Design of the Grab-Bot

Meaghan Busteed
Worcester Polytechnic Institute

Amanda Rinaldi

Follow this and additional works at: https://digitalcommons.wpi.edu/atrc-projects

Part of the Biomechanical Engineering Commons, and the Biomedical Engineering and Bioengineering Commons

Suggested Citation

This Other is brought to you for free and open access by the Assistive Technology Resource Center at Digital WPI. It has been accepted for inclusion in Assistive Technology Resource Center Projects by an authorized administrator of Digital WPI. For more information, please contact digitalwpi@wpi.edu.
Grab-Bot: Reaching/Retrieving Aid

A Major Qualifying Project Report
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science
by

Meaghan Busteed
Amanda Rinaldi

Date: April 28, 2011

Approved:
Professor Holly K. Ault, Co-Advisor
Professor Allen H. Hoffman, Co-Advisor

This report represents the work of WPI undergraduate students. It has been submitted to the faculty as evidence of completion of a degree requirement. WPI publishes these reports on its website without editorial or peer review.
Abstract

There is a need to develop an assistive device for persons who have difficulty reaching, retrieving, picking and placing objects in a household or office setting. Our goal is to design and prototype an electromechanically operated “grabber” to aid users in completing these tasks in the safest manner possible. A first generation prototype was successfully designed and manufactured utilizing several types of plastic and a simple circuit with DC motor. Testing has shown that the Grab-bot extends the user’s reach by 2 feet and is designed to retrieve various objects weighing up to 2 pounds in a safe manner with little physical strain.
Acknowledgements

Our team has several individuals whom we would like to thank for their input and contributions to the completion of this project. Our Major Qualifying Project advisors, Professor Allen Hoffman and Professor Holly Ault, have provided us with guidance in our design procedure. Neil Whitehouse from the Worcester Polytechnic Institute Machine Shop was a great help with manufacturing our prototype, and providing sound advice for appropriate materials and parts to use and order. NISH/DEED Financial Assistance Program for Assistive Technology Development has graciously funded our project.
# Table of Contents

- **Abstract** ............................................................................................................................................... i
- **Acknowledgements** ............................................................................................................................... ii
- **List of Figures** ......................................................................................................................................... v
- **List of Tables** ......................................................................................................................................... vi
- **Authorship Page** ..................................................................................................................................... vii
- **1.0 Introduction** ....................................................................................................................................... 1
- **2.0 Problem Statement** ........................................................................................................................... 4
- **3.0 Background Research** ....................................................................................................................... 5
  - **3.1 Identification of Need** .................................................................................................................. 5
    - **3.1.1 General Disabilities** .............................................................................................................. 5
    - **3.1.2 Arthritis** .................................................................................................................................. 6
    - **3.1.3 The Elderly** ......................................................................................................................... 7
    - **3.1.4 Musculoskeletal Disorders** .................................................................................................. 7
  - **3.2 Existing Solutions** ......................................................................................................................... 8
    - **3.2.1 Mechanical Devices** ........................................................................................................... 8
    - **3.2.2 Patents** .................................................................................................................................. 14
  - **3.3 Research Summary** ....................................................................................................................... 16
- **4.0 Design Goals** ..................................................................................................................................... 18
- **4.1 Design Specifications** ...................................................................................................................... 18
- **5.0 Preliminary Design Concepts** ......................................................................................................... 23
  - **5.1 Grabber Assembly** ....................................................................................................................... 23
    - **5.1.1 Preliminary Design 1** ............................................................................................................. 23
    - **5.1.2 Preliminary Design 2** ............................................................................................................. 24
    - **5.1.3 Preliminary Design 3** ............................................................................................................. 25
    - **5.1.4 Preliminary Design 4** ............................................................................................................. 26
    - **5.1.5 Preliminary Design 5** ............................................................................................................. 27
    - **5.1.6 Preliminary Design 6** ............................................................................................................. 27
  - **5.2 Controls Assembly** ......................................................................................................................... 28
    - **5.2.1 Preliminary Design 7** ............................................................................................................. 28
    - **5.2.2 Preliminary Design 8** ............................................................................................................. 29
    - **5.2.3 Preliminary Design 9** ............................................................................................................. 30
    - **5.2.4 Preliminary Design 10** .......................................................................................................... 30
  - **5.3 Arm Attachment Assembly** .......................................................................................................... 31
    - **5.3.1 Preliminary Design 11** ........................................................................................................... 31
    - **5.3.2 Preliminary Design 12** ........................................................................................................... 32
Appendix C: Informed Consent Form
List of Figures
Figure 1: Rheumatoid Arthritis ................................................................. 6
Figure 2: "Raptor Reacher" .................................................................... 8
Figure 3: "Gator Grabber" ...................................................................... 9
Figure 4: "Gopher Grabber" ................................................................. 10
Figure 5: "EZ Reacher Pro" ................................................................. 11
Figure 6: Vee-Zee C5 Reacher Schematic ........................................... 12
Figure 7: Schematic of Tool for Retrieving Objects .............................. 14
Figure 8: Self-Gripping Reacher Schematic ......................................... 15
Figure 9: Preliminary Design 1 ........................................................... 23
Figure 10: Preliminary Design 2 .......................................................... 24
Figure 11: Preliminary Design 3 .......................................................... 25
Figure 12: Preliminary Design 4 .......................................................... 26
Figure 13: Preliminary Design 5 .......................................................... 27
Figure 14: Preliminary Design 6 .......................................................... 28
Figure 15: Ergonomic Handles ............................................................ 28
Figure 16: Preliminary Design 7 .......................................................... 29
Figure 17: Preliminary Design 8 .......................................................... 29
Figure 18: Preliminary Design 9 .......................................................... 30
Figure 19: Preliminary Design 10 ....................................................... 31
Figure 20: Contoured Arm Support .................................................... 31
Figure 21: Preliminary Design 11 ....................................................... 32
Figure 22: Preliminary Design 12 ....................................................... 32
Figure 23: Pins and Grippers ............................................................... 41
Figure 24: Free Body Diagram of Single Gripper .................................. 42
Figure 25: X Shear and Moment Diagram .......................................... 45
Figure 26: Y Shear and Moment Diagram .......................................... 45
Figure 27: Z Shear and Moment Diagram .......................................... 46
Figure 28: Arm Shape ...................................................................... 48
Figure 29: Arm Forces ...................................................................... 49
Figure 30: Controls Assembly: Rocker Switch .................................... 49
Figure 31: Entire Grab-Bot Assembly .................................................. 50
Figure 32: Finished Prototype of the Grab-Bot .................................... 56
Figure 33: User Testing the Grab-bot in a Household Setting .................. 58
Figure 34: Intuitiveness Survey Results ............................................ 61
Figure 35: Comfort Survey Results ................................................... 62
Figure 36: Effectiveness Survey Results ............................................. 63
Figure 37: Maximum Price Participants Would Pay for Grab-bot .......... 64
List of Tables

Table 1: Summary of Commercial Devices.................................................................................. 13
Table 2: List of Design Goal Significance for Each Sub-Assembly ............................................. 33
Table 3: Grabber Assembly Weight Factor ............................................................................... 34
Table 4: Controls Assembly Weight Factor .............................................................................. 34
Table 5: Arm Assembly Weight Factor .................................................................................... 34
Table 6: Range of Preliminary Design-Rating Factors ............................................................... 35
Table 7: Final Decision Matrix .................................................................................................. 39
Table 8: Available Parts ............................................................................................................ 52
Table 9: Gripper Material Comparison ..................................................................................... 57
Table 10: Rank Ordering Grabber Assembly ............................................................................ 70
Table 11: Rank Ordering Controls Assembly ........................................................................... 71
Table 12: Arm Attachment Rank Ordering ................................................................................ 72
Table 13: Grabber Assembly Decision Matrix .......................................................................... 73
Table 14: Controls Assembly Final Decision Matrix ................................................................. 74
Table 15: Arm Attachment Final Decision Matrix .................................................................... 75
Authorship Page

Both Meaghan Busteed and Amanda Rinaldi contributed equally to the design, manufacturing, and written components of this MQP.
1.0 Introduction

With the advent of assistive technology devices in the world, many people with various physical disabilities are given the opportunity to live and function independently of others. Assistive technology serves to assist an individual in performing a task that they otherwise would be unable to do or at least increase the ease and safety of which a task may be performed (McCreadie, 2005). Addressing transportation, mobility, or injury prevention, assistive devices have served a great purpose in assisting people to feel more useful and be able to participate in society as contributing members (Riemer-Reiss, 2000).

Assistive technology devices address many types of disabilities, including “physical, cognitive, sensory, emotional, and developmental disorders” (Disability, 2010). In particular, physical disabilities, such as muscular dystrophy, multiple sclerosis, arthritis, scoliosis, joint pain, and weakened muscle strength resulting from injury, old age, or genetics are some of the most common reasons for using assistive devices. In fact, those who are 65 years and older use the majority of assistive devices, with expected increases as the baby boomers age and the average life expectancy increases (DiGiovanni, Marrion, & Nina, 2009). With this need for assistance without a compromise of independence, wheelchairs, walkers, canes, and grabbers, among many other aids, have been created to serve as a means of reducing task difficulty and bodily stress in the safest way possible.

A particular type of problem that people with disabilities face is reaching for items that are out of their reaching range. For the elderly or for those confined in a wheelchair, the task of safely reaching and retrieving an object on a high shelf or from the floor is daunting and can be difficult to execute. To accommodate this problem, assistive devices called grabbers were created to serve as an extended arm with “grabber” ends to retrieve objects. Consisting simply of a shaft and mechanical claw that mimic
certain functions and motions of the human hand, the grabber helps make everyday tasks easier and less frustrating (Allen, Freitas, Hunnewell, & Lee, 2010). Several grabbers on the market have incorporated other features into their design in order to serve a wider range of users, including those with arthritis, scoliosis, multiple sclerosis or anyone who suffers from weakened hand and finger strength. These added features include a locking mechanism serving to maintain a steady grip on a target object without requiring prolonged muscle strength as well as suction cup grabber tips to allow for a secure grip.

However, many grabbers that are available today primarily rely on mechanical operation, i.e. manual hand trigger and grip that can present new difficulties to its users. For those with weak hand and finger strength, the task may cause considerable muscle stress and unneeded frustration. With that in mind, grabbers with electro-mechanical components have been made, requiring a simple click of a button to accomplish the same task. Also for those with weak gripping strength, just simply holding onto the grabber while picking up an object can be just as unsafe and can cause injury. To help with this problem, grabbers with arm straps have been created to securely attach onto the user’s forearm to prevent slippage and promote optimal retrieving strength.

Based on our knowledge of the users and existing designs of reaching aid devices, our team formulated the concept of an effective grabber design. In order for our device to be successful, it needed to offer an improvement on the devices currently on the market but still be competitively priced. Our main objective was to have an electromechanically working prototype that could effectively reach, secure onto, and retrieve an object for a person needing assistance for these tasks. From our benchmarking and background research we noticed that most of the devices used for this function were mechanical, and the few electronic ones found did not seem to have sufficient controls for accurate targeting of a range of objects. Our electromechanical design will enable people, who may have
previously had difficulty or were unable to use mechanical grippers due to limited strength in one or more muscle groups, to use a gripping device.
2.0 Problem Statement

There is a need to develop an assistive device for persons who have difficulty reaching, retrieving, picking and placing objects. An electromechanical reaching aid would be useful to persons with a range of disabilities restricting their reach capacity or an elderly person with diminished strength. Such a device could improve independence and help maintain a more natural lifestyle, while decreasing the risk of injury or bodily stress for the user.
3.0 Background Research

Persons with disabilities are prevalent in the United States, ranging from wheelchair users to office personnel suffering from neck and wrist pain. Determining user needs will help in the design process for the reaching aid to ensure those needs are met accordingly.

3.1 Identification of Need

The grabber must be used as a means of assistance to a user with disabilities for whom reaching and retrieving out of reach objects is a constant strain and difficulty. People with various types of disabilities would benefit greatly from using the grabber in a daily setting.

3.1.1 General Disabilities

According to the US Census, 18.7% of the total U.S. population has a disability as defined by the Americans with Disability Act; this can mean any type of disability ranging from Attention Deficit Disorder to quadriplegia. This is a large percent of the population, representing about 56 million Americans that could have the potential need for an assistive device in a daily living activity. To further break down this number, 7.5% of the population between the ages 18-65 and 31.1% of the population age 65 and over have ambulatory difficulty that may require the need for a wheelchair or other assistive device. This figure becomes even larger in the particular group of women over the age of 80 at a staggering percentage of 74.6% having ambulatory difficulty requiring assistance. These numbers give a good illustration of the need for assistive technology, specifically for our purposes of an aid in reaching objects (U.S. Census Bureau, 2005).

