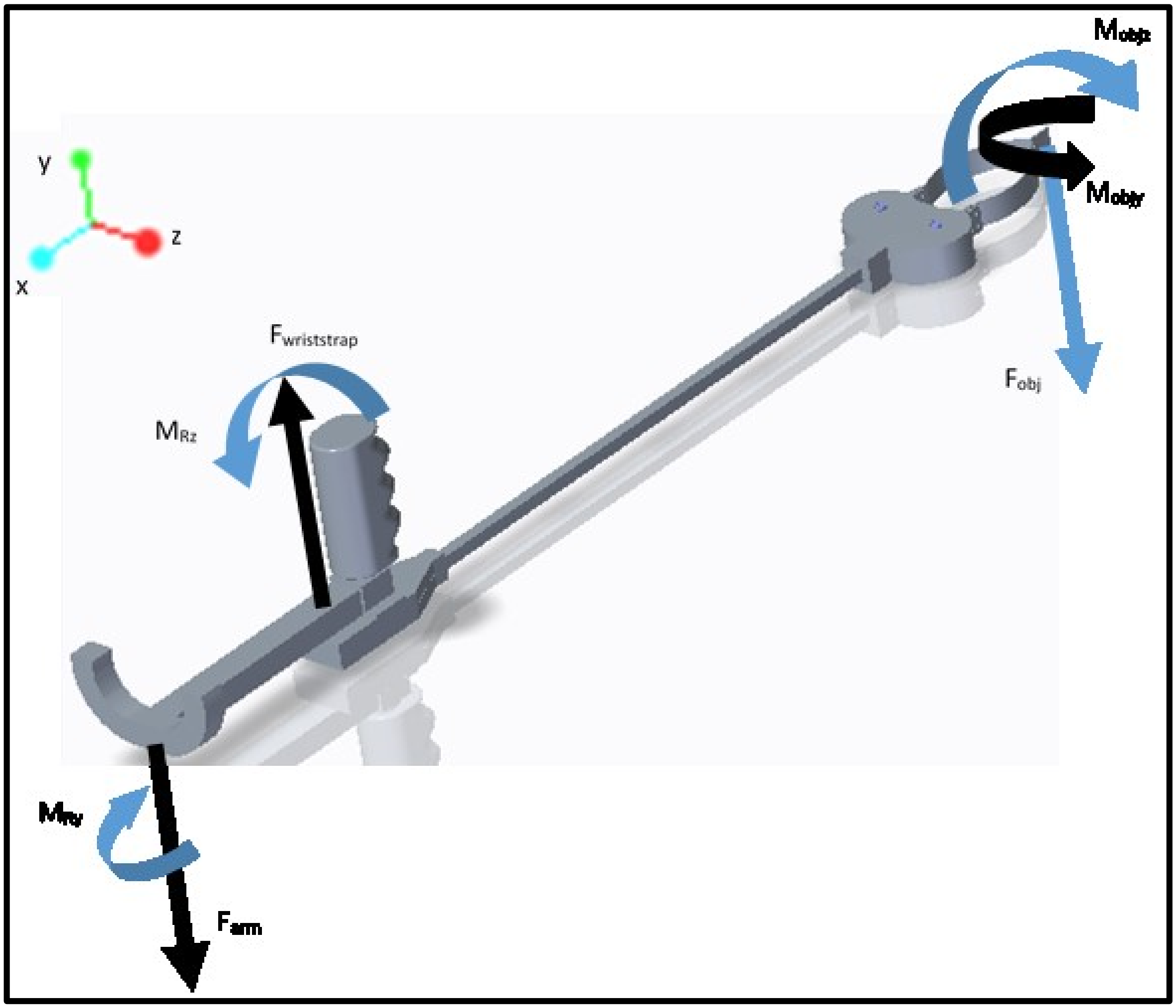


Figure 56: FBD of Full Device

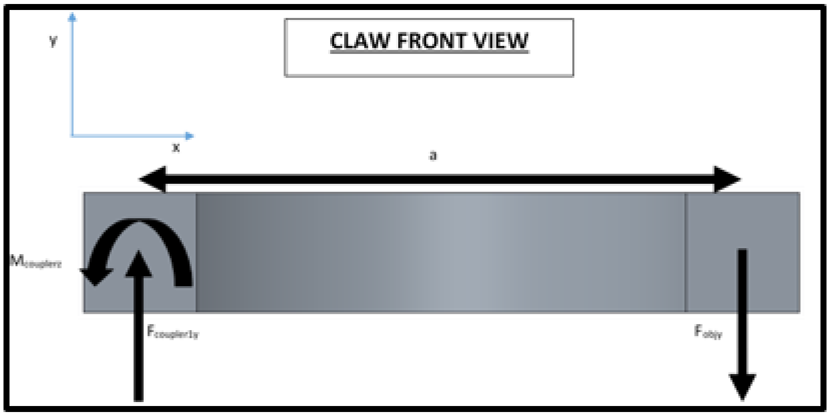


Figure 58: FBD of Claw (Front View)

$F_{obj.y} := 5.7\,lbf \quad a := 5.09\,in$

$\Sigma F_y = -F_{obj.y} + F_{coupler1.y} = 0$

$F_{coupler1.y} := F_{obj.y} = 25.355\,N$

$\Sigma M_z = M_{coupler1.z} - F_{obj.y} \cdot a = 0$

$M_{coupler1.z} := F_{obj.y} \cdot a = 3.278\,J$

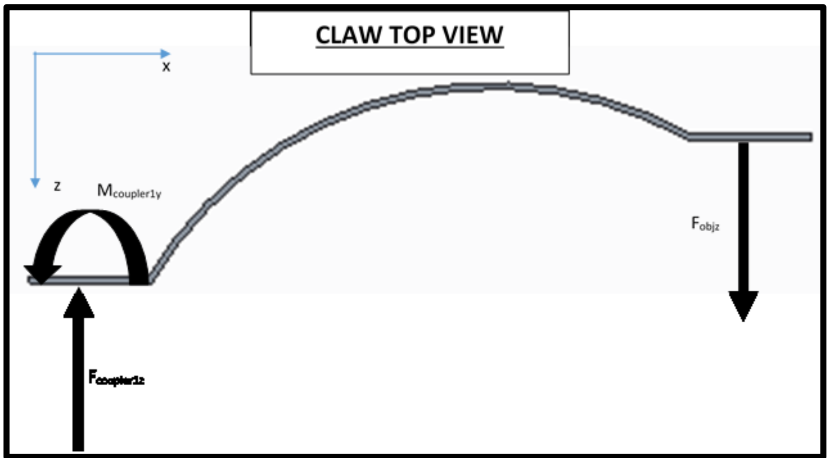


Figure 57: FBD of Claw (Top View)

$\mu := 0.45$

$F_{obj.z} := \frac{F_{obj.y}}{(2 \cdot \mu)} = 6.333\,lbf$

$\Sigma F_z = F_{coupler1.z} - F_{obj.z} = 0$

$F_{coupler1.z} := F_{obj.z} = 6.333\,lbf$

$\Sigma M_y = M_{coupler1.y} - F_{obj.z} \cdot a = 0$

$M_{coupler1.y} := F_{obj.z} \cdot a = 0.819\,m\,lbf$

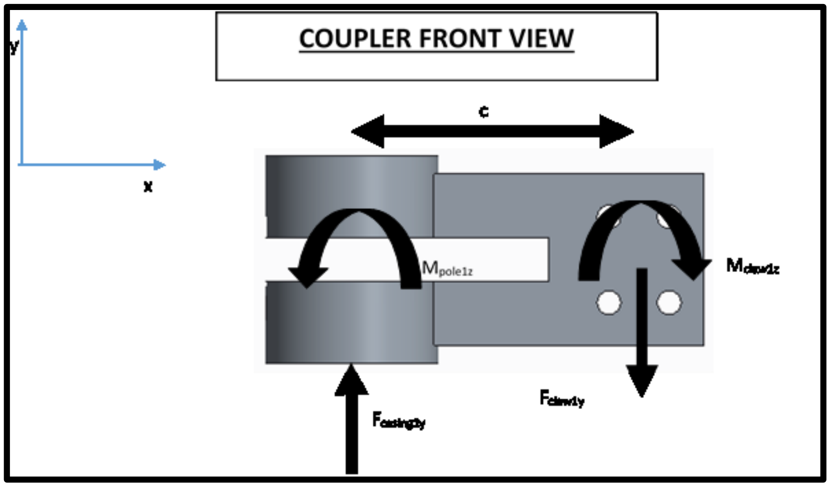


Figure 59: Claw Coupler (Front View)