Specifically, 1%, or 2.8 million people in the United States population use wheelchairs, according to a 2005 census survey. Of those people, there are many different reasons why their mobility is restricted. These reasons can be anything from a muscular disease to simply a broken leg, or paralysis. One of the main reasons for being in a wheelchair is paralysis: about 5.6 million people in the U.S. are paralyzed. This category includes stroke victims and injuries causing paralysis. Multiple sclerosis is
another common disease affecting 400,000 people in the U.S. Also, cerebral palsy affects about 750,000 people in the United States. This may seem like a small percentage of the population, but when combined these conditions affect a large number of people. (U.S. Census Bureau, American Community Survey, 2008)

Anyone in a wheelchair or with general ambulatory difficulty or weakness is likely to have difficulty in reaching and retrieving items needed for everyday living. Many people confined to wheelchairs rely on others for many tasks throughout the day but would prefer to have a more independent lifestyle. Many assistive technologies exist on the market to aid in completing these tasks but there is room for improvement. The specific task of reaching and retrieving objects is one that is difficult for many people in wheelchairs. The use of a grabbing aid would greatly improve the user’s sense of self-reliance and restore some independence in their life. Everyday activities such as reaching food on shelves, grabbing items such as the television remote, grocery bags, and clothes on the floor can be easily accomplished with the use of a quality functioning grabbing aid.

3.1.2 Arthritis

Classified as one of the rheumatic diseases which cause pain and inflammation to joints or muscles (WebMD, 2010), arthritis is the inflammation of joints, causing great amounts of pain and limited joint use in its victims. As seen in the Figure 1, types of arthritis, like Rheumatoid arthritis, can cause bone and joint deformation.

With numbers of 350 million worldwide and nearly 40 million people in the United States, arthritis is prevalent and the most common chronic illness among men, women, and children in the United States, with half of arthritis victims being under the age of 65 years (MedicineNet, 1996-2010).
Symptoms include fever, swollen lymph nodes, fatigue, stiffness, and symptoms of organ abnormalities due to bone erosion, all detriments when it comes to performing even the simplest of household tasks.

3.1.3 The Elderly

According to the 2009 population estimates (US Census Bureau, 2009), the elderly, people who are 65 years and older, comprise 12.9% of the United States population. With the progression of human aging past its prime, regular functions become limited in reference to performing specific mental or physical tasks such as lifting ten pounds or walking a mile (Cutler, 2001). As humans age, the decrease of strength and body mass is observed which can cause physical frailty, falls, functional decline, and impaired mobility (Maria A. Fiatarone, Kehayias, Lipsitz, & Evans, 1994). Falling was rated the leading cause of unintentional injuries and death among the elderly with an estimated number of 16,000 fall-related deaths and 1.8 million non-fatal fall injuries in the United States. This risk has caused much fear to the elderly, restricting their activities, diminishing their social interactions, increasing depression, and further increasing their risk of falling (Boyd & Stevens, 2009). For the elderly these functional limitations can really impede their independence as fully functioning humans and cause a rift in their regular method of living.

3.1.4 Musculoskeletal Disorders

Usually caused by damage to bones, joints, muscles, tendons, ligaments, nerves, and other common injuries, musculoskeletal pain can range from mild to severe and in some cases can remain permanently with the individual, depending on the severity of the damage. Muscular pain in particular is affected by an injury, an autoimmune reaction, and loss of blood flow to the muscle, infection, or invasion by a tumor and can cause difficulty in movement, joint disorders, and overall weakness to the body. Musculoskeletal disorders include diseases such as Parkinson’s, muscular dystrophy, carpal tunnel syndrome, and fibromyalgia (Library, 2009) among many others and can limit daily activities at home or
in an office environment. Muscular disorders are prevalent in the United States; from one study in a sample population of 9,696 adults of working age, 36% reported pain in their shoulders, neck, elbows, and wrists and 45% report a soft-tissue disorder (Karen Walker-Bone, 2004).

3.2 Existing Solutions

In order to address the issues people with disabilities would endure while retrieving an item out of their reach, the assistive technology devices called grabbers were invented to make the task more bearable, comfortable, and cause the least amount of bodily stress while in use. Most importantly, these devices reduce the risk of injury or any accidental bodily harm to the user. With this concept in mind, many types of mechanical grabbers have been made with features that are more user-friendly, ergonomic, and economical.

3.2.1 Mechanical Devices

There are many existing devices on the market that perform the tasks of a grabber through purely mechanical motions. These devices work through an array of mechanisms as described below. The most widely used grippers are the Raptor Reacher, Gator Grabber, Gopher Grabber, EZ Reacher Pro, and VeeZee C5 Reacher.

3.2.1.1 Raptor Reacher

The Raptor Reacher is a very basic mechanical gripping device featured at a very low cost on the market. It is a voluntary closing device that closes when the user squeezes the handle. The trigger mechanism is attached to a wire that pulls on the grabbers, causing them to contract around the intended object.

The Raptor Reacher is advertised at a price of about $10-15 and is made out of lightweight plastic, weighing

Figure 2: "Raptor Reacher"
approximately six ounces. It extends the user’s reach by about 24 inches. The jaw at the gripping end opens to 2.5 inches. There is also a hook on the side of the reacher that can be used for dressing or other purposes. The advantages of the Raptor Reacher are that it is an extremely inexpensive option for those needing occasional assistance picking up light objects and also has a very easy to use design. The reacher has several reviews on the website it is sold on (allegromedical.com) and was reviewed by several users who found a few disadvantages as well. Users claimed that the device was not long enough for some purposes and it was also not useful in picking up small objects such as pens or heavy objects such as jars of food. One reviewer also noted that it was not practical for use in the kitchen and found that it was best at picking up clothes.

3.2.1.2 The Gator Grabber

The Gator Grabber is another mechanical device with a different user and intent than the Raptor Reacher. The Gator Grabber is targeted towards able-bodied independent people who need assistance in some instances to pick up objects. The grabber is very sturdy and can be used in outdoor applications such as doing yard work or picking up larger items around the house. Mechanically, the Gator Grabber works like scissors: it is a first class double lever with the pivot point acting as the fulcrum. It has telescoping handles that can accommodate lengths of up to 37 inches. It requires the use of both hands on the handles and the arm strength of both arms.

The Gator Grabber is priced at about $30-40 and is made out of heavy-duty powder coated steel with poly fiber jaws. The advantages of this product are that it is very robust and can pick up objects that other grabbers on the market may not be able to accommodate. It also can be used by people of varying heights due to the telescoping handles. This tool can be an asset to persons with back pain or other injuries that prevent them from doing tasks as they normally would. The disadvantages to this device are that it...
requires a large amount of strength and coordination to use as it is heavier than plastic grabbers at about 64 oz. and requires the use of both arms. It is also limited in its applications; reviewers found that it was not proficient in obtaining smaller household objects such as pens and paper.

### 3.2.1.3 Gopher Grabber

The Gopher Grabber is a very inexpensive option for grabbers and was one of the more well-known “grabbers” on the market, as seen in Figure 4. It is advertised for picking up very small objects such as a paper clip to bulkier items such as a 5-pound bag of sugar. The intended user is anyone needing help in or around the house to pick up such a range of objects; the user does not necessarily have a disability. It features suction cups at the gripping end as well as magnetic tips. The device is a voluntary closing mechanism that has a trigger on the handle. Each suction cup is attached to two strips of metal: one goes into the shaft and connects to the trigger and the other is attached to the side of the device. When the trigger is pulled the inner strips are retracted into the shaft, thus closing the suction cup grips and grasping the object.

This product costs approximately $10 and extends the user’s reach by 3 feet. The device weighs about 1.5 pounds, and is made out of aluminum. Many reviewers from the website (harborfreighttools.com) were pleased with the device and said it performed as it had claimed. Others found the device to be of poor quality and found that it had broken just after the warranty expired. One user claimed that they disposed of 3 gopher grabbers in a 2-year period. The advantages of this device are that is inexpensive, very easy to use, has a good extension distance and can pick up a wide range of objects.

Disadvantages are that it has limited gripping strength, as the contractile force in the hand is...
proportional to the gripping force applied at the other end. If the user has poor wrist/hand strength he or she will be limited to picking up lightweight objects. The device also features a locking mechanism; once the object is grasped, a small lever near the user’s thumb can be pulled down to lock the object in the gripper and pushed back up to release the object. This lever locks the metal strips in place so they do not contract or release any further.

3.2.1.4 EZ Reacher Pro

The EZ Reacher Pro is very similar to the Gopher Grabber in terms of function with a few differences for intended use. Since this product can reach up to 10 feet in length it has more outdoor uses than the Gopher Grabber. It is intended for able-bodied people needing some extra assistance in tasks such as outdoor lawn care/pickup, object retrieval in a pool or tree, or picking up anything on high shelves in a garage or basement setting as well. Similar to the Gopher Grabber, the EZ Reacher Pro has a trigger mechanism connected to the strips of metal that contract to grab the object when the trigger is pulled.

This device is priced at about $80 due to its heavy-duty capabilities and expensive materials. It is made from industrial quality stainless steel and aluminum and has the added feature of being able to fold in half into a more compact form. This is done with a sliding plastic sleeve that when fully extended keeps the gripper at the device’s longest length, but once retracted, a toggle is released and allows for the top half of the shaft and gripper to collapse down to half its length as shown in Figure 5. The device also features a locking mechanism when the object is grasped and the ends also have magnets and rubber suction cup grips.

Figure 5: “EZ Reacher Pro"
There is no specified weight limit for objects the EZ Reacher Pro can pick up, but the gripping end extends to a 4-inch span to grasp the object. The advantages of this product are the long reaching length for outdoor applications and far away objects, the durable construction materials and comfortable/ergonomic grip handles. The disadvantages for this product are that having the trigger grip directly correspond to the grasping strength is limiting for those with poor grasping strengths, the cost is significantly higher than other grabbers, and the 10 foot length is not applicable for many daily household tasks.

3.2.1.5 Vee-Zee C5 Reacher

Designed for users with severe arthritis, spinal injuries, and wrist deformities, the Vee-Zee C5 Reacher, Figure 6, completely eliminates finger functions of previous grabber models. Instead of a manual trigger, the device is operated from a t-shape toggle lever located on top of the device as well as with the mouth via a cord and ball. The toggle is connected to the tongs via a cord, which through tension caused by the toggle action lever, causes the tongs to open and close. The arm and wrist support is positioned to help relieve all stress on the radial side of the wrist as well as preventing non-functional wrist extension. There is also a support on the inside of the palm grips that helps to control ulnar deflection of the wrist.

Constructed from lightweight aluminum with rubber-lined claws that open to 3.5 inches and completely close, the Vee-Zee Reacher has an overall length of 36 inches, a folded length of 20 inches, and weighs 11.5 ounces. The device is currently on the market for approximately $199.99.
3.2.2 Summary of Commercial Devices

The mechanically operated devices previously discussed provide many users an opportunity to retrieve and place objects from varying locations. Table 1 lists all the previously mentioned reaching aid devices and highlights the main components such as function, cost, operation, advantages and disadvantages.

<table>
<thead>
<tr>
<th>Uses</th>
<th>Cost</th>
<th>How it Operates</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raptor Reacher</td>
<td></td>
<td>Voluntary close pulley system</td>
<td>Inexpensive, easy to use</td>
<td>Not long enough, only picks up light objects</td>
</tr>
<tr>
<td>Picking up small, lightweight objects</td>
<td>$10-15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gator Grabber</td>
<td></td>
<td>Similar to scissors, double lever pivot system</td>
<td>Useful by a user of any height; picks up heavy objects</td>
<td>Need strength in both arms to use it, heavy</td>
</tr>
<tr>
<td>Picking up robust heavy duty items; outdoor use</td>
<td>$30-40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gopher Grabber</td>
<td></td>
<td>Voluntary close with trigger manipulating metal strip that open and close device</td>
<td>Picks up wide variety of items, easy to use, lightweight</td>
<td>Requires sufficient gripping strength by user</td>
</tr>
<tr>
<td>Picking up very small items up to 5lbs</td>
<td>$10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EZ Reacher Pro</td>
<td></td>
<td>See Gopher Grabber</td>
<td>Long reaching length, durable materials, ergonomic/compact</td>
<td>Higher cost, not applicable to household applications</td>
</tr>
<tr>
<td>Long-reaching such as in outdoor settings (10’ length)</td>
<td>$80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vee Zee C5 Reacher</td>
<td></td>
<td>T-shaped toggle lever connected to grippers activates motion</td>
<td>Does not require high gripping strength to activate motion</td>
<td>High cost, requires two arms to strap on, picks up limited objects</td>
</tr>
<tr>
<td>Picking up lightweight objects</td>
<td>$199.99</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These devices will serve as a method of comparison and design improvement in the design of an electro-mechanical reaching aid.
3.2.2 Patents

There are several patents for mechanical grabbers that add in unique features to make reaching and retrieving an item even more simple and easy on the user.