$c := 1.67\,in$

$F_{claw1.y} := F_{coupler1.y} = 5.7\,lbf$

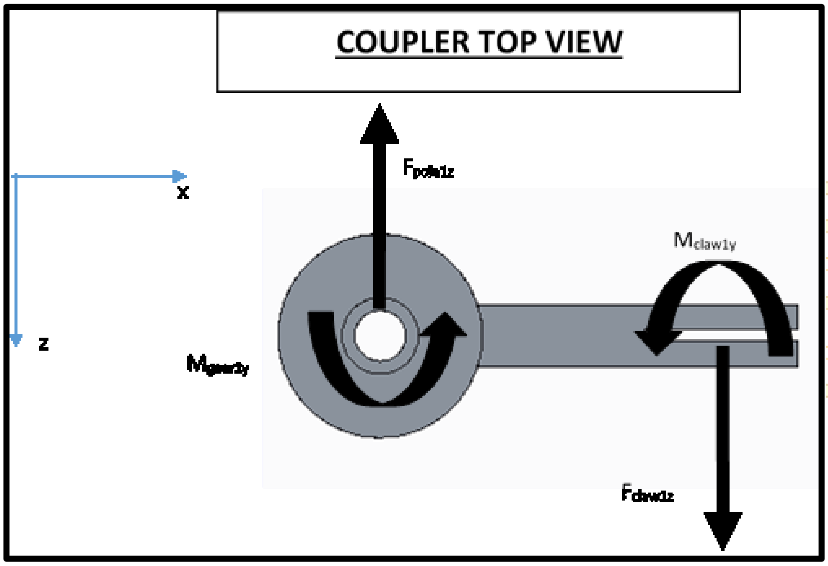
$M_{claw1.z} := M_{coupler1.z} = 29.013\,in \cdot lbf$

$\Sigma F_y = -F_{claw1.y} + F_{casing1.y} = 0$

$F_{casing1.y} := F_{claw1.y} = 5.7\,lbf$

$M_z = -F_{claw1.y} \cdot c + M_{pole1.z} - M_{claw1.z} = 0$

$M_{pole1.z} := F_{claw1.y} \cdot c + M_{claw1.z} = 38.532\,in \cdot lbf$



$M_{claw1.y} := M_{coupler1.y} = 32.237\ \text{in}\cdot\text{lbf}$

$F_{claw1.z} := F_{coupler1.z} = 6.333\ \text{lbf}$

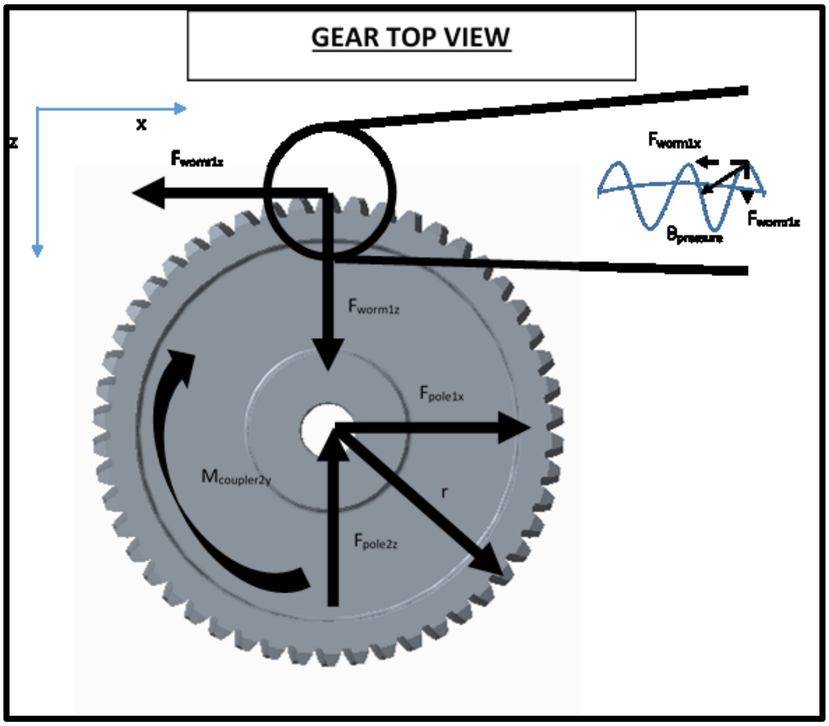
$\Sigma F_x = F_{pole1.z} - F_{claw1.z} = 0$

$F_{pole1.z} := F_{claw1.z} = 6.333\ \text{lbf}$

$\Sigma M_y = M_{gear1.y} - M_{claw1.y} - F_{claw1.z}\cdot c = 0$

$M_{gear1.y} := M_{claw1.y} + F_{claw1.z}\cdot c = 42.813\ \text{in}\cdot\text{lbf}$

Figure 60: FBD Claw Coupler (Top View)



$M_{coupler2.y} := M_{gear1.y} = 42.813\ \text{in}\cdot\text{lbf}$

$r := 1.042\text{in}$

$\theta_{pressure} := 20\text{deg}$

$\Sigma M_y = -M_{coupler2.y} + F_{worm1.x}\cdot r = 0$

$F_{worm1.x} := \dfrac{M_{coupler2.y}}{r} = 41.088\ \text{lbf}$

$\Sigma F_x = F_{pole1.x} - F_{motor1.x} = 0$

$F_{pole1.x} := F_{worm1.x} = 41.088\ \text{lbf}$

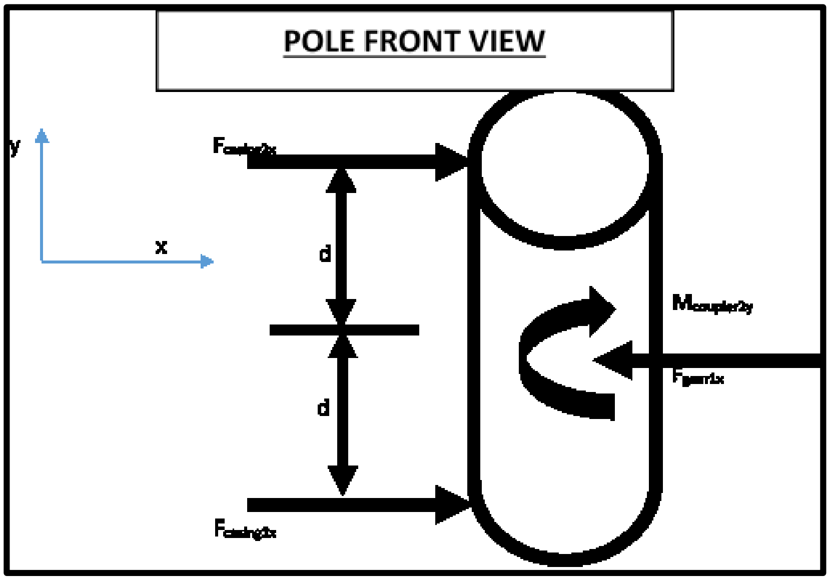
$\tan(\theta_{pressure}) = \dfrac{F_{worm1.z}}{F_{worm1.x}}$

$F_{worm1.z} := F_{worm1.x}\cdot\tan(\theta_{pressure}) = 14.955\ \text{lbf}$

$\Sigma F_z = -F_{worm1.z} + F_{pole2.z} = 0$

$F_{pole2.z} := F_{worm1.z} = 14.955\ \text{lbf}$

Figure 61: FBD Worm Gear (Top View)



$d := 0.5\text{in}$

$M_{coupler2.z} := M_{pole1.z} = 38.532\ \text{in}\cdot\text{lbf}$

$F_{gear1.x} := F_{pole1.x} = 41.088\ \text{lbf}$

Guess:

$F_{casing1.x} := 1\text{lbf}$

$F_{casing2.x} := 1\text{lbf}$

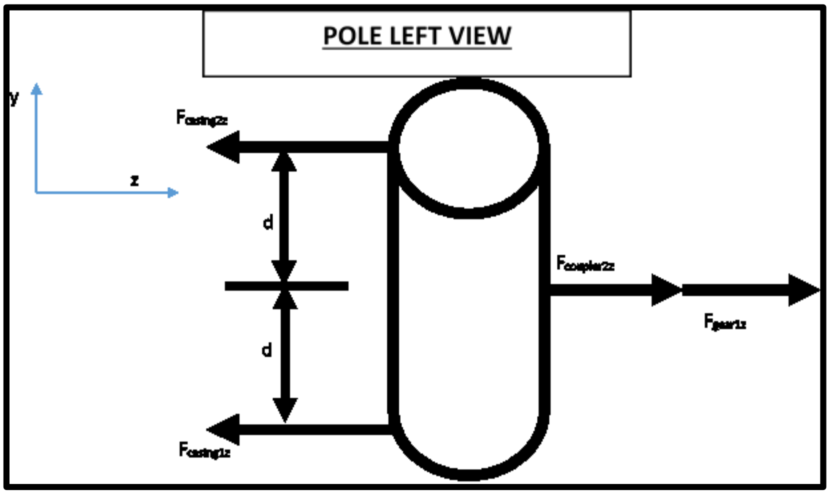
Given

$0 = F_{casing1.x} + F_{casing2.x} - F_{gear1.x}$

$0 = -M_{coupler2.z} + \left(F_{casing1.x} - F_{casing2.x}\right)\cdot d$

$$\begin{pmatrix} F_{casing1.x} \\ F_{casing2.x} \end{pmatrix} := \text{Find}\left(F_{casing1.x}, F_{casing2.x}\right) = \begin{pmatrix} 59.076 \\ -17.988 \end{pmatrix}\text{lbf}$$

Figure 62: FBD Pole (Front View)



$F_{coupler2.z} := F_{pole1.z} = 6.333\ \text{lbf}$

$F_{gear1.z} := F_{pole2.z} = 14.955\ \text{lbf}$

Guess

$F_{casing1.z} := 1\text{lbf}$

$F_{casing2.z} := \text{lbf}$

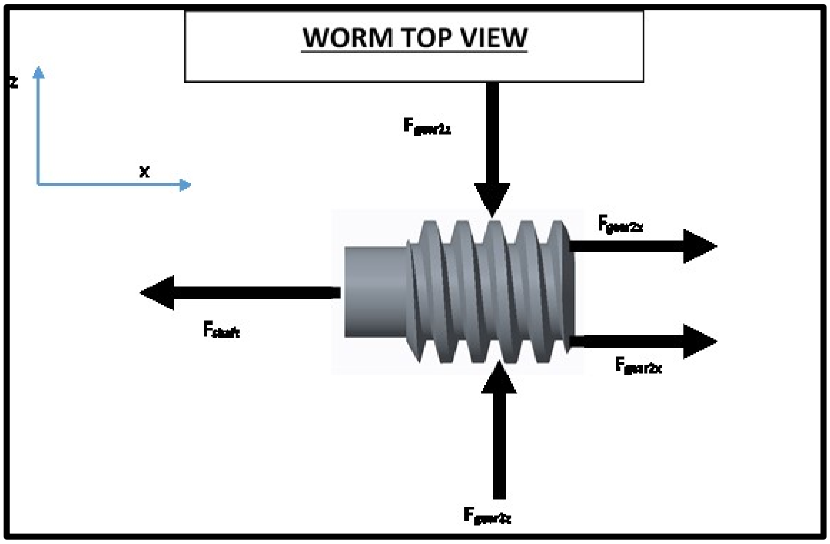
Given

$0 = F_{coupler2.z} + F_{gear1.z} - F_{casing1.z} - F_{casing2.z}$

$0 = \left(-F_{casing1.z} + F_{casing2.z}\right)\cdot d$

$$\begin{pmatrix} F_{casing1.z} \\ F_{casing2.z} \end{pmatrix} := \text{Find}\left(F_{casing1.z}, F_{casing2.z}\right) = \begin{pmatrix} 10.644 \\ 10.644 \end{pmatrix}\text{lbf}$$

Figure 63: FBD Pole (Left View)



$$F_{gear2.x} := F_{worm1.x} = 41.088\,\text{lbf}$$

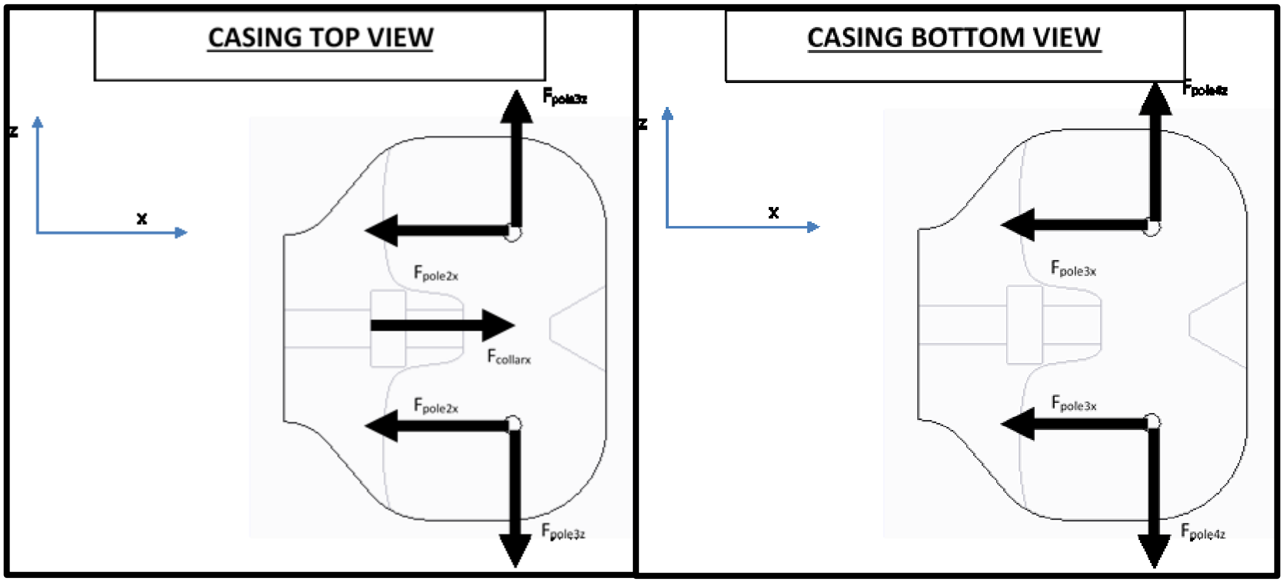
$$F_{gear2.z} := F_{worm1.z} = 14.955\,\text{lbf}$$

$$\Sigma F_z = F_{gear2.z} - F_{gear2.z} = 0$$

$$\Sigma F_x = 2\cdot F_{gear2.x} - F_{motor.x} = 0$$

$$F_{worm.x} := 2\cdot F_{gear2.x} = 82.175\,\text{lbf}$$

Figure 65: FBD Worm (Top View)