3.2.2.1 Tool for Retrieving Out-of-Reach Objects, 4441746 (1984)

Designed to retrieve out of reach objects from a lower area, this mechanical hand-operated 3-bar link invention is made for users who have difficulty stooping, bending, or reaching for objects and articles on the ground such as persons who use wheelchairs, persons with neck pain, persons with back pain, and women who are pregnant. With a combination of a movable jaw assembly, the user can begin using the invention by manually squeezing the sliding handle piece (27) of the handle assembly. The jaws include a soft rubbery or vinyl tip (21) to provide enough friction while grasping small objects from a surface as well as magnets to pick up small metallic objects; it is also capable of grasping and holding small to medium sized objects, and is curved (22) to retrieve large, wider objects such as soda and beer cans. Comprised of an elongated rigid tube (11), with a jaw assembly (12) at one end of the tube, a handle assembly (13) at the opposite end of the tube, and a connecting rod (30) between the handle and jaw assembly, the invention operates as a 3 bar linkage mechanism. The two linkage pieces (17) and (18) link the two jaw pieces (14) and (15) to a linkage insert piece (19); jaws (14) and (15) are linked to the linkage piece (18) by a fastener (20), and both jaws (14) and (15) pivot about the pivot bolt (16). The handle assembly (13) consists of a fixed handle (26) and movable trigger (27) that is attached to a centrally placed connecting rod (30) running longitudinally through the tube (11) and attaches to the linkage insert (19). The connecting rod (30) is surrounded by compression springs (43) that maintain the...
movable jaws at a default open position. As the connecting rod (30) is moved, it couples the sliding handle (27) to the linkages of the jaw assembly (12) causing the jaw pieces to close toward one another, eventually “pinching” the object between the jaw tips(21)or held between the curved sections(22) of the jaw.

3.2.2.2 Self Gripping Reacher, 4758035 (1988)

In addition to aiding persons with disabilities by extending their reaching and gripping abilities, the self-gripping reacher also helps those with grip and wrist disabilities in reaching and lifting objects. This invention is mainly comprised of the forearm brace (12), the extension arm (14) and the gripper (16), and it enables persons with disabilities to grip objects with sufficient force to permit lift independent of hand and wrist strength, and can be triggered by either hand of the user, relieving bending stresses on the hand and wrist and avoiding imparting a torsional force to the forearm and wrist; to further relieve hand and wrist stress, a forearm brace (12) is provided that is easily accessible to the user.

Attached to the forearm brace (12) and aligned slightly below the axis of the user’s forearm is the extension arm (14), held against its own weight in a horizontal position by a retention spring (57), containing opposed gripper jaws (60). The trigger mechanism (44) carried also by the forearm brace (12) and held in place by a spring detent (97) carried within the ratchet wheel (85) is linked by a cable (71) to the

Figure 8: Self-Gripping Reacher Schematic

(Kevin Shimasaki, 1988)
opposed gripper jaws (60) and is actuated to move the jaws (60) toward one another to initially grip the object (102). A cable (71) that extends through the extension arm (14), guided by guide pins (83), (84) and (86) and clamped to a cable-tensioning screw (88) threaded to the housing (40), links the gripper jaw (60) to a ratchet tightening wheel (85), mounted within the housing (40), and is rotated to tension with a ratchet pawl, by means of the trigger mechanism (44). The gripper jaws (60) contain facing surfaces (101) formed of high friction elastomeric bands (103), which deflect to conform to the object’s shape (102). Upon operating the trigger (44), the ratchet (85) rotates, causing the notches (91) to advance against the ratchet pawl (92) and lock the ratchet (85), thereby eliminating the need for a grip on the trigger (44) to keep a secure hold on the lifted object (102), as well as a tensioning of the cable (71), causing the gripper jaws move (60). To release the object, the user rotates the ratchet releasing mechanism (93) with his thumb, causing the ratchet (85) to return to its original position, and in effect, causes the tension in the cable (71) to be released, permitting the grippers (60) to return to an open position.

3.3 Research Summary

Researching the number of disabilities and current reaching aids out on the market demonstrates the prevalence of disabilities in both a home setting and the workplace and the necessity of a reaching device to alleviate these problems. The use of a grabbing aid would greatly improve the user’s sense of self-reliance and independence, empowering them to perform daily tasks in a household or office setting and boost their self-esteem. With the mechanical reaching aids available, the user must have a good amount of strength, especially in the wrist to lift items. This may be very difficult and stressful for users, particularly those with poor grip strength or the elderly. An electro-mechanical reaching aid that reduces the need for
user strength and ensures safety in retrieving objects will help users feel more independent and comfortable performing every-day tasks.
4.0 Design Goals

The Grab-bot device is meant to extend the reach of the user when retrieving objects that are out of reach. The device’s functionality is decomposed into a set of design goals that are used as criteria to measure the performance of each preliminary design. These design goals are based on information about expected users, operating environment, and other relevant factors. The design goals are listed as follows: safety, object selection variety, weight, manufacturability, locking mechanism, reliability, cost, and life span.

4.1 Design Specifications

Function

1. The device is intended to extend the reach of a user to the front and side by 2 feet in all directions.
2. The device should be able to retrieve an object 2 feet out of the user’s reaching distance from a high or low area and place the object within the user’s reaching distance at a more comfortable level to the user for purposes of manipulation.
3. The device should be able to retrieve an object 2 feet out of the user’s reaching distance from a high or low area and move it from its origin to another location within the individual user’s extended 2-foot reaching radius.
4. The device grabber component should be able to press buttons, flip switches, turn knobs, and other manual controls effectively and adeptly.
5. This device can be operated using one hand.

Intended Users

6. This device is intended for users with varying disabilities:
• Physical disabilities: muscular dystrophy, ALS, multiple sclerosis, arthritis, rheumatoid arthritis, scoliosis, cerebral palsy, paralysis, fibromyalgia, Parkinson’s, tremors, and general injuries requiring assistive technology

• Aging: weakening joints and diminished strength due to increase of age

**Intended Uses**

7. Household setting: The device is to be used for activities of daily living and occasional work outdoors. Examples of uses include meal preparation, ingredient selection, setting a table, putting groceries away, pulling down a shade, making a bed, picking up clothes, retrieving closet items such as clothing on hangers or in shoe boxes, moving laundry items from hamper to washer or washer to dryer or dryer to hamper, picking up a remote, retrieving toilet paper, turning on a ceiling fan, holiday decorating, dusting, wall-painting, electrical work, cleaning a fish aquarium, changing a light bulb, picking up litter, etc.

8. Outdoor Setting: light yard work/gardening, picking up outdoor pet waste, retrieving items from pools, trees, garage, sheds, putting up outdoor lighting and decorations, apple-picking, painting shingles, cleaning gutters, retrieving items from the roof, etc.

9. Office setting: The device is to be used for activities of daily office work and tasks. Examples include stocking books, clothing, or food on a high or low shelf, removing products from a shelf, retrieving or placing back items in a filing cabinet, retrieving or placing back items from a supply closet shelf, picking up chalk, picking up a stack of papers, pens and pencils, etc.

10. The device will be capable of holding objects depending on their shape, size, texture, and weight:
It will be capable of picking up items in various packaging such as the following: soup cans, peanut butter jars, cereal boxes, pasta boxes, medication bottles, shopping bags, spices, light pans, light pots, utensils, glass cups, plastic cups, ceramic mugs, granola bars, apples, bunches of grapes, peppers, eggs, carton or quart of milk and juice, jar of sauce, clothing, kitty litter scoop, remote controls, eyeglasses, mouthwash, shoes, toothpaste, comb, light bulbs, hats, keys, umbrella, books, pens, pencils, paperclips, single pieces of paper, stack of paper, etc.

11. The maximum weight the device can hold is 2 lbs.

**Dimensions**

12. The device’s shaft longitudinal length will not exceed 3 feet.

13. Weighs a maximum of 1.5 pounds with battery.

   *All Benchmarked devices do not exceed 11.5 ounces.*

**Safety**

14. Device grabber ends should contain locking mechanisms.

   *This is a safety feature to ensure secure grip upon retrieving an object.*

15. Device grabber ends should eliminate any possibilities of objects slipping from its grip, maintaining a secure grip at coefficients of frictions as low as 0.1.

16. There should be no sharp edges, no loose wires, and no exposed moving parts.

   o *Wires should be bound together and stored away from moving parts such as gears and motors.*

17. Use of the device should not cause any excessive bodily stress or strain on the user.

18. There will be a method of securing the device to the user in the event of unintentional release of the user’s grip on the device itself.
Quality

19. The device must be durable; it should be able to be dropped from a maximum of 3 feet and still function.

20. The device must be reliable in an office and household setting.
   - The device should be able to be used up to 75 times a day for a total lifespan of up to 5 years (approximately 150,000 uses).

Ergonomics

21. The device should be compact and portable; all parts should be contained within an envelope having a maximum diameter of 9 in. and a maximum length of 26 in. long in its most compact configuration.

22. The electrical control system will be intuitive and ergonomic; no training is required to understand the operation of the controls.
   - This would ensure proper user interface and safety.

23. The device must be battery operated.
   - Battery life is dependent on usage: high usages may require a battery change monthly while occasional uses will be less frequent.

24. Battery packs will be located in a convenient location on or in the vicinity of the device.

Life Cycle

25. The device will have a life-expectancy of 5 years
**Economics**

26. A first generation prototype costs a maximum of $320 to build.

**Environmental**

27. The device’s optimum operating environment is at a temperature of 72° F (room temperature).
28. Water on device: the device can work with small amounts of water on the surface, but need not be designed to withstand submersion. The device should be able to withstand light to medium rainfall.
29. Water on grabber end: The grabber ends can be immersed completely in water up to 2 inches deep.
30. Ambient temperature: The device should be able to operate within an ambient temperature range of 32°-110° F.  
   *This accounts for the hottest summer temperatures in the event of outdoor use.*
31. Temperature of retrieved objects: The device’s grabber ends should be able to withstand temperatures up to 212° F.  
   *This is the boiling point of water, which may be experienced during food preparation.*

**Manufacturability**

32. The prototype must be able to be manufactured using on campus machine shops.
33. The device’s manufacturing should minimize the need for sophisticated machining operations.
5.0 Preliminary Design Concepts

Taking design specifications and design goals into consideration, several preliminary designs were created for each subassembly of the Grab-bot. These include the grabber assembly, controls assembly and arm attachment assembly.

5.1 Grabber Assembly

For the grabber assembly, we concentrated on designing a grabber that would most effectively pick up and retrieve objects from several different heights and locations, as well as have a good weight distribution.

5.1.1 Preliminary Design 1

Preliminary Design 1, Figure 9, has a similar grabber assembly design to the Gopher Grabber. With this design, the thin metal strips (7) have suction cups (10) attached by a fastener (9) to one end serving as the grabber tip and the other end of the strip (7) is attached to a protective plastic housing (11) that is subsequently attached to the aluminum shaft (14). On the top portion of the housing (11) is a battery pack (13) that will serve to power the motor (1).

Figure 9: Preliminary Design 1
Attached to the metal strips (7) by a set of fasteners (6) are wire cords (5) that pull the strips (7) toward one another to hold onto an item. The wire cords (5) wrap around a metal shaft (4) that is powered by a motor driven gear train (2) and (3). As the motor (1) turns, a spur gear (2) will turn another spur gear (3) attached to the metal shaft (4), which will cause the shaft (4) to revolve; as the metal shaft(4) turns, the cord (5) will wrap around the shaft (4) and thus cause wire tension and a pulling of the strips(7) toward one another. The electrical components of the motor (1), gears (2) and (3), shaft (4), as well as a battery pack (13) are covered by a plastic container (11) which provides safety and optimal part operation.

5.1.2 Preliminary Design 2

Preliminary Design 2 eliminates the need for a shaft and metallic strips and instead attaches the gears directly onto the grabber, Figure 10. The grabber links (6 and 7) are ‘C’ shaped with an upper flat surface; an elastomeric material (8) is wrapped around the entire linkage. When picking up an object, if flat, the flat surface of the grabber along with the friction of the elastomeric material will make retrieving easy, and, if round, the rounded grabber hooks with the elastomeric skin will wrap around the object, enveloping it and holding the item in place with the frictional characteristic of the skin.

The link grabber ends are attached with gears (4, 5) and aligned with one another as shown. A motor (1) will turn a shaft (2) that turns a bevel gear (3) which will mate with another bevel gear (5), and will thus cause the other gear (4) to turn. As
both the link hook spur gears turn, the link hooks themselves will also turn towards one another. When
the motor is reversed, the link hooks will turn away from one another, thus opening the grabber ends in
the opposite motion.

5.1.3 Preliminary Design 3
Preliminary Design 3 operates on a linkage system, Figure 11.

The motor (1) located at the end of the device in a housing container (12) will turn a shaft (2); the shaft (2) is attached to a wire cord (3) that winds and unwinds as the shaft (2) rotates. The wire cord (3) runs through the aluminum shaft (14) of the device and attaches on the link ends (5), which are contained within the device housing (11). As the shaft (2) rotates and the wire cord (3) wraps around the shaft (2), a wire tension is created, causing a downward pull on the link ends (5). While, the entire link (7) is pulled down, the other links (9) will proceed to follow, pivoting at points (6), (8), and (13). The grabber link (9) contains a “C” shaped grabber end (10) that will come together to grab and retrieve an object. To release the object, the motor (1) will reverse in rotation direction, unwinding the wire cord (3) from the shaft (2), releasing tension in the wire cord (3) and bringing the link ends (5) back to a default open position. This opening of the link ends (5) causes the grabber link (7) to resume an open position.
5.1.4 Preliminary Design 4

Preliminary Design 4 functions very much like a compass drawing tool, Figure 12. With a threaded bar (6) running through the two linkage hooks (7), a motor (1) will turn a shaft (3) which is attached to a gear (4), and the gear (4) will turn the gear (5) attached to the threaded bar (6).