$$F_{pole2.x} := F_{casing2.x} = -17.988\,\text{lbf}$$

$$F_{pole3.x} := F_{casing1.x} = 59.076\,\text{lbf}$$

$$F_{pole3.z} := F_{casing2.z} = 10.644\,\text{lbf}$$

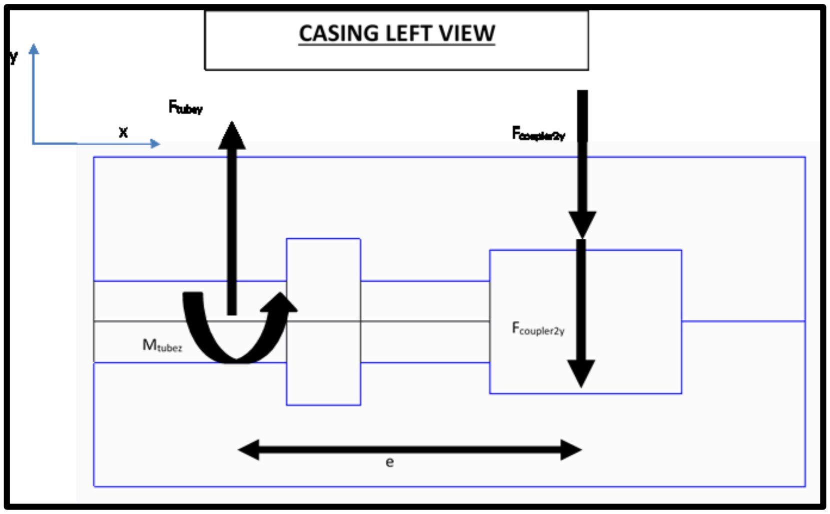
$$F_{pole4.z} := F_{casing1.z} = 10.644\,\text{lbf}$$

$$\Sigma F_z = F_{pole.3} - F_{pole.3} + F_{pole4.z} - F_{pole4.z} = 0$$

$$\Sigma F_x = -2F_{pole2.x} - 2F_{pole3.x} + F_{collar.x} = 0$$

$$F_{collar.x} := 2F_{pole2.x} + 2F_{pole3.x} = 82.175\,\text{lbf}$$

Figure 64: Front Casing (Top & Bottom View)



$e := 4\text{in}$

$F_{coupler2.y} := F_{casing1.y} = 5.7\,\text{lbf}$

$\Sigma F_y = -2F_{coupler2.y} + F_{tube.y} = 0$

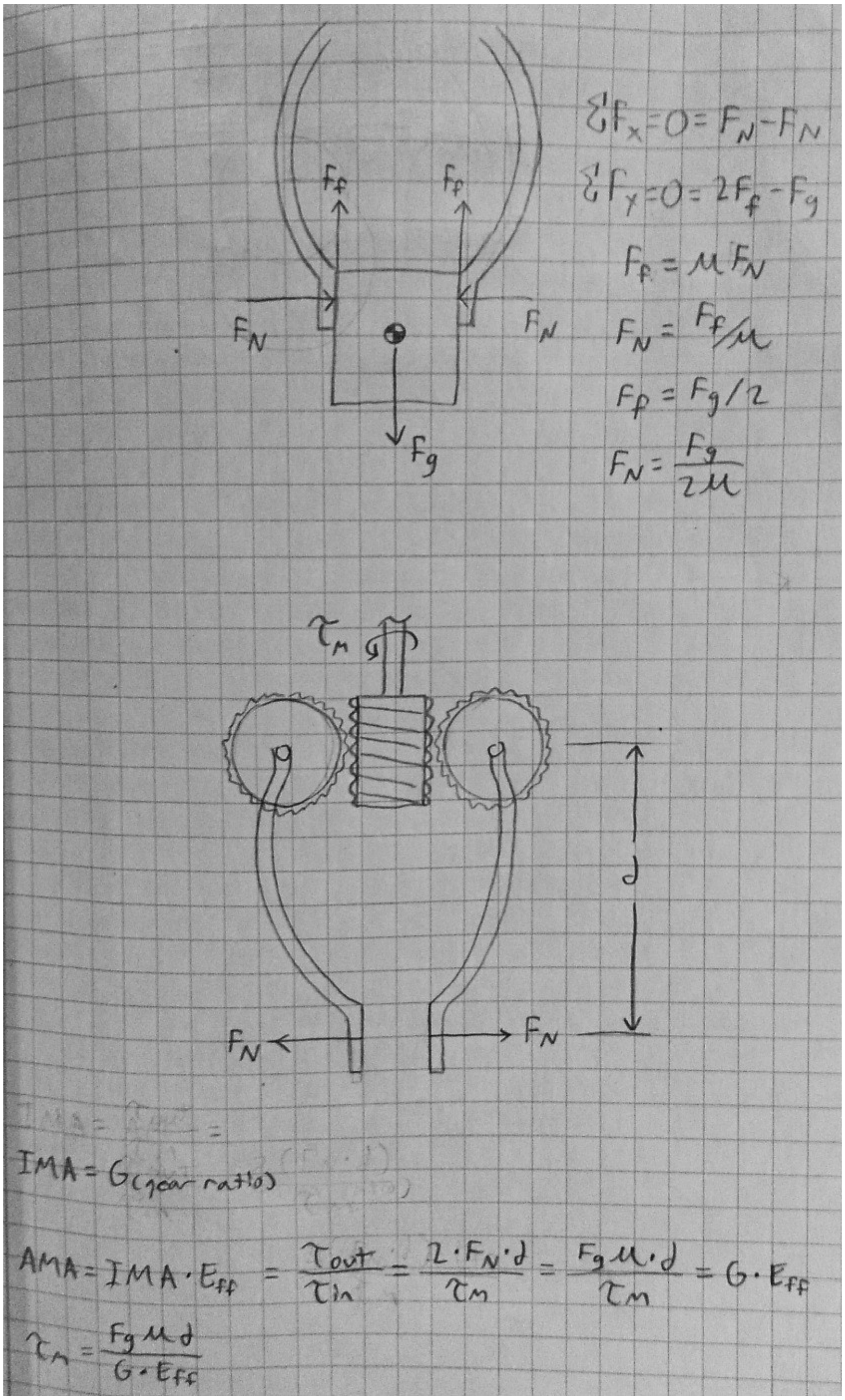
$F_{tube.y} := 2F_{coupler2.y} = 11.4\,\text{lbf}$

$\Sigma M_z = M_{tube.z} - 2F_{coupler2.y} \cdot e = 0$

$M_{tube.z} := 2F_{coupler2.y} \cdot e = 45.6\,\text{in} \cdot \text{lbf}$

Figure 66: FBD of Front Casing (Left View)

Appendix C: Kinematics of Final Design



$$\Sigma F_x = 0 = F_N - F_N$$

$$\Sigma F_y = 0 = 2F_f - F_g$$

$$F_f = \mu F_N$$

$$F_N = F_f/\mu$$

$$F_f = F_g/2$$

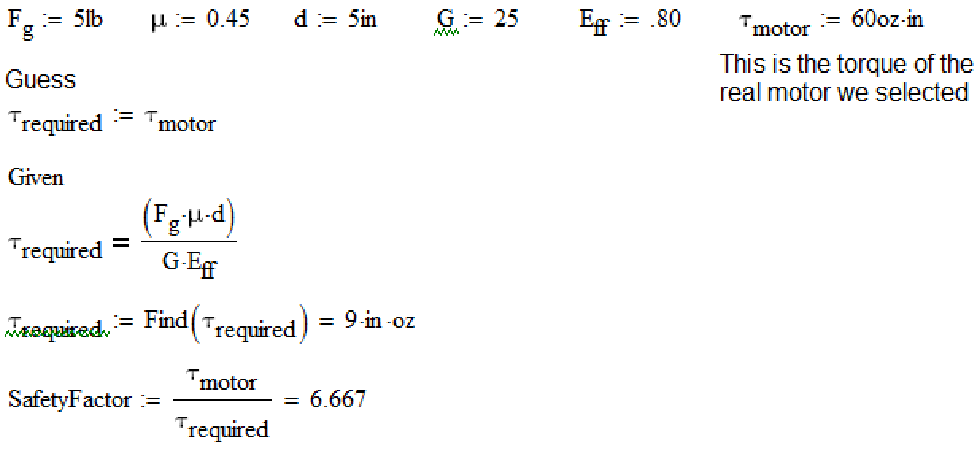
$$F_N = \frac{F_g}{2\mu}$$

IMA = G(gear ratio)

$$AMA = IMA \cdot E_{ff} = \frac{\tau_{out}}{\tau_{in}} = \frac{2 \cdot F_N \cdot d}{\tau_m} = \frac{F_g \mu \cdot d}{\tau_m} = G \cdot E_{ff}$$

$$\tau_m = \frac{F_g \mu d}{G \cdot E_{ff}}$$

Figure 67: FBD of Gear Mechanism and Basic Calculations



$F_g := 5lb$ $\mu := 0.45$ $d := 5in$ $G := 25$ $E_{ff} := .80$ $\tau_{motor} := 60oz \cdot in$