As the gear (5) turns the bar (6), the threaded rod rotates and the gripper ends either close or open. The grabber hooks (7), which have threaded holes (15) that are aligned horizontally with one another, will travel along the threads of the bar (6) towards one another turning on a pivot (2) until closed. The threaded bar (6) serves as a locking mechanism and allows for multiple grabber hook (7) open positions. Very much like preliminary design 2, the grabber hook (7) structure of a ‘C’ shaped hook (8) wrapped with an elastomeric material (10) and fastened (12) to the hooks (7) is utilized to accommodate for objects of various shapes. The moving components, including the threaded bar (6), gears (5) and (4), shaft (3), pivot (2) and motor (1), are enclosed within a plastic housing (13).
5.1.5 Preliminary Design 5

Preliminary Design 5 relies on gear functioning to move the grabber hooks, Figure 13. A motor (1) turns a worm (2) drives a worm gear (3).

Another worm gear (4) with the same number of teeth is adjacent to the rotating worm gear and also rotates. The Grabber hooks (5) and (6) are attached to the rotating worm gears and in turn move towards or away from one another as their respective worm gears turn. The entire gear mechanism is encased in a hollow, plastic covering (10) to prevent any outside interference. The grabber hooks maintain a “C” shaped configuration (8) and (9), similar to Preliminary Design 4, surrounded by an elastomeric material (6) to serve as a means of enveloping and retrieving a spherical or cylindrical object. At point (7), the surfaces are flat, allowing for rectangular or box-like object retrieval.

5.1.6 Preliminary Design 6

Preliminary design 6 focuses on one sliding hook (4) that will open and close upon an item of interest onto a fixed hook (6), Error! Reference source not found.
A motor (1) turns a rod (2); the rod and motor are attached to the aluminum arm (9) of the Grab-bot. Wrapped around the rod is a metal cord (3) that pulls the movable hook linkage (4) about a pivot point (5). The hook (4) proceeds to move into a closed position by going towards the fixed hook link (6) in the act of grabbing an item. When the item is retrieved, the motor (1) will turn in the opposite direction, causing the cord (3) to slack and bring the link hook (4) to its default open position.

On both the hooks at points (7) and (8), the surfaces are flat to allow for rectangular or box-like items; while, the “c” shaped part of the hook (10) and (11) focus on retrieving items that are more spherical or cylindrical in shape.

5.2 Controls Assembly
To fully implement the electro-mechanical feature of the grab-bot, a controls assembly is considered in the design with special attention to user comfort and user interface.

5.2.1 Preliminary Design 7
Preliminary Design 7 is shaped very similarly to the ergonomic handles, seen in Figure 15 featuring molded handgrips for optimal comfort.

As seen in Figure 16, the grip features a molded finger grip (5) and palm rest (4) that effectively mimics a comfortable side hand position. The grip itself is attached to the aluminum shaft (6) of the device and on top of the grip are two touch sensors (1) that when activated by a thumb press will send a
signal through the grip structure into a plastic holder directly beneath the aluminum shaft (not shown) which contains a micro board and batteries. The micro-board will power the motor to turn on and control the grabber assembly. The touch sensor area will be clearly labeled to indicate its particular function, whether it be to open (8) or close (7) the grabber assembly hooks.

5.2.2 Preliminary Design 8

Preliminary Design 8 has a controller (1) shaped like an electronic computer mouse and is attached to the aluminum shaft, allowing the hand to lie parallel to the shaft.

As seen in Figure 17, on the controls are two touch sensors (2) that open and close the grabber assembly which are activated primarily by the index and middle finger. Once activated, the signal from the touch sensor will travel along a wire the aluminum shaft to a plastic container with a micro board and battery pack (3). There, the micro board will send an electric signal to turn on the motor.
5.2.3 Preliminary Design 9

In Preliminary Design 9 the control design stabilizes the entire gripper, as shown in Figure 18.

This concept is different from the others in that it introduces a two level system- the arm attachment beam (1) is at one level, then the grip (4) and controls (5) rises up and the gripper shaft continues on at a different level. The grip is similar to the trigger grip in design 7; it is ergonomic and contoured to the hand. The grip would be angled away from the hand as shown for comfort so the hand does not need to be at a perfect 90-degree angle to grip the trigger. The sensors (4) would be positioned under the thumb with full view to the user with clear open and close labels and symbols as shown. This design would distribute the load of the object more evenly as the beam below the forearm would push up on the arm and thus utilize the biceps and triceps in lifting as opposed to the wrist.

5.2.4 Preliminary Design 10

In design 10 the controls would be featured on top of the gripper’s main shaft, as seen in Figure 19.
For the design to be more ergonomic, a gel-like material shaped to fit the hand would be mounted underneath the shaft (2). The hand would wrap around the metal shaft and grip the gel-like material (similar to a Wii controller) while using touch controls (1) to open and close the grabber ends. The advantage of this control system is that it would be very comfortable and easy to use; however, it would make stabilizing the device difficult, as the user would have to maintain a stable grip on the device to use it.

5.3 Arm Attachment Assembly
When considering the arm attachment assembly, the concept of easily slipping into a secured forearm position on the grab-bot was taken into consideration, as well as adjustability to suit a wider user audience.

5.3.1 Preliminary Design 11
Preliminary Design 11 imitates the contoured arm support design shown in Figure 20, which primarily consists of neoprene padding and mounting plate.
As seen in Figure 21, the contoured arm support (1) is attached to the aluminum shaft of the grab-bot. Since only a portion of the forearm is covered, a spandex material (2) running across the arm support serves to keep the forearm in place with the device. The spandex will allow users with varying forearm shape to easily squeeze into the arm support.

![Figure 21: Preliminary Design 11](image1)

5.3.2 Preliminary Design 12
With Preliminary Design 12, the aluminum shaft contains an “arm-band” with an adjustable strap (1) that wraps around a metal U-shaped shaft (2) and attaches onto itself with Velcro, as can be seen in Figure 22. A similar concept to this found in a doctor’s office would be a blood pressure cuff with Velcro strap. This design can adjust to any arm width but has the disadvantage of requiring both hands to attach it to the arm.

![Figure 22: Preliminary Design 12](image2)
6.0 Design Selection
In order to determine the optimal features for each subassembly of the grab-bot, a series of preliminary design matrices were formulated.

6.1 Preliminary Decision Matrices: Rank Ordering
With rank ordering, each design goal is compared with the other in order to estimate which goal is more important to consider. A design goal is awarded a score of 1 if perceived to be more important than another goal. A rank of 0 is awarded to the design goal that is deemed less important than a column goal. If two goals are deemed to be of equal significance, they are each awarded ½ point. See Appendix A, part 1 for rank ordering charts for the grabber, controls, and arm assembly.

Once all the numbers are assigned, the entire row is summed; a design goal that has a larger sum is considered more significant than a design goal with a lower sum, and if two design goals have the same sum, they are deemed equally important compared to one another. Observing Table 2, the order of design goal significance, for each subassembly of the grab-bot, starting from most significant and ending with least significant are listed.

Table 2: List of Design Goal Significance for Each Sub-Assembly

<table>
<thead>
<tr>
<th></th>
<th>Grabber Assembly</th>
<th>Controls Assembly</th>
<th>Arm Attachment Assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most Significant</td>
<td>Functionality</td>
<td>Stability</td>
<td>Safety</td>
</tr>
<tr>
<td></td>
<td>Safety</td>
<td>Ergonomic</td>
<td>Ease of Use</td>
</tr>
<tr>
<td></td>
<td>Object Selection</td>
<td>User Interface</td>
<td>Stability</td>
</tr>
<tr>
<td></td>
<td>Variety/Locking</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mechanism</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reliability</td>
<td>Weight</td>
<td>Ergonomic</td>
</tr>
<tr>
<td></td>
<td>Weight</td>
<td>Reliability</td>
<td>Weight</td>
</tr>
<tr>
<td></td>
<td>Life span</td>
<td>Manufacturability</td>
<td>Manufacturability</td>
</tr>
<tr>
<td></td>
<td>Manufacturability</td>
<td>Cost</td>
<td>Cost/Aesthetics</td>
</tr>
<tr>
<td>Least Significant</td>
<td>Aesthetics</td>
<td>Aesthetics</td>
<td></td>
</tr>
</tbody>
</table>
6.2 Assigning Weight Factors to Design Goals

Once the order of goal significance is determined, each design goal is given a weight factor from a scale of 0 to 100, as seen in Table 3, Table 4, Table 5. A score between 0 and 30 is deemed an optional design goal; a score between 31 and 70 is deemed an important but not a necessary design goal; and a score between 71 and 100 is deemed an important, necessary design goal.

Table 3: Grabber Assembly Weight Factor

<table>
<thead>
<tr>
<th>Critical (100-71)</th>
<th>Important (70-31)</th>
<th>Optional (30-0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionality (100)</td>
<td>Safety (90)</td>
<td>Object selection</td>
</tr>
<tr>
<td>Locking mechanism (85)</td>
<td>Reliability (65)</td>
<td>variety (70)</td>
</tr>
<tr>
<td></td>
<td>Weight (65)</td>
<td>Re</td>
</tr>
<tr>
<td></td>
<td>Life span (55)</td>
<td>liability (50)</td>
</tr>
<tr>
<td></td>
<td>Manufacturability (50)</td>
<td>Cost (40)</td>
</tr>
</tbody>
</table>

Table 4: Controls Assembly Weight Factor

<table>
<thead>
<tr>
<th>Critical (100-71)</th>
<th>Important (70-31)</th>
<th>Optional (30-0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Interface (90)</td>
<td>Ergonomics (85)</td>
<td>Weight (70)</td>
</tr>
<tr>
<td>Stability (75)</td>
<td>Manufacturability (50)</td>
<td>Cost (40)</td>
</tr>
<tr>
<td></td>
<td>Reliability (60)</td>
<td>Re</td>
</tr>
</tbody>
</table>

Table 5: Arm Assembly Weight Factor

<table>
<thead>
<tr>
<th>Critical (100-71)</th>
<th>Important (70-31)</th>
<th>Optional (30-0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety (100)</td>
<td>Stability (95)</td>
<td>Ease of Use (70)</td>
</tr>
<tr>
<td></td>
<td>Ergonomic (70)</td>
<td>Aesthetics (10)</td>
</tr>
<tr>
<td></td>
<td>Weight (65)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Manufacturability (50)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cost (35)</td>
<td></td>
</tr>
</tbody>
</table>

6.3 Decision Matrix

The decision matrix functions as a means of comparing the preliminary designs with the design goals and how effectively each design goal was achieved. Each goal was listed in the order of rank significance, with their respective weight factors. Each preliminary design is scored from 10 to 0, with 10
representing a preliminary design that is an excellent demonstration of a certain design goal and 0 representing a preliminary design that completely fails a certain design goal. The range of design rating factors is seen in Table 6.

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Excellent</td>
</tr>
<tr>
<td>8</td>
<td>Good</td>
</tr>
<tr>
<td>6</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>4</td>
<td>Mediocre</td>
</tr>
<tr>
<td>2</td>
<td>Unacceptable</td>
</tr>
<tr>
<td>0</td>
<td>Failure</td>
</tr>
</tbody>
</table>

As each preliminary design is given a rating, the rating factor is multiplied by the respective design goal weight factor. Once a preliminary design has been rated against all the design goals in this manner, all the numbers are summed. Whichever sum is greatest among the preliminary designs is deemed the design of best choice. See Appendix A, part 2 for grabber, controls, and arm assembly decision matrix.

### 6.4 Grab-Bot Assembly Rubric

**Functionality**

Functionality was given the highest ranking of 100 for the grabber assembly decision matrix because it encompasses our entire goal for designing the grab-bot. If the grabber accomplishes all the other goals but does not actually pick up any objects then it is considered a failure. The rankings went from 1-10 with 10 being the most functional for the method of grabbing. A rating of 9-10 is designated for a high functioning grabber that works every time it is used. From there the quality goes down, with a 5 designating that it only picks up objects some of the time, and 0 being never.

**Safety**

Safety was given the next highest ranking of 90 because it is critical that the Grab-bot not injure the user. The highest ranking of 10 is given to those assemblies that will demonstrate a high level of
safety, with few or no moving parts and electrical hazards. Numbers under 5 designate a grabber that may pose a risk to the user, such as pinching or dangerous moving parts. Another consideration was weight, as heavier devices increase the risk of stresses to the user.

**Locking Mechanism**
Another category related to safety is the locking mechanism used on the grabber. This category is important as it is rated 85; the locking mechanism will ensure the object is not lost in transit, and be dropped and cause a hazard. Assemblies with a working locking mechanism received high scores (8-10) while those with no locking mechanism or a weak mechanism received lower scores (<6).

**Object Selection Variety**
This category was ranked with a weighing factor of 70 as the quality and usability of the grabber depends on what applications the user will be able to use the device for. Grabbers that will be able to obtain more objects are given a high score (7-10) and those that may not be able to obtain as many objects due to weight or size limitations were given a low score (<6).

**Reliability**
Reliability was given a weighting factor of 65. It is important that the grabber be able to function repeatedly otherwise it cannot be depended on and will quickly break or fail. The desired reliability is multiple times a day for 5 years. Grabber assemblies expected to fulfill this requirement were given a high score (8-10) and other grabbers were reduced accordingly.

**Weight**
Weight was ranked with a 65. This is important as the weight is correlated with safety as well as user interface. An ideal Grab-bot would have a low weight (2-3) pounds. Assemblies matching this goal are awarded high scores (7-10) and assemblies that would add significantly to the weight were reduced proportionally.
Life Span

Highly related to reliability, life span is an important factor as a device on the market must have an advertised life span or it may be susceptible to breaking prematurely. Though the grabber will not come with a guarantee, the desired lifespan is 3-5 years with regular use. It is difficult to guess estimate how long each of these assemblies will last but the score is based on materials, design, and the motions involved in grabbing.

Manufacturability

Given a weight of 50 for the grabber assembly, manufacturability also contributes to selection process significantly. The ease of manufacture will dictate how quickly the prototype will be made, but also affect a mass manufacturing process if it ever went to the market. Manufacturability depends on the materials used, number of custom parts vs. standard parts, as well as complexity of parts. Simpler designs with fewer custom parts are given high scores (>7) and more complex designs with more parts are given lower scores.

Cost

An important parameter but not completely critical to the design and manufacture of the grabber is cost. Though this must be considered it is only ranked 40 since it would probably not be a deciding factor in our selection process. The overall cost of the Grab-bot should be no more than $200; assemblies that fit this criterion are awarded a high score while assemblies that are more costly receive a low score.

Aesthetics

Lastly, and least important is aesthetics, which was given a ranking factor of 10. The way the grabber appears will not affect the overall success and functionality, but if it looks appealing it may sell better on the market. Neat, compact, and streamline designs were given scores of 7 or better, and more bulky and less appealing designs were ranked lower than this.
**User Interface**

Given a weighting of 90, user interface is crucial in the controls assembly. The goal for controls is for the switch to be very user friendly and intuitive for first time users. In the case of all these controls interfaces, all received a 9 because they are extremely easy to use and intuitive.

**Ergonomics**

Also important to the controls interface is ergonomics, with a ranking of 85. The user’s comfort should be considered while designing the handle and switch to turn the grab-bot on. Two of the designs received 10’s as they were found to be extremely ergonomic while the other was slightly less ergonomically shaped for the hand and received a 7.

**Stability**

Stability was ranked with a 75 as it contributes to the general usability of the device, especially for elderly users. If the handle/controls help to keep the device stable they receive a high score (>8), but if they do not contribute to this factor at all they receive a lower score.

**Ease of Use**

Ease of use pertains to how the user will be able to attach the device to their arm, how well it stays on, and how easy it is to take the device off. Consideration was given to how long it takes to accomplish these tasks, if assistance is needed, the amount of strength needed, and intuitiveness for first time users. Since both arm attachment assemblies did well in these categories they were awarded a high score of 9.

**6.5 Final Decision Matrix**

From the previous decision matrices, the decision matrix for the Grabber Assembly contained two preliminary designs, 4 and 5, that were almost similar in their sum. In order to pick the final design, another decision matrix was constructed comparing the two designs in greater detail. The same categories of features have been used with the same weight factor of each with each category further broken down into detailed sub categories with the same weighting factors of their respective category.
6.5.1 Final Decision Matrix

<table>
<thead>
<tr>
<th>Functionality</th>
<th>Weighting Factor</th>
<th>Prelim 4</th>
<th>Prelim 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gear/Thread Alignment</td>
<td>100</td>
<td>8/800</td>
<td>7/700</td>
</tr>
<tr>
<td>Gripper Speed</td>
<td></td>
<td>9/900</td>
<td>5/500</td>
</tr>
<tr>
<td>Gear/Thread Precision</td>
<td></td>
<td>9/900</td>
<td>7/700</td>
</tr>
<tr>
<td>Safety</td>
<td>90</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume occupied</td>
<td></td>
<td>8/720</td>
<td>5/450</td>
</tr>
<tr>
<td>Minimal Backsliding</td>
<td></td>
<td>9/810</td>
<td>9/810</td>
</tr>
<tr>
<td>Weight</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gear/Thread</td>
<td></td>
<td>9/585</td>
<td>3/195</td>
</tr>
<tr>
<td>Life Span</td>
<td>55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor Life-Span</td>
<td></td>
<td>8/440</td>
<td>5/275</td>
</tr>
<tr>
<td>Cost</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gear/Thread cost</td>
<td></td>
<td>9/360</td>
<td>5/200</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>5515</td>
<td>3830</td>
</tr>
</tbody>
</table>

6.5.2 Explanation of Final Decision Matrix Criteria

Drawing from the Final Decision Matrix, Table 7, Preliminary Design 4, featuring the threaded rod component is the final design choice for several reasons. In terms of functionality, the alignment of the threaded rod design was awarded one point higher with an 8 over the geared design. With gears, it is much more difficult to keep them perfectly aligned so they mesh properly whereas once the rod is threaded into a pin; it will always rotate on the same axis. For gripper speed, the threaded rod design outranked the geared design as the speed can be controlled much more easily because it directly correlates to the motor speed, whereas the gear speed may not be as easily controlled as it must go through a series of reductions, etc. to have the desired range. For gear/thread precision, again the threaded rod design received a higher score since the fine threads produce a more precise range. The gear’s teeth will be wider and therefore each revolution will have a larger opening/closing motion for the grippers, with less room for error.
For safety, the volume occupied contributes to this factor as a bulkier and larger grabber may be harder to handle and may cause the user to have a hard time wielding the device. The threaded rod is very small dimensionally, with a 3/8” diameter, while the gears are thick and wide and require a system of bevel gears to transmit the motion from the motor. Also, the two designs tied in terms of locking mechanisms and being able to be back driven from the object as they both have locking mechanisms that prevent this from happening.

The motor life span will be longer for the threaded rod designs as there are mechanisms such as snap switches that will keep the motor from shorting and burning out. Also, the motor will be able to transmit motion more smoothly and there is less chance of error because the motion is being transmitted right to the rod instead of through a series of gears.

With cost there is a great difference between the threaded rod model and the spur/worm gear model. The threaded rod will cost about $3 to order from a supplier with any adjustments made in the machine shop. Gears can cost as much as $40 each depending on the material used, and this design requires 2 spur gears and 1 worm gear, which will cost within a range of $50-$100, up to 30 times greater than the threaded rod cost.
7.0 Final Design: Preliminary Analysis

7.1 Grabber Assembly Analysis

The grabber assembly of the Grab-bot is one of the most important sub-assemblies because it contains detailed manufactured parts, particularly the gripper and pins, Figure 23. When the grippers were originally designed, our team experimented with several pivot configurations about which the grabbers would rotate, as well as the appropriate locations for the cylindrical pins containing the threaded hole for the threaded rod to fit through.

7.1.1 Static Analysis

First, a three-dimensional free body diagram of the grabber was made, Figure 24, assuming the threaded rod and pins are included in the diagram, and that the gripper itself has picked up an 8 pound object.
Figure 24: Free Body Diagram of Single Gripper

Where,

- $F_f$ is the friction force of the retrieved object to the grabber, 4 lbs.
- $F_{obj}$ is the force of the retrieved object acting on the grabber, 8lbs.
- $\alpha$ is the angle the retrieved object is picked up in relation to the gripper flat face (x-y plane)\(^1\),
- $R_{yp}$ is the reaction force in the y-axis of the rotating pin onto the gripper
- $R_{xp}$ is the reaction force in the x-axis of the rotating pin onto the gripper
- $R_{yc}$ is the reaction force in the y-axis of the rotating cylindrical pin onto the gripper
- $R_{xc}$ is the reaction force in the x-axis of the rotating cylindrical pin onto the gripper

---

\(^1\) See Appendix B: Section 1 for “$\alpha$” value calculation
\(M_y\) is the moment of the gripper about the \(y\)-axis

\(M_x\) is the moment of the gripper about the \(x\)-axis

c is the vertical distance from the center of the cylindrical pin to the center of the rotating pin.

d is the vertical distance from the retrieved object force to the center of the rotating pin

With these variables, the grabber’s reaction forces were calculated. The sum of forces and moments in the \(x\) direction results in the following equation:

\[
R_{xp} + R_{xc} - F_{obj} \cdot \cos(\alpha) = 0
\]

\[
M_x = -R_{xc} \cdot c - F_{obj} \cdot \cos(\alpha) \cdot d = 0
\]

This results in the magnitudes of \(R_{xc} = 12\text{lb}\) and \(R_{xp} = 19.4\text{lb}\).

The sum of forces and moments in the \(y\) direction results in the following equation:

\[
R_{yp} + R_{yc} - F_{obj} \cdot \sin(\alpha) = 0
\]

\[
M_y = -R_{yc} \cdot c - F_{obj} \cdot \sin(\alpha) \cdot d = 0
\]

The resulting magnitudes are \(R_{yp} = 0\text{lb}\) and \(R_{yc} = 0\text{lb}\)

The sum of forces in the ‘\(z\)’ direction is expressed in the following equation:

\[-F_{arm} + F_r = 0\]

This results in the magnitudes of \(F_{arm} = 4\text{lb}\)

Once these variables are solved, singularity functions, a class of mathematical functions that can easily calculate and represent bending moment and shear diagrams for complex loadings across the entire length of the beam by a single analytical function, were used. Singularity functions are a great visual tool and a good way to computerize the solution. Singularity functions are denoted by a binomial
in angled brackets, with a variable of interest like ‘x’ as the distance along the beam length, and ‘a’ as
the user-defined parameter which indicates where in ‘x’ the singularity function either acts or begins to
act. Once these values have been determined, the concentrated forces can be represented by the unit
impulse function

\(<x-a>^1\)

Which is defined as 0 when \(x<a\), \(\infty\) when \(x=a\), and 0 when \(x>a\).

The singularity functions for the x direction were written as thus:

Loading (q)

\[-F_{obj} \cos(\alpha)<x-d>^1 + R_{xc}<x-c>^1 - P<x-b>^1 + R_{xp}<x-0>^1\]

Shear (V)

(Integrated from ‘q’ function)

\[-F_{obj} \cos(\alpha)<x-d>^0 + R_{xc}<x-c>^0 - P<x-b>^0 + R_{xp}<x-0>^0 + C_1\]

Moment (M)

(Integrated from ‘V’ function)

\[-F_{obj} \cos(\alpha)<x-d>^1 + R_{xc}<x-c>^1 - P<x-b>^1 + R_{xp}<x-0>^1 + C_1 x + C_2\]

The equations for the shear and moment are then graphed, Figure 25, resulting in the following graphs,
respectively\(^2\):

\(^2\) Refer to Appendix B: Section 2 for the detailed Mathcad calculations
According to the graphs, the maximum shear force is approximately -90.5lb, at length “d”. The maximum moment in the ‘x’ is approximately -634 lb*in at the value ‘L’.

The y and z planes follow the same procedure in determining the shear and moment diagrams, and can be viewed in greater detail in Appendix B: Section 2. The y and z diagrams are shown below in Figure 26 and Figure 27, respectively.
The shear diagram for the Y forces indicates no shear and zero for the maximum moment.

The graphs indicate that the maximum shear force and moment are \( V(0)=4 \text{ lbs} \) and \( M(L)=33.24 \text{ lb*in} \). Therefore, when the grabber picks up an 8 pound object, it will experience a maximum ‘z’ moment of 33.2 lb*in about the x-axis. This moment can be assumed to be the overall ‘z’ moment experienced by the entire grab-bot.

7.2 Threaded Rod Configuration

From our calculated forces, a power screw will be needed to transmit the appropriate amount of torque from the motor to the grippers.

One criterion considered when choosing a thread size was the minimum required pitch diameter of 0.049in, since the thread is pinned on both its ends, and acts similar to an Euler column. A standard 3/8-16 coarse square thread is a good choice since the grippers do not require large axial loads on the threaded rod, and is above the required minimum pitch diameter. The rod is made of AISI 1050 steel and will have a single lead with yield strength of 117ksi, and non-lubricated threads, producing a
coefficient of friction of 0.30. The thread will have an axial load that is the value of the “x” reaction force in the cylindrical pin, 37.6lb. Refer to Appendix B: Section 3 for full thread calculations.

A clockwise torque of approximately 2.53lb*in is required for the thread to move the load upward along its threads and 1.7lb*in to move down along the threads. The threads are self-locking since the coefficient of friction is greater than the product of the lead angle divided by pitch diameter and pi. The screw has an efficiency of 0.149, and a stripping area factor of safety of 2590, which is a sufficient indication of a strip-free thread.