This is the torque of the real motor we selected

Guess

$\tau_{required} := \tau_{motor}$

Given

$$\tau_{required} = \frac{(F_g \cdot \mu \cdot d)}{G \cdot E_{ff}}$$

$$\tau_{required} := Find(\tau_{required}) = 9 \cdot in \cdot oz$$

$$SafetyFactor := \frac{\tau_{motor}}{\tau_{required}} = 6.667$$

Figure 68: Required Torque Calculations Using MathCAD

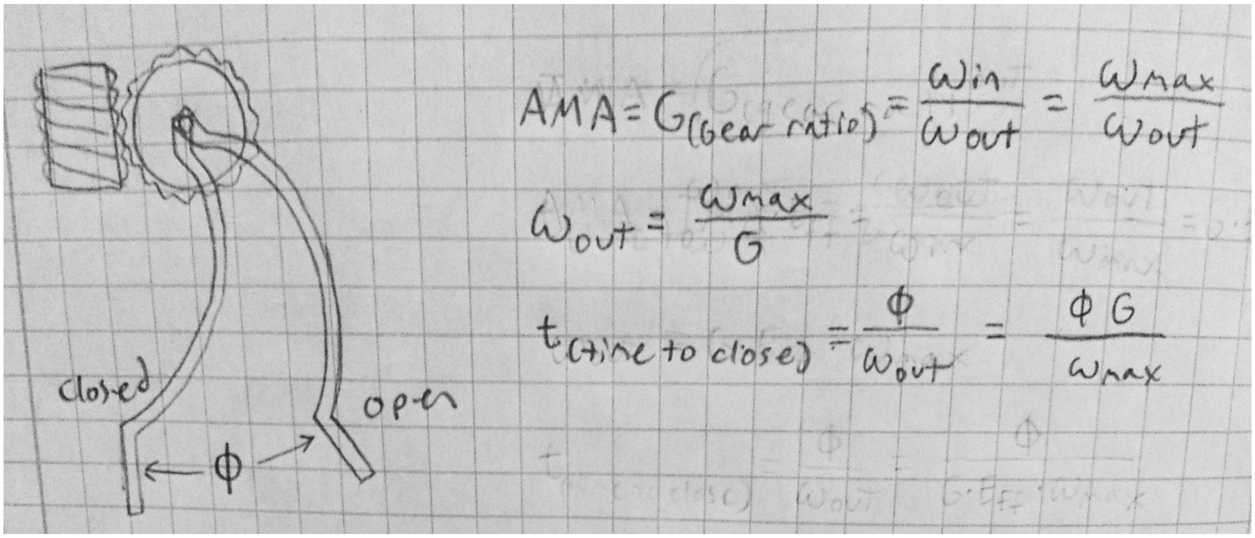
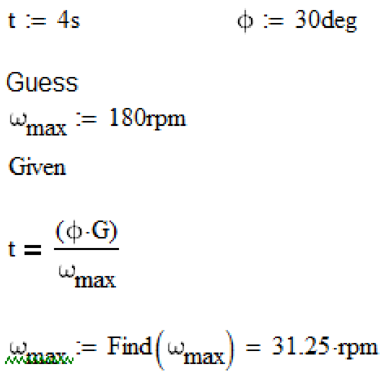


Figure 70: Kinematic Diagram of Claws



$t := 4s$ $\phi := 30deg$

Guess

$\omega_{max} := 180rpm$

Given

$$t = \frac{(\phi \cdot G)}{\omega_{max}}$$

$$\omega_{max} := Find(\omega_{max}) = 31.25 \cdot rpm$$

Figure 69: Closing Speed Calculation of Claws

Appendix D: User Evaluation

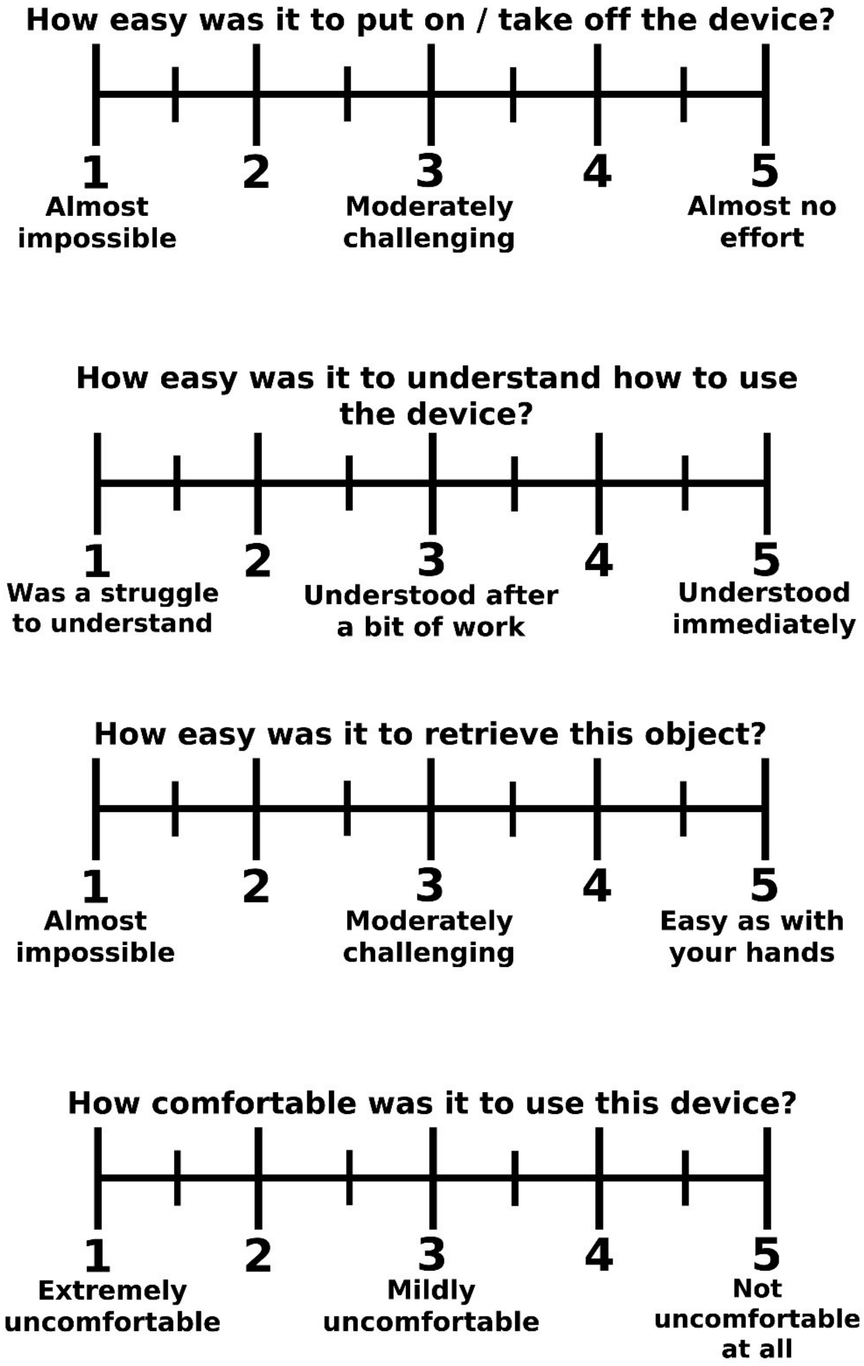


Figure 71: User Evaluation Forms for Donning, Intuitiveness, Usability, and Comfort

Grab Bot II Testing Survey Responses

WPI Department of Mechanical Engineering

Principle Investigators:

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Student Investigators:

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Matthew Lesonsky: milesonsky@wpi.edu 603-289-3733
Reed Standley: rmstandley@wpi.edu 781-561-5626

Participant Number_____

Participant Gender_____

Participant Age_____

Date_____________

Location / Residency______________________________

Do you have any sort of impairments or difficulties with grasping or lifting objects?

____

Have you ever used reacher-grippers, such as the one we have here, for picking up objects?