7.2.1 Motor Requirements

An appropriate motor that will provide enough torque to transmit to the threaded rod is necessary. The motor needed to meet several requirements. It needed to output at least 2.6 lb*in of torque and 120rpm. The RPM calculations are as follows:

Ratio (grabber radius/thread radius) = 8”/2.5”=3.2
For a 3/8-16 thread:
Pitch= .0625”
For every turn of the rod, it closes the grabbers:
.0625” x 3.2 (ratio) = 0.2”/rev
For a max 8” open span or 4” on either side,
4”/0.2” = 20 revolutions to fully open grabbers
For a 10s opening/closing time
(20 rev/10s)(60s/1 min) = 120 rev/min

Since a coarse thread for the rod is being used with 16 threads per inch, the grippers need to open and close a distance of 8 inches to their optimal positions within 10 seconds. Essentially, one gripper needs to translate 4 inches across the threaded rod within 10 seconds. With a motor that runs 120rpm, it will turn the thread and translate the grippers 8 inches in 10 seconds.
7.3 Grabber Arm

The grabber arm originally was designed to be a straight rectangular piece with the user holding onto a protruding hand grip. This type of configuration calls for greater grip force on the user’s part, and may present further difficulties in the long run. Therefore, the grabber arm shape was changed to a ‘z’ like shape, as seen in Figure 28.

The raised part serves as the handgrip for the user and the forearm holder cups the user’s forearm into place. A major advantage of this arm shape is when the user actually picks up an object via the gripper assembly. The weight of the object will create a downward moment but the shape will allow the user’s arm to create a counter moment from the forearm to balance the weight.
When the grippers experience a moment of approximately 33 lb*in about the x axis, as seen in Figure 29, from the retrieved 8 pound object, the opposite end of the grabber arm, containing the forearm holder, experiences the same moment, acting as class 1 lever. The forearm holder then has a distributed load from the user’s forearm, thus keeping it in place. The resultant of the distributed load on the forearm is 16.3lb and the force of the hand is approximately 81.6 lb. See Appendix B, section 4 for detailed calculations.

7.4 Controls Assembly
Since the preliminary design that contained two touch sensors to indicate “on” and “off” was the final choice, a few changes were made in terms of type of controls and placement on the grabber arm. Similar to the “on” and “off” idea, a momentary rocker switch, Figure 30, would be used that would turn the motor one direction when pressed on one end of the
wedge, stop when the user relieves pressure on the switch, and turn the motor in the opposite direction when the opposite wedge on the switch is pressed. In terms of the ergonomics, the user’s fingers are already gripping the “hand grip” of the arm assembly, and putting a switch that is easily accessible with their index finger as opposed to their thumb requires less hand movement.

7.5 Entire Grab-Bot Assembly

Combining all the preliminary design choices for the gripper, arm, and controls assembly, the entire assembly looks similar to Figure 31.

Several changes were made to the motor, gear, and battery placement. Starting with the gear placement, in order to avoid alignment issues, a pulley and a toothed belt were implemented. A motor was placed inside the arm that can turn one pulley along its shaft and the torque is transmitted via the toothed belt to the other pulley attached to the threaded rod in the grabber assembly. In order to evenly distribute the weight of the entire Grab-bot, especially while picking up an item, the motor was placed towards the center of the device and the battery pack inside the arm assembly under the forearm holder.
8.0 Detailed Analysis of Final Design

8.1 Grabber Stress Analysis

Since the grabber will experience bending in the z direction, stress analysis for bending was conducted in that direction. The grabber was given several specifications. The grabber will be made of aluminum with the maximum moment taken from Figure 27, which is 33.2lb*in with no concentration factors and torsion is negligible. The bending stress is 31.4 lb/in\(^2\) and the maximum shear stress, taking into account the maximum shear from Figure 27, is 2.51lb/in\(^2\). Since the stresses are uniaxial and only in the “z”, the principal stress and the Von Mises effective stress is 31.4 lb/in\(^2\). The principal shear stress is 15.7lb/in\(^2\). Please refer to Appendix B: Section 5 for a more detailed stress analysis.

8.2 Grabber Assembly Fatigue Analysis

As a safety measure, the grabber assembly fatigue analysis was performed\(^3\). Under the conditions that the grabbers are machined finished, operating at room temperature with 99.9% reliability, correction factors were calculated to determine the modified endurance strength, which is 9820lb/in\(^2\). This, along with the Von Mises stress calculated in stress analysis, produces a safety factor of 312, a good indication that fatigue will have little effect on the grabber assembly.

---

\(^3\) Refer to Appendix A: Section 6 for detailed Mathcad Calculations
9.0 Manufacturing

9.1 Commercially Available Parts

Many of the parts needed for the Grab-bot are available through various vendors used by WPI, in particular McMaster-Carr and Jameco. Below is a list of the materials used to construct the Grab-bot.

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Size</th>
<th>Qty</th>
<th>Source</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reversible Gear Head Motor</td>
<td>1.5&quot; D 1.7&quot; L</td>
<td>1</td>
<td>Jameco</td>
<td>$18.95</td>
</tr>
<tr>
<td>DPDT (on)-off-(on) Rocker Switch</td>
<td>1.26&quot;x.78&quot;</td>
<td>1</td>
<td>McMaster</td>
<td>$19.00</td>
</tr>
<tr>
<td>Basic Snap Limiting Switch</td>
<td>.78&quot;x.25&quot;x.4&quot;</td>
<td>4</td>
<td>Jameco</td>
<td>$6.36</td>
</tr>
<tr>
<td>Small PC mount Relay switch</td>
<td>.50x.30x.40</td>
<td>1</td>
<td>Jameco</td>
<td>$2.29</td>
</tr>
<tr>
<td>Battery mount</td>
<td>for 4 AA's</td>
<td>1</td>
<td>McMaster</td>
<td>$1.62</td>
</tr>
<tr>
<td>AA Batteries</td>
<td></td>
<td>4</td>
<td></td>
<td>$8.00</td>
</tr>
<tr>
<td>3/8&quot;-16 LH and RH Threaded Rod</td>
<td>6&quot;</td>
<td>1</td>
<td>McMaster</td>
<td>$1.56</td>
</tr>
<tr>
<td>Clevis with cotter pin</td>
<td>1/2&quot;D 1.25&quot; L</td>
<td>1pk/5</td>
<td>McMaster</td>
<td>$5.70</td>
</tr>
<tr>
<td>Clevis with retaining ring</td>
<td>1/2&quot;D 1.5&quot;L</td>
<td>4</td>
<td>McMaster</td>
<td>$17.12</td>
</tr>
<tr>
<td>Nylon washer</td>
<td>for 1/2&quot; screw</td>
<td>1pk/5</td>
<td>McMaster</td>
<td>$2.08</td>
</tr>
<tr>
<td>Set Screws</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Piano hinge</td>
<td>1' long with holes</td>
<td>1</td>
<td>McMaster</td>
<td>$3.99</td>
</tr>
<tr>
<td>Timing Belt (250 teeth)</td>
<td>20&quot; long 1/4&quot; W .08&quot; pitch</td>
<td>1</td>
<td>McMaster</td>
<td>$4.91</td>
</tr>
<tr>
<td>Pulley</td>
<td>3/8&quot; bore, 3.8&quot; diameter 1&quot;W</td>
<td>2</td>
<td>McMaster</td>
<td>$66.66</td>
</tr>
<tr>
<td>Sheet of 1/16&quot; thick PC plastic</td>
<td>24&quot;x48&quot;</td>
<td>1</td>
<td>McMaster</td>
<td>$20.85</td>
</tr>
<tr>
<td>Sheet of 3/4&quot; thick aluminum</td>
<td>12&quot;x12&quot;</td>
<td>1</td>
<td>McMaster</td>
<td>$55.88</td>
</tr>
<tr>
<td>Metal shaft for motor</td>
<td>.5&quot; D 1.5&quot; L</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>$234.97</td>
</tr>
</tbody>
</table>

9.2 Detailed Part Descriptions of Selected Items

The materials selection process for the Grab-bot is critical in the manufacturing stage of this project. The materials determine whether or not the device is cost effective as well as durable and long
lasting in the applications described in the design specifications. The following materials were chosen for their contributions to these aspects.

**9.2.1 Reversible DC Gear Head Motors**

We selected a geared DC motor among others because of its reversibility, compact size, variable torque range, and lower rpm than most other DC motors. The target range from analysis was about 2.5 lb-in of torque and about 110 rpm depending on thread size used. The gear head motor was an ideal selection, as it would eliminate the need to reduce the speed of the motor by means of gear reduction. The gearing is included in this motor and reduces the speed to a more practical value for this application. The particular motor that we chose is from Jameco and has an output torque of 3200 g-cm (2.56 lb-in) and 60 rpm. Although this motor does not meet the ideal RPM, it will still output the appropriate amount of torque to turn the threaded rod for the grippers; in any case, the grippers will turn at double the time specified (i.e. 20 seconds) instead of the goal of 10 seconds.

**9.2.2 Panel Mount Rocker Switch**

Rocker switches work well both ergonomically and in terms of user interface as well as safety. The “double pole double throw” rocker switch works in a way that if the user lets go of the switch it returns to the center and the motor stops turning and the grabbers stay in position. One position of the switch will open the grabbers and the opposite position will close them. The “on-off-on” configuration allows current to run through when it is ON and has infinite resistance in the OFF position. The switch will be positioned in the handle directly under the fingers for easy access while in use.

**9.2.4 Pulley system**

A timing belt will be used to transmit the power from the motor down the shaft to the pulley affixed to the threaded rod in the grabber sub-assembly. When the motor turns, it will turn a shaft attached to a pulley wheel. The benefit of using a timing or toothed belt is that the teeth ensure
minimal slipping on the wheel while it turns. Directly down the shaft a second same size pulley (with a 1:1 ratio) will be affixed to the threaded rod. Rotation of the rod, depending on direction, will either close the grippers or open the grippers.

9.2.5 Threaded Rod

The 3/8-16 threaded rod indicates a 3/8” diameter with 16 threads per inch. It is crucial that one side of this rod is a left-handed thread and the other side is a right-handed thread. McMaster-Carr makes a 6” rod with 1” on each of the ends left- and right-hand threaded. One inch of threads on each side will not provide enough revolutions to completely close the grippers; therefore it was necessary to continue the threads to the center of the rod.

9.2.6 6061 Aluminum

This type of aluminum was chosen for the skeleton of the gripping claws. This alloy is precipitation hardened and it is mainly alloyed with magnesium and silicon. It has good mechanical properties and is known for being easy to weld, as well as other machining tasks such as drilling and threading. This alloy has approximately 36 kpsi as its ultimate tensile strength and a density of about .98 lb/in³. The Young’s modulus of aluminum is about 10x10⁶ psi. Common uses of this alloy are in aircraft, car, and boat manufacture. We chose this particular alloy because it is lightweight and cost-effective and its machining capabilities will make prototype manufacture run smoothly.

9.2.7 Lexan Plastic

Lexan is a polycarbonate plastic that has high strength capacities but is easy to mold. The flexibility of this material will make it possible to shape both the shaft in a U and L shape for the bottom and top, respectively, and the arm holder. The two-piece shaft with piano hinge will allow the top to be opened on the shaft from the motor to the grabbers for easy access and disassembly if necessary. When bent, the material still retains exceptional strength, which is critical to the success of the grabber.
9.3 Manufactured Parts

Some of the parts for the Grab-bot are custom made in order to manufacture our design. The actual grabbers needed to be machined from a sheet of aluminum stock about ¾” thick. Additionally, the two clevis pins used to hold the threaded rod in the grabber arms needed to be adjusted to have a threaded hole through the middle. The overall shaft was heated and bent from stock plastic to hold the Z shape it needs to have. The arm saddle was also heated and curved to fit the shape of a forearm. The handle had a square hole cut out for the switch as well. Lastly, the pulleys used to transmit the power from the motor to the threaded rod were custom machined to fit the dimensions of our rod and motor shaft on either end.

9.3.1 Assembly Process/Procedures

The procedure to assemble the Grab-bot is crucial as many parts’ manufacture depend on the dimensions of other parts. The insides of the shaft (motor, pulley, batteries, switch, etc.) dictate its dimensions. The length of the shaft will be adjusted to be able to fit and tension the pulley inside. The order of assembly started from the inside out. Once the motor and pulley subassembly were in working order the exact length and width of the shaft could be assigned and the plastic could be bent to fit around it. All the electrical components could be put into place inside the shaft. From this, the housing for the grabbers was constructed, as this must fit like a sleeve into the shaft and be pinned in place.

The grippers were then be machined to fit within the housing. The threaded rod had to be fully threaded as it only came with left and right hand threads an inch into each side. The threaded clevis pins were then be turned onto the rod, and put into place in the pre-cut holes in the grabber arms. The pins stay in place with a retaining ring. Once these sections are built, the arm attachment assembly of a Velcro strap and plastic arm piece can be affixed to the end of the grabber with glue.

Below is a general schedule of how the grab-bot was assembled:
1) Assemble motor and pulley assembly

   - Affix motor shaft to larger metal rod, attach pulley wheel

2) Thread rod until threads meet in center. Affix other end of pulley to rod.

3) Tap clevis pins and thread onto rod

4) Machine grippers from aluminum sheet

5) Tap holes in grabbers for end pins and pins for the rod

6) Attach rod via the pins in the grabber

7) Mold gripper housing as well as overall shaft from plastic

8) Cut holes in shaft where needed for pins, switch, batteries, etc.

9) Assemble electrical components, mount the motor, battery pack and switch

10) Construct arm saddle and Velcro assembly, attach to shaft

11) Assemble grabber housing inside shaft, attach grabbers

12) Align pulley

The finished prototype is pictured in Figure 32.