____

If so, do you ever experience any problems when using reacher grippers? What type?

____

Grip n' Grab:

Ease of picking up 1st light object from the ground _____

Ease of picking up 2nd light object from the ground _____

Ease of picking up 1st heavy object from the ground _____

Ease of picking up 2nd heavy object from the ground _____

Ease of picking up 1st light object from a shelf _____

Ease of picking up 2nd light object from a shelf _____

Ease of picking up 1st heavy object from a shelf _____

Ease of picking up 2nd heavy object from a shelf _____

How comfortable was it to use the Grip ‘n Grab (scale 5-1)? _____

How easy was it to understand how to use the Grip ‘n Grab (scale 5-1)? _____

What were some things that you liked about the device?

____

____

What were some things that you disliked about the device?

____

____

Any other comments?

____

Grab Bot II:

Ease of picking up 1st light object from the ground _____

Ease of picking up 2nd light object from the ground _____

Ease of picking up 1st heavy object from the ground _____

Ease of picking up 2nd heavy object from the ground _____

Ease of picking up 1st light object from a shelf _____

Ease of picking up 2nd light object from a shelf _____

Ease of picking up 1st heavy object from a shelf _____

Ease of picking up 2nd heavy object from a shelf _____

How easy was it to put on the Grab Bot (scale 5-1)? _____

How easy was it to take off the Grab Bot (scale 5-1)? _____

How comfortable was it to use the Grab Bot (scale 5-1)? _____

How easy was it to understand how to use the Grab Bot (scale 5-1)? _____

What were some things that you liked about the device?

____

____

What were some things that you disliked about the device?

____

____

Would you presently have use for this device? If so, what tasks would you use it for?

____

____

What improvements would you make to this device, if any?

____

____

How much would you be willing to pay for this product? ____________

Any other comments?

Informed Consent Agreement for Participation in a Research Study

Investigators: Nathan Alvord, Matthew Lesonsky, and Reed Standley

Contact Information:

Student Investigators:

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Principle Investigators:

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Title of Research Study: Grab Bot II Evaluation

Introduction
You are being asked to participate in a research study. Before you agree, however, you must be fully informed about the purpose of the study, the procedures to be followed, and any benefits, risks or discomfort that you may experience as a result of your participation. This form presents information about the study so that you may make a fully informed decision regarding your participation.

Purpose of the study: The purpose of this study is to evaluate the "Grab Bot II," a new type of reacher-gripper. The study will look at the Grab Bot II's functionality, how easy it is to operate, and its marketability. The results and suggestions we receive from this study will help in making further improvements to the Gab Bot II.

Procedures to be followed: You will be conducting identical trials for each of several assistive devices including the Grab Bot II and commercially available reacher-grippers. You will take hold of the device by yourself if you are able. You will then retrieve heavy and light objects from high and low locations. Both during and after these trials, you will be asked to answer questions about your experience using the assistive devices. The complete procedure is expected to take 45 minutes.

Risks to study participants: There is a possible risk of dropping a small object onto your lower extremities, such as your feet, while using the reacher-grippers. There is also the possibility of experiencing discomfort in the hand or arm due to the weight of the objects being manipulated. You should discontinue the test if you experience more than minor discomfort.

Benefits to research participants and others: There are no directs benefits you for participating in this activity. Involvement in this activity may aid the development of a product available for purchase.

Record keeping and confidentiality: All records will be kept confidential. Participants will remain anonymous, as their names will not be linked to any data. Surveys will be kept in a locked drawer. Once data is compiled electronically, the surveys will be destroyed and the compilation will be kept under a password. The three student investigators along with project advisors, Professors Ault and Hoffman, will have the only access to the data. Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

Compensation or treatment in the event of injury: If the assistive devices are used properly as instructed there should be no risk of injury. In the event that an accident happens, please report it to the student investigators who will take further action. You do not give up any of your legal rights by signing this statement.

For more information about this research or about the rights of research participants, or in case of research-related injury, please contact the student investigators with the information listed at the top of the page or one of the following contacts:

IRB Chair- Professor Kent Rissmiller, Tel. 508-831-5019, Email: kjr@wpi.edu

University Compliance Officer- Jon Bartelson, Tel. 508-831-5725, Email: jonb@wpi.edu

Your participation in this research is voluntary. Your refusal to participate will not result in any penalty to you or any loss of benefits to which you may otherwise be entitled. You may decide to stop participating in the research at any time without penalty or loss of other benefits. The project investigators retain the right to cancel or postpone the experimental procedures at any time they see fit.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

______________________________ Date: ____________________

Study Participant Signature

____
Study Participant Name (Please print)

_______________________________________ Date: ____________________
Witness (Student Investigator)

____
Witness Name (Please print)

Team Gripper 15

Grab Bot II Testing Survey Script

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Thank you for taking the time to help us evaluate the Grab Bot II. Today you will be using two different reacher-gripper devices designed for picking up objects at a distance. The first of these devices is a commercially available reacher gripper. The second device, the Grab Bot II, was designed and built by students at Worcester Polytechnic Institute. You will be using these two devices to pick up a variety of objects from different locations, and then give your opinions on what it was like to use the devices. Your feedback and suggestions will help improve the Grab Bot II. Before we begin the trials, we have a few quick questions:

What is your age?

(For Village at Willow Crossing) Do you live at Willow Crossing or do you live elsewhere?

Do you have any sort of impairments or difficulties with grasping or lifting objects (e.g. arthritis, nerve damage, muscular atrophy)? If so, what are they?

Have you ever use reacher-grippers, such as the one we have here, for picking up objects?

If so, do you ever experience any problems when using reacher grippers? What type of problems? Any discomfort?

We will now begin the trials. There will be two trials: one using the Grip n' Grab and one using the Grab Bot II. In each trial, you will attempt to pick up eight objects: two light objects on the ground, two heavy objects on the ground, two light objects on a shelf, and two heavy objects on a shelf. Using the assistive devices in any way you like, you will attempt to retrieve the objects, bringing them as close to your body as possible. If you experience great discomfort at any point, stop using the device and notify one of us.

We will start with the Grip n' Grab. Please pick up the device. Squeezing the trigger opens and closes the claws. The head of the device can be rotated by pulling the head outward and twisting.

Take a few moments to practice with the device.

Please retrieve the light object on the ground.

> On a scale of 1 to 5, how easy was it to retrieve this object, with 5 being as easy as picking it up with your own hands if it were in reach, and 1 being almost impossible?

Please retrieve the next light object on the ground.

> How difficult was it to retrieve this object on a scale of 5 to 1, 5 being as easy as using your hands, and 1 being almost impossible?

Please retrieve the heavy object on the ground.

> How difficult was it to retrieve this object on a scale of 5 to 1?

Please retrieve the next heavy object on the ground.

> How difficult was it to retrieve this object on a scale of 5 to 1?

Please retrieve the light object on the shelf.

> How difficult was it to retrieve this object on a scale of 5 to 1?

Please retrieve the next light object on the shelf.

> How difficult was it to retrieve this object on a scale of 5 to 1?

Please retrieve the heavy object on the shelf.

> How difficult was it to retrieve this object on a scale of 5 to 1?

Please retrieve the next heavy object on the shelf.

> How difficult was it to retrieve this object on a scale of 5 to 1?

Please put down the Grip n’ Grab. We will now ask you some additional questions about the Grip n’ Grab.

> On a scale of 5 to 1, how comfortable was it to use the Grip n’ Grab, 5 being not uncomfortable at all, and 1 being extremely uncomfortable?

> On a scale of 5 to 1, how easy was it to understand how to use the Grip n' Grab, 5 being you understood how to use it immediately with almost no practice needed, and 1 being it was a struggle to figure out how to get the Grab Bot to do what you wanted, even after using it for a while.
>
> What were some things that you liked about the device?
>
> What were some things that you disliked the device?
>
> Do you have any additional comments about the device?

Now we will begin the Grab Bot II trial. Please put on the Grab Bot II, tightening the strap around your arm. Attempt to do this yourself, but let us know if you need assistance.

A switch on the handle controls the claws. The bottom switch position automatically sets the claws to an open position. The middle position on the switch automatically sets the claws to a closed position that lightly grips an object. The top position on the switch automatically sets the claws to a closed position that tightly grips an object. The head of the device can be rotated by pushing the grip near the head outwards and then twisting it.

Take a few moments to practice with the device.

Please retrieve the light object on the ground.

> On a scale of 5 to 1, how difficult was it to retrieve this object, with 5 being as easy as picking it up with your own hands if it were in reach, and 1 being almost impossible?

Please retrieve the next light object on the ground.

> How difficult was it to retrieve this object on a scale of 5 to 1, 5 being as easy as using your hands, and 1 being almost impossible?

Please retrieve the heavy object on the ground.

> How difficult was it to retrieve this object on a scale of 5 to 1?

Please retrieve the next heavy object on the ground.

> How difficult was it to retrieve this object on a scale of 5 to 1?

Please retrieve the light object on the shelf.

> How difficult was it to retrieve this object on a scale of 5 to 1?

Please retrieve the next light object on the shelf.

How difficult was it to retrieve this object on a scale of 5 to 1?

Please retrieve the heavy object on the shelf.

How difficult was it to retrieve this object on a scale of 5 to 1?

Please retrieve the next heavy object on the shelf.

How difficult was it to retrieve this object on a scale of 5 to 1?

Please take off the Grab Bot II.

The trials have concluded. We will now ask you some additional questions about the Grab Bot II.

On a scale of 5 to 1, how easy was it to put on the Grab Bot, with 5 being almost no effort to 1 being almost impossible?

Using the same scale, how easy was it to remove the Grab Bot?

On a scale of 5 to 1, how comfortable was it to use the Grab Bot, 5 being not uncomfortable at all, and 1 being extremely uncomfortable?

On a scale of 5 to 1, how easy was it to understand how to use the Grab Bot, 5 being you understood how to use it immediately with almost no practice needed, and 1 being it was a struggle to figure out how to get the Grab Bot to do what you wanted, even after using it for a while.

What were some things that you liked about the device?

What were some things that you disliked the device?
Would you presently have use for this device? If so, what tasks would you use it for?

What improvements would you make to this device, if any?

If a device like this were to become a refined, commercially available product, how much would you be willing to pay for it?

Do you have any additional comments about the device?

This concludes the evaluation. Thank you very much for your time and effort here today. Do you have any questions for us?

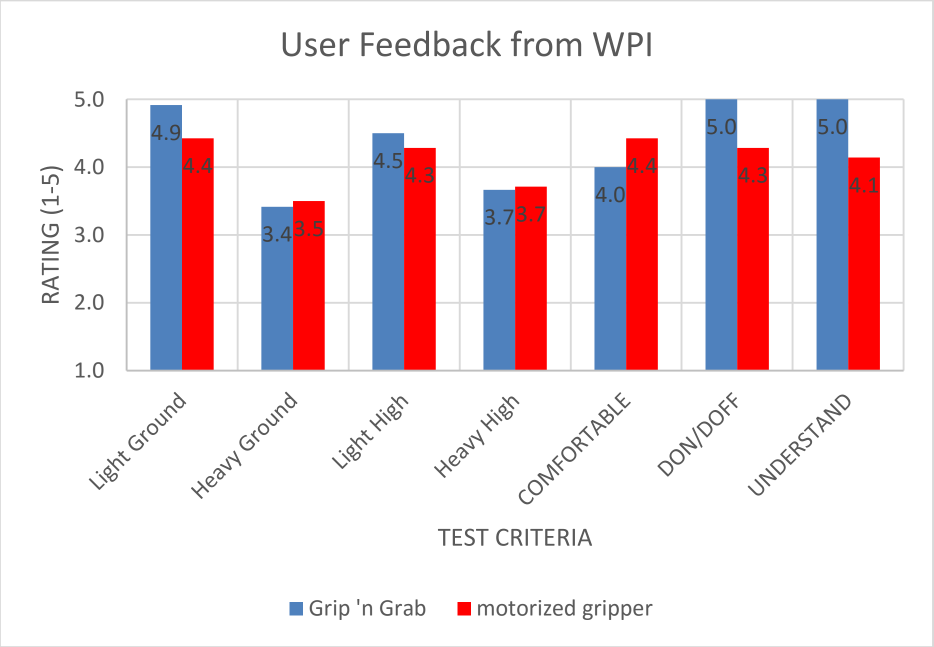

Figure 73: Overall User Feedback from WPI

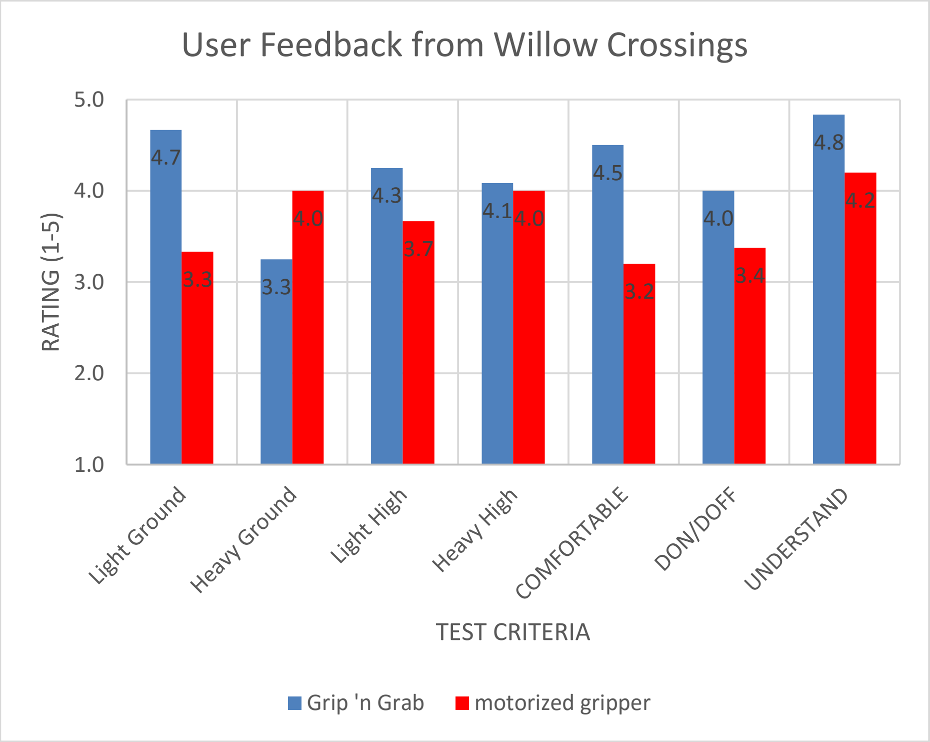

Figure 72: Overall User Feedback from Willow's Crossing

Appendix E: Deflection Calculations

Tubing

$F := 5\,\mathrm{lbf}$

$L := 29\,\mathrm{in}$

$D := 0.875\,\mathrm{in}$

$d := 0.805\,\mathrm{in}$

$S_y := 35000\,\mathrm{psi}$

$E := 10000\,\mathrm{ksi}$

$\rho := 0.099\dfrac{\mathrm{lb}}{\mathrm{in}^3}$

$0.97 - 0.08\cdot 2 = 0.81$

$$I := \frac{\pi\cdot\left(D^4 - d^4\right)}{64} \qquad I = 8.161\times 10^{-3}\cdot\mathrm{in}^4$$

$$\delta := \frac{F L^3}{3\cdot E\cdot I} \qquad \boxed{\delta = 0.498\,\mathrm{in}}$$

$$\sigma := \frac{F\cdot L\cdot d}{2I} \qquad \boxed{\sigma = 7.152\times 10^{3}\,\mathrm{psi}}$$

$$SF := \frac{S_y}{\sigma} \qquad \boxed{SF = 4.894}$$

$$A := \pi\cdot\frac{\left(D^2 - d^2\right)}{4} = 6.414\times 10^{-4}\,\mathrm{ft}^2$$

$$\mathrm{Weight} := \rho\cdot A\cdot L \qquad \boxed{\mathrm{Weight} = 0.265\,\mathrm{lb}}$$