Figure 32: Finished Prototype of the Grab-bot
9.3.2 Redesign

The Grab-bot weighs 2.6 lbs., 32% of which is attributed to the aluminum grippers. This presents a concern since the load can fatigue users, especially the elderly and those with little physical strength in their arms. Therefore, a lighter material like nylon can be used to decrease the gripper weight and thus the force of the forearm and hand. Taking into account solely the grippers without an object, the following values were calculated in Table 9.

<table>
<thead>
<tr>
<th>Gripper Material</th>
<th>Weight of Grippers</th>
<th>Moment about X-axis</th>
<th>Force of the Forearm</th>
<th>Force exerted by the Hand</th>
</tr>
</thead>
<tbody>
<tr>
<td>6061 Aluminum T6 (Original Material)</td>
<td>0.84 lbs</td>
<td>3.49 lb*in</td>
<td>1.72 lbs</td>
<td>8.56 lbs</td>
</tr>
<tr>
<td>Nylon 101</td>
<td>0.34 lbs</td>
<td>1.41 lb*in</td>
<td>0.70 lbs</td>
<td>3.50 lbs</td>
</tr>
</tbody>
</table>

Table 9: Gripper Material Comparison

Observing the results from the table, grippers made with Nylon 101 are 60% lighter than the original 6061 aluminum, and as a result the forces required by both the forearm and hand are reduced by that percentage. Once the substitution between aluminum and nylon was made, the entire Grab-bot weighed approximately 2.11 lbs., with the gripper weights contributing only 16%.
10 Testing of Final Design

Once the final adjustments and nylon gripper substitution was made, the device was tested. In order to effectively test the grab-bot and compile data for analysis, we had several participants from 3 age brackets use the grab-bot. The target age groups are 20-40, 40-60, and 60-90 with 4-5 people from each group. In order to effectively test the Grab-bot and compile data for analysis, we created a test and questionnaire for volunteers to complete. We tested 14 participants from age 19 to age 87. The average age of our participants was 44.5 years; 9 of the participants were male and 5 female.

The participants were given an informed consent form and short questionnaire (below), both approved by the WPI Institutional Review Board, with clear instructions before beginning the test (SEE APPENDIX C FOR INFORMED CONSENT FORM). The test took an average of about 5-15 minutes depending on the participant.

Survey for Testing of Major Qualifying Project (MQP): The Grab-bot

Department of Mechanical Engineering

Students: Meaghan Busteed  mbusteed@wpi.edu
Amanda Rinaldi  Amanda_rita88@wpi.edu

Participant Number_______________________
Participant Age____________
Participant Gender ______________
Date_____________
Thank you for taking the time to participate in the testing of our device. To maintain consistency among participants we ask that you perform the following tasks:

1) Please attach the device to your arm by adjusting the arm strap to fit tightly around your forearm.
2) There will be 9 objects in varying locations provided for you to pick up and place as close to your body as possible using the open/close switch on the handle:
   a. Light objects
      i. Scissors on the floor
      ii. Box of tissues on a table
      iii. Toilet paper on a shelf
   b. Medium-weight objects
      i. Keys on the floor
      ii. Apple on a table
      iii. Can of soda on a shelf
   c. Heavier Objects
      i. Coat on the floor
      ii. Candle on the table
      iii. Cleaner on a shelf
3) Once the above steps have been completed, please remove the Grab-bot from your arm and complete the following questions.

**Questionnaire**

Part I. Please rate on a scale from 1-10:

1) How intuitive was:
   a. Attaching the Grab-bot to your arm?
      (1=not at all, 10=very intuitive) __________
   b. Operating (opening/closing) the Grab-bot?
      (1=not at all, 10=very intuitive) __________
   c. Picking up and placing objects?
      (1=not at all, 10=very intuitive) __________

2) How comfortable did you feel:
a. Wearing the Grab-bot without picking up any objects? (1=uncomfortable, 10=very comfortable) __________

b. Wearing the Grab-bot while picking and placing objects?
   (1=uncomfortable, 10= very comfortable) __________

3) How effective was the device in picking and placing the following objects:
   (1=was not successfully picked up, 10= successfully picked and placed)

   a. Light objects
      i. Scissors on the floor ______
      ii. Box of tissues on a table ______
      iii. Toilet paper on a shelf _____

   b. Medium-weight objects
      i. Keys on the floor ______
      ii. Apple on a table ______
      iii. Can of soda on a shelf ______

   c. Heavier Objects
      i. Coat on the floor ______
      ii. Candle on the table ______
      iii. Cleaner on a shelf ______

Part II: Please answer the following short-response questions:

4) What specific tasks or objects would you personally use the Grab-bot for?
   __________________________________________________________________________
   __________________________________________________________________________
   __________________________________________________________________________

5) What, if any, suggestions would you make to improve the quality of the Grab-bot?
   __________________________________________________________________________
   __________________________________________________________________________
   __________________________________________________________________________

6) If the device were improved according to your suggestions, would you purchase the Grab-bot?
   Why or why not?
   __________________________________________________________________________
7) What would be the maximum price you would consider paying for such a device?
$___________________

The results were compiled with the following average scores:

![Intuitiveness Bar Chart]

*Figure 34: Intuitiveness Survey Results*

In terms of intuitiveness, the Grab-bot scored well with average scores of 9, 8.8, and 8.5, shown in Figure 34, for the three categories. This is most likely due to the simplicity of the circuit with a simple open/close switch that actuates the motion and simple Velcro strap to secure the arm.
In the category of comfort, shown in Figure 35, the Grab-bot scored slightly lower averages of 7.8 for comfort while wearing the device without picking up an object and 7.4 for wearing the device while picking up objects. The score was slightly lower as many users commented on the heavy weight, which affected their comfort level while using the grab-bot. Some users expressed discomfort during long-term use as the arm can become strained.
All objects used in effectiveness testing scored well, shown in Figure 36, with the lowest average score of 7.4 for the scissors and the highest average score of 9.6 for the box of tissues. This shows that it is harder to pick up smaller objects and easiest to pick up larger objects with a more defined shape. The cleaner was also difficult for users to pick up as it was only half full so the center of mass was not at the geometric center of the object.

Figure 36: Effectiveness Survey Results
When asked the maximum price the participants would pay for the Grab-bot, the results, shown in Figure 37, showed a slight increasing trend in price with respect to age with an outlier for a 68 year old participant at $500. Within the younger participants the price they would pay varied from $20 to $100. Within the older participants the price they would pay varied from $15 to $500. This could also be correlated to the fact that 36% of the users, primarily between the ages of 20 to 40, did not see an immediate need for the Grab-bot; however, the rest of the users, primarily those between the ages of 40-90 did see a need for the device, and verified they would indeed use the Grab-bot for their daily activities.

Responses varied for the personal uses the participants would apply the Grab-bot to in their everyday life. Many of the participants (57%) mentioned generally reaching objects that are on high shelves or slightly out of their reach. Some testers specified particular places or applications the Grab-bot would be of use to them, such as in a garage or warehouse.
Another interesting result was that 57% of the users suggested that the Grab-bot body be streamlined to reduce bulkiness. Another 21% recommended changing the orientation of the switch to be horizontally aligned, as opposed to its vertical position, as it requires less thumb movement.
11 Conclusion

Our team successfully designed and developed a means for a person with disabilities to reach, grasp, and move an object they may have not been able to reach without an assistive device. The Grab-bot stands apart from other grabbing devices on the market with its electrical controls that relieve some of the physical stresses presented by its mechanical predecessors. Based on the ratings received during the testing portion of the project, the device is highly effective in picking up lightweight objects up to 2 pounds. The Grab-bot’s simple design and high functionality make it attractive and usable to anyone who has the ability to activate the switch on and off.

The highest priority in designing the device was safety, and several safety features were implemented into the prototype such as its locking grip and Velcro arm strap. The device is easy to use and has many useful workplace applications. For those with limited mobility, the Grab-bot extends the user’s reach by 2 feet in all directions, allowing them to reach objects across a desk, on a bookshelf, or on the floor. The Grab-bot should not present a challenge to users having difficulty targeting or with poor motor skills since the gripping claws open to a 6” wide span to adjust to many objects with a simple “open/close” switch. Specific instances in which an employee with disabilities can benefit from using the Grab-bot are turning on/off light switches, opening/closing a high file cabinet, stocking items on a shelf, hanging coats, retrieving pens/pencils from the floor, picking up small packages, and retrieving books.

Aside from practical applications, the Grab-bot can restore a sense of independence and empowerment to the employee. Instead of asking a co-worker to grab a file from the top shelf
the user can obtain the file without asking for help, thus saving time for everyone involved and increasing productivity.
Works Cited


Appendix A:

1.0 Preliminary Design Ranking Tables

Table 10: Rank Ordering Grabber Assembly

<table>
<thead>
<tr>
<th>Total</th>
<th>Functionality</th>
<th>Aesthetic</th>
<th>Cost</th>
<th>Life Span</th>
<th>Reliability</th>
<th>Locking Mechanism</th>
<th>Manufacturability</th>
<th>Weight</th>
<th>Object Selection Variety</th>
<th>Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.75</td>
<td>0.65</td>
<td>0.45</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Table 1: Rank Ordering Controls Assembly

<table>
<thead>
<tr>
<th></th>
<th>User Interface</th>
<th>Ergonomics</th>
<th>Weight</th>
<th>Manufacturability</th>
<th>Stability</th>
<th>Cost</th>
<th>Reliability</th>
<th>Aesthetics</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>User Interface</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Ergonomics</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Weight</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Manufacturability</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Stability</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Cost</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Reliability</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Safety</td>
<td>Ergonomic</td>
<td>Weight</td>
<td>Manufacturability</td>
<td>Stability</td>
<td>Cost</td>
<td>Ease of Use</td>
<td>Aesthetics</td>
<td>Total</td>
</tr>
<tr>
<td>--------</td>
<td>--------</td>
<td>-----------</td>
<td>--------</td>
<td>-------------------</td>
<td>-----------</td>
<td>------</td>
<td>-------------</td>
<td>------------</td>
<td>-------</td>
</tr>
<tr>
<td>Safety</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>½</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Ergonomic</td>
<td>0</td>
<td></td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>½</td>
<td>1</td>
<td>4.5</td>
</tr>
<tr>
<td>Weight</td>
<td>½</td>
<td>0</td>
<td></td>
<td>1</td>
<td>½</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Manufacturability</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Stability</td>
<td>½</td>
<td>1</td>
<td>½</td>
<td>1</td>
<td>1</td>
<td>½</td>
<td>1</td>
<td>1</td>
<td>5.5</td>
</tr>
<tr>
<td>Cost</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>½</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>0</td>
<td>½</td>
<td>1</td>
<td>1</td>
<td>½</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>½</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>GOALS</td>
<td>Functionality</td>
<td>Safety</td>
<td>Locking Mechanism</td>
<td>Object Selection Variability</td>
<td>Reliability</td>
<td>Weight</td>
<td>Life Span</td>
<td>Manufacturability</td>
<td>Cost</td>
</tr>
<tr>
<td>-------</td>
<td>---------------</td>
<td>--------</td>
<td>-------------------</td>
<td>-----------------------------</td>
<td>-------------</td>
<td>--------</td>
<td>----------</td>
<td>-------------------</td>
<td>------</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>90</td>
<td>85</td>
<td>70</td>
<td>65</td>
<td>65</td>
<td>55</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>GOALS</td>
<td>User Interface</td>
<td>Ergonomics</td>
<td>Weight</td>
<td>Stability</td>
<td>Cost</td>
<td>Reliability</td>
<td>Manufacturability</td>
<td>Aesthetics</td>
<td>Total</td>
</tr>
<tr>
<td>-------------</td>
<td>----------------</td>
<td>------------</td>
<td>--------</td>
<td>-----------</td>
<td>------</td>
<td>-------------</td>
<td>-------------------</td>
<td>------------</td>
<td>-------</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>85</td>
<td>70</td>
<td>75</td>
<td>40</td>
<td>60</td>
<td>50</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Preliminary</td>
<td>9/810</td>
<td>10/850</td>
<td>8/500</td>
<td>7/525</td>
<td>8/320</td>
<td>8/480</td>
<td>8/400</td>
<td>7/70</td>
<td>4015</td>
</tr>
<tr>
<td>GOALS</td>
<td>Safety</td>
<td>Stabilit</td>
<td>Ease of Use</td>
<td>Ergonomi</td>
<td>Weight</td>
<td>Manufacturabilit</td>
<td>Cost</td>
<td>Aestheti</td>
<td>Total</td>
</tr>
<tr>
<td>----------------</td>
<td>--------</td>
<td>----------</td>
<td>-------------</td>
<td>----------</td>
<td>--------</td>
<td>------------------</td>
<td>------</td>
<td>----------</td>
<td>--------</td>
</tr>
<tr>
<td>y</td>
<td>0.00</td>
<td>0.95</td>
<td>0.70</td>
<td>0.65</td>
<td>0.50</td>
<td>0.50</td>
<td>0.35</td>
<td>0.10</td>
<td>2.965</td>
</tr>
<tr>
<td>y</td>
<td>0.00</td>
<td>0.95</td>
<td>0.70</td>
<td>0.65</td>
<td>0.50</td>
<td>0.50</td>
<td>0.35</td>
<td>0.10</td>
<td>2.965</td>
</tr>
<tr>
<td>Priend</td>
<td>0.00</td>
<td>0.95</td>
<td>0.70</td>
<td>0.65</td>
<td>0.50</td>
<td>0.50</td>
<td>0.35</td>
<td>0.10</td>
<td>2.965</td>
</tr>
<tr>
<td>Preli m11</td>
<td>0.00</td>
<td>0.95</td>
<td>0.70</td>
<td>0.65</td>
<td>0.50</td>
<td>0.50</td>
<td>0.35</td>
<td>0.10</td>
<td>2.965</td>
</tr>
<tr>
<td>Preli m12</td>
<td>0.00</td>
<td>0.95</td>
<td>0.70</td>
<td>0.65</td>
<td>0.50</td>
<td>0.50</td>
<td>0.35</td>
<td>0.10</td>
<td>2.965</td>
</tr>
</tbody>
</table>
Appendix B: Grabber Analysis