Claws

assume horizontal claw orientation

$L := 5.25\,\text{in}$

$b := 0.083\,\text{in}$

$h := 0.875\,\text{in}$

$S_y := 60000\,\text{psi}$

$E := 30000000\,\text{psi}$

$\rho := 482\,\dfrac{\text{lb}}{\text{ft}^3} = 0.279\,\dfrac{\text{lb}}{\text{in}^3}$

$F_z := \dfrac{5.7}{2\cdot 0.87}\,\text{lbf} = 3.276\,\text{lbf}$ max force on claws due to grasping

$F_y := 5.7\,\text{lbf}$ max force on claws due to gravity & swinging (adjusted from FBD calculations...μ changed to rubber not steel)

$$I_x := \frac{b\cdot h^3}{12} \qquad I_x = 4.634\times 10^{-3}\cdot\text{in}^4$$

$$I_y := \frac{b^3\cdot h}{12} \qquad I_y = 4.169\times 10^{-5}\cdot\text{in}^4$$

$$\delta_y := \frac{F_y\cdot L^3}{3\cdot E\cdot I_x} \qquad \boxed{\delta_y = 1.978\times 10^{-3}\cdot\text{in}}$$

$$\delta_z := \frac{F_z L^3}{3\cdot E\cdot I_y} \qquad \boxed{\delta_z = 0.126\,\text{in}}$$

$$\sigma := \frac{F\cdot L\cdot b}{2 I_y} \qquad \boxed{\sigma = 2.613\times 10^4\,\text{psi}}$$

$$SF := \frac{S_y}{\sigma} \qquad \boxed{SF = 2.296}$$

$$A := b\cdot h = 5.043\times 10^{-4}\,\text{ft}^2$$

$$\text{Weight} := \rho\cdot A\cdot L \qquad \boxed{\text{Weight} = 0.106\,\text{lb}}$$

Appendix F: Gripper Benchmark Testing

Table 11: Grip 'n Grab Task Evaluation Scores

	Product:	Grip n Grab		
Task	Weight	Difficulty (1-5)	Weighted	notes
Pick up remote controls	36	1	36	
Pick up newspaper from floor	34	1	34	
Put cans into cupboards (full)	31	1	31	the jaws barely fit around the container. it couldn't fit around a salsa jar. This is a big problem because salsa jars are very common and there are a lot of common containers that are bigger than it
Take out cans from cupboards (full)	31	1	31	
Put dishes into cupboards	30	3	90	
Take out dishes from cupboards	30	2	60	had trouble getting between plates, two hand operation, required too much grip force to carry safely
Dressing, pulling up pants	30	5	150	
Open and close drawers	28	1	28	
Clean up	27	1	27	very fast, the head is quickly rotatable so the gripper can easily be changed back and forth for quick clean up
Take out clothes from the closets	26	3	78	decreased sensitivity played a part in this,
Open or close the doors	24	3	72	would work better with more grip force/less deflection
Pull out slippers from under the beds	22	1	22	
Take out clothes from racks or coat hangers	22	1	22	rubber helps jaws grip cloth very well
Take out mail from the mailbox	22	2	44	better with pointier ends
Turn lights on or off	21	1	21	lightweight and agile, very easier to do precise things
Open or close the refrigerator	20	3	60	this required a lot of grip strength, the cable seemed to stretch inside
Open/close the oven or microwave oven	19	1	19	
REACHER SCORE			84%	

Table 12: Medline Task Evaluation Scores

	Product:	Medline		
Task	Weight	Difficulty (1-5)	Weighted	notes
Pick up remote controls	36	1	36	jaws barely wide enough to grip controller
Pick up newspaper from floor	34	1	34	very firm grip
Put cans into cupboards (full)	31	3	93	the jaws BARELY fit around it. big problem. it was so close that the gripper could not release the object
Take out cans from cupboards (full)	31	3	93	requires a lot of grip strength when horizontal
Put dishes into cupboards	30	3	90	
Take out dishes from cupboards	30	2	60	had trouble getting between the plates, but was able to carry the plate using medium grip strength
Dressing, pulling up socks	30	5	150	
Open and close drawers	28	1	28	Hard to aim/control when hand is not clenched, but when hand is clenched you have a lot of control
Clean up	27	2	54	fast, but a rotatable head would have helped
Take out clothes from the closets	26	4	104	handle slips in the hand a lot, required a lot of forearm strength due to overhand grip (nonrotatable head)
Open or close the doors	24	3	72	
Pull out slippers from under the beds	22	1	22	
Take out clothes from racks or coat hangers	22	1	22	
Take out mail from the mailbox	22	2	44	pointier ends would help
Turn lights on or off	21	1	21	shaft directly in-line with forearm makes easier to push things up or down
Open or close the refrigerator	20	2	40	solid rod reduces required user gripping strength
Open/close the oven or microwave oven	19	1	19	
REACHER SCORE			77%	

Table 13: GripLoc Task Evaluation Scores

	Product:	GripLoc		
Task	Weight	Difficulty (1-5)	Weighted	notes
Pick up remote controls	36	1	36	jaws could be better
Pick up newspaper from floor	34	5	170	not enough grip strength
Put cans into cupboards (full)	31	2	62	grip feels very insecure
Take out cans from cupboards (full)	31	2	62	
Put dishes into cupboards	30	5	150	the jaws deflected too much and there wasn't enough grip force
Take out dishes from cupboards	30	5	150	
Dressing, pulling up socks	30	5	150	no grip with the tips of jaws, they deflect very easily
Open and close drawers	28	5	140	lock mechanism doesn't lock very hard
Clean up	27	3	81	it wasn't as quick as the other devices
Take out clothes from the closets	26	1	26	when using jaw tips it is completely impossible, but just letting the coat hanger hang on it works great. two hand action is way more easy to control
Open or close the doors	24	5	120	it has no strength or grip for this application
Pull out slippers from under the beds	22	2	44	
Take out clothes from racks or coat hangers	22	2	44	no mechanical feedback to the user...could just be because it is so darn weak
Take out mail from the mailbox	22	3	66	
Turn lights on or off	21	1	21	
Open or close the refrigerator	20	5	100	
Open/close the oven or microwave oven	19	5	95	could use pointier ends, also awkward to maneuver without a handle like the other ones. you have to put your elbow up just to get the jaws in line with the object
REACHER SCORE			53%	

Table 14: Grab-Bot Task Evaluation Scores

		Product:	Grab-Bot	
Task	Weight	Difficulty (1-5)	Weighted	notes
Pick up remote controls	36	1	36	grip is very strong, but jaws are slow
Pick up newspaper from floor	34	5	170	Jaws too bulky to get under newspaper, foam deflects too much
Put cans into cupboards (full)	31	2	62	the circular jaws are useless because nothing fits into there. the other more elliptic jaws contact objects much better
Take out cans from cupboards (full)	31	2	62	slow
Put dishes into cupboards	30	4	120	two hands required for this. caused the central pulley to move out of the channel, so jaws were no longer fixed from rotating side to side.
Take out dishes from cupboards	30	5	150	the jaws were too big to fit in between the plates at all. no chance. plus the head cant rotate so you can't get anything
Dressing, pulling up socks	30	5	150	
Open and close drawers	28	1	28	the foam conforms to the shape of the drawer handle, allowing the gripper to use a lateral force on the handle instead of frictional
Clean up	27	3	81	SO SLOW. however it could pick up a very heavy olive oil container which none of the others could handle
Take out clothes from the closets	26	4	104	jaws are very clunky, speed is a huge issue trying to find out the proper way to grip something takes WAY longer because each attempt takes like 10x longer than the manual grippers
Open or close the doors	24	5	120	the circular section of the jaws hit the doorframe, preventing it from being able to grasp the door knob
Pull out slippers from under the beds	22	2	44	
Take out clothes from racks or coat hangers	22	4	88	it took a long time for the motor to squeeze the last fractions of an inch to be able to grasp the shirt and the foam tips provided no help
Take out mail from the mailbox	22	5	110	the jaws were too big to fit into the mailbox
Turn lights on or off	21	1	21	
Open or close the refrigerator	20	1	20	the non-backdrivability and stiff jaws made this perfect
Open/close the oven or microwave oven	19	2	38	
REACHER SCORE			58%	