1.0 Alpha Calculations

\[ F_{obj} = 83 \text{lb} \quad L_{oc} = 8.31 \text{in} \]

\[ N = 0.225 \text{lb} \quad d = 7.35 \text{in} \quad c = 1.533 \text{in} \]

**range of alpha for x component**

\[ \alpha = (0 \text{deg}, 360 \text{deg}) \]

\[ W(\alpha) = F_{obj} \cos(\alpha) \]

**range of Alpha**

- \( W(0 \text{deg}) = 8 \text{ lb} \)
- \( W(170 \text{deg}) = -7.878 \text{ lb} \)
- \( W(175 \text{deg}) = -7.991 \text{ lb} \)
- \( W(180 \text{deg}) = -8 \text{ lb} \)
- \( W(181 \text{deg}) = -7.999 \text{ lb} \)
- \( W(360 \text{deg}) = 8 \text{ lb} \)
$F_{\text{obj}} = 8\text{lb}$  
$L_x = 8.3\text{lin}$

$N = 0.225\text{lb}$  
$d = 7.196\text{in}$  
$c = 1.533\text{in}$

**range of alpha for y component**

$\alpha = (0\text{deg}, 360\text{deg})$

$\frac{W(\alpha)}{lb} = F_{\text{obj}} \sin(\alpha)$

**range of Alpha**

$W(0\text{deg}) = 0.1\text{lb}$

$W(100\text{deg}) = 7.878\text{lb}$

$W(130\text{deg}) = 0.1\text{lb}$

$W(280\text{deg}) = -7.878\text{lb}$

For the worst case scenario, use alpha =180 from the x component, since it produces a force of 8lb
2.0 Singularity Functions of Grabber Assembly

\( x \) force

\( \alpha := 180 \text{deg} \)

Given

\[-R_{xp} + F_{xc} - F_{obj} \cos(\alpha) = 0\]

\[-R_{xp} + R_{xc} = 7.378 \text{lb}\]

\[M_x = -R_{xc} c + F_{obj} \cos(\alpha) \cdot d\]

\[R_{xc} = \frac{-1 \cdot (F_{obj} \cos(\alpha) \cdot d)}{c} = 37.553 \text{lb}\]

\[R_{xp} = 7.378 \text{lb} + F_{xc} = 44.931 \text{lb}\]

\[P := F_{xc} = 37.553 \text{lb}\]

\[q\]

\[-F_{obj} \cos(\alpha) (x - d)^{-1} + R_{xc} (x - c)^{-1} + R_{xp} (x - 0)^{-1}\]

\[V\]

\[F_{obj} \cos(\alpha) (x - d)^0 - R_{xc} (x - c)^0 - R_{xp} (x - 0)^0 + C_1\]

\[M\]

\[F_{obj} \cos(\alpha) (x - d)^1 - R_{xc} (x - c)^1 - R_{xp} (x - 0)^1 + C_1 \cdot x + C_2\]

Since the shear and moment are 0 at \( x=0 \) and \( x=L \), \( C_1 \) and \( C_2 \) thus are 0.

\( C_1 := 0 \quad C_2 := 0 \)

range of \( x \)

\( x := 0, 0.005, 0.01, \ldots, L \)

\( S(x, z) := \text{if}(x \geq z, 1, 0)\)

\[V(x) = -R_{xp} S(x, 0\text{in}) - R_{xc} S(x, c) + F_{obj} \cos(\alpha) S(x, d)\]
max shear stress

\[ V(\phi) = -90.483 \, \text{lb} \]

\[ V(\phi) = -82.483 \, \text{lb} \]

\[ M(\phi) = F_{\text{obj}} \cos(\phi) (x - d) \cdot S(x, d) - R_{xc} (x - c) \cdot S(x, c) - R_{zp} (x - 0) \cdot S(x, 0) \]

Moment, lb-in, X Forces

\[ M(\phi) = -535.98 \, \text{lb-in} \]

\[ M(\phi) = -68.878 \, \text{lb-in} \]

\[ M_{\text{max}} = M(L) = -636.778 \, \text{lb-in} \]
Y forces FBD calculations

\( C_x = 0.198 \text{in} \)
\( d_x = 0.293 \text{in} \)

\[-F_{\text{obj}} \sin(\alpha) + R_{yc} + R_{yp} = 0\]

\[M_y = F_{\text{obj}} \sin(\alpha) \cdot d - R_{yc} \cdot c\]

\[R_{yc} = \frac{(F_{\text{obj}} \sin(\alpha) \cdot d)}{c} = 1.45 \times 10^{-15} \text{lb}\]

\[R_{yp} = F_{\text{obj}} \sin(\alpha) - R_{yc} = 0.1 \text{lb}\]

\[q\]

\[-F_{\text{obj}} \sin(\alpha) \cdot (y - d)^{-1} + R_{yc} \cdot (y - c)^{-1} + R_{yp} \cdot (y - 0)^{-1}\]

\[v\]

\[F_{\text{obj}} \sin(\alpha) \cdot (y - d)^0 - R_{yc} \cdot (y - c)^0 - R_{yp} \cdot (y - 0)^0 + C_1\]

\[M\]

\[F_{\text{obj}} \sin(\alpha) \cdot (y - d)^1 - R_{yc} \cdot (y - c)^1 - R_{yp} \cdot (y - 0)^1 + C_1 \cdot x + C_2\]

\[C_x = 0 \quad C_{\infty} = 0\]

range of \( y \)

\[y = 0 \text{in}, 0.005 \text{L..L}\]

\(S(y, \alpha) = \text{if}(y \geq 2, 1, 0)\)
\[ V(y) = F_{obj} \sin(\alpha) (y - d)^0 S(y, d) - R_{yc} (y - c)^0 S(y, c) - R_{yp} (y - 0)^0 S(y, 0in) \]

Shear Diagram, Y Forces

\[ V_{\text{max}} = V(c) = 0.1 \text{ lb} \]

\[ \frac{V(y)}{\text{lb}} \]

\[ \frac{y}{\text{in}} \]

\[ M(y) = F_{obj} \sin(\alpha) (y - d)^1 S(y, d) - R_{yc} (y - c)^1 S(y, c) - R_{yp} (y - 0)^1 S(y, 0in) \]

Moment Diagram, Y Forces

\[ M_{\text{max}} = M(c) = 0.1 \text{ lb \cdot in} \]

\[ M(d) = 0.1 \text{ lb \cdot in} \]

\[ \frac{M(y)}{\text{lb \cdot in}} \]

\[ \frac{y}{\text{in}} \]
**Z force FBD Calculations**

\[ L = 8.31\text{in} \]
\[ d = 7.196\text{in} \]
\[ s = 1.533\text{in} \]

\[ F_{\text{arm}} + F_f = 0 \]

\[ F_f = 4\text{lb} \]

\[ F_{\text{arm}} = F_f = 4\text{lb} \]

\[ q \]

\[ -F_{\text{arm}}(z - 0)^{-1} + F_f(z - L)^{-1} \]

\[ V \]

\[ F_{\text{arm}}(z - 0)^0 - F_f(z - L)^0 + C_1 \]

\[ M \]

\[ F_{\text{arm}}(z - 0)^1 - F_f(z - L)^1 + C_1 z + C_2 \]

Since the reactions have been included in the loading function, the shear and moment diagrams both close to 0 at each end of the beam, making \( C_1 = 0, C_2 = 0 \)

range of \( z \)

\[ z = 0\text{in}, 0.005\cdot L \ldots L \]

\[ S(z, z_1) = \text{if}\{z \geq z_1, 1, 0\} \]

\[ M(z) = F_{\text{arm}}(z - 0)^1 \cdot S(z, 0) - F_f(z - L)^1 \cdot S(z, L) \]

**Moment Diagram, Z force**

\[ M_{\text{max}} = M(L) = 33.24\text{lb-in} \]
\[ V(z) = F_\text{arm}(z - 0) \cdot S(z, 0) - F_F(z - L) \cdot S(z, L) \]
3.0 Threaded Rod Calculations

Threaded Rod Calculations

\[ S_{y,\text{screw}} = 117 \text{ksi} \quad E = 30 \times 10^6 \text{ psi} \]

column is pinned-pinned

\[ L_{\text{eff}} = 1 \text{in} \quad N_d = 2 \]

\[ S_{tD} = \pi \left( \frac{(2E)}{S_{y,\text{screw}}} \right) = 71.143 \]

\[ P_{cr} = \frac{A \cdot (\pi)^2 \cdot E}{(S_t)^2} \quad k_t^2 = \frac{L_{\text{eff}}}{I} = \frac{(\pi \cdot d^4)}{64} \quad A = \frac{(\pi \cdot d^2)}{4} \]

\[ P_{cr} = \frac{A \cdot (\pi)^2 \cdot E}{(S_t)^2} = N_d \cdot P \]

minimum required pitch diameter, assuming a Euler column

\[ d_p = \left[ \left( \frac{4 \cdot N_d \cdot P}{\pi \cdot S_{y,\text{screw}}} \right) + \left( 16 \cdot \frac{S_{y,\text{screw}}}{E} \right) \left( \frac{L_{\text{eff}}}{2 \cdot \pi} \right)^2 \right]^{\frac{1}{2}} = 0.049 \text{ in} \]

pitch diameter needs to be at least 0.036 in

\[ A_r = \left( \frac{\pi}{4} \right) \cdot d_p^2 = 1.883 \times 10^{-3} \text{ in}^2 \]

\[ I = \left( \frac{\pi}{64} \right) \cdot d_p^4 = 2.823 \times 10^{-7} \text{ in}^4 \]

\[ k_r = \sqrt{\frac{I}{A_r}} = 0.012 \text{ in} \]

\[ S_t = \frac{L_{\text{eff}}}{k_r} = 81.685 \quad S_t > S_{tD} \quad \text{Thus, Euler column} \]
Type: Standard coarse square thread 3/8-16

force of thread $P_{xc} = 37.553$ lb

pitch diameter $d_{pm} = 0.375$ in $\mu = 0.30$

pitch $p = 0.063$ in $\mu_c = 0$

Lead of thread $L = p = 1.6 \times 10^{-3}$ m

mean diameter of the thrust collar $d_c = 0$ in

radial angle of thread $\alpha = 0$ deg

AISI 1050 steel $S_y = 117$ ksi

$\lambda = \arctan \left( \frac{L}{\pi d_p} \right) = 3.061$ deg

Given

$F_t = N \cdot \cos(\alpha) - N \cdot \mu \cdot \cos(\lambda) = 0$

$-P + N \cdot \sin(\alpha) - N \cdot \mu \cdot \sin(\lambda) = 0$

$N = \frac{P}{\left( \sin(\alpha) - \mu \cdot \sin(\lambda) \right)} = -2.344 \times 10^3$ lb

$F_t = N \cdot \cos(\alpha) - N \cdot \mu \cdot \cos(\lambda) = -1.642 \times 10^3$ lb

$T_{ui} = \mu_c \cdot P \cdot \frac{d_c}{2} + \left[ \frac{P \cdot d_c}{2} \right] \left( \frac{\mu \cdot \pi d_p + L \cdot \cos(\alpha)}{\pi d_p \cdot \cos(\alpha) - \mu L} \right) = 2.529$ lb in

$T_d = \mu_c \cdot P \cdot \frac{d_c}{2} + \left[ \frac{P \cdot d_c}{2} \right] \left( \frac{\mu \cdot \pi d_p - L \cdot \cos(\alpha)}{\pi d_p \cdot \cos(\alpha) + \mu L} \right) = 1.708$ lb in

self locking?

$\mu \geq \frac{L \cdot \cos(\alpha)}{\pi d_p}$

$\mu = 0.3$

$\frac{L \cdot \cos(\alpha)}{\pi d_p} = 0.013$ yes
\[ W_{in} = 2\pi T_u = 15.893 \text{ lb-in} \]

\[ W_{out} = P \cdot L = 2.366 \text{ lb-in} \]

screw efficiency
\[
\eta = \frac{(1 - \mu \tan(\lambda))}{(1 + \mu \cot(\lambda))} = 0.149
\]

\[ D_{maj} = 0.3750 \]

\[ D_{min} = 0.2938 \quad \text{and} \quad d_r = D_{min} \]

stripping shear area for one screw thread
\[ w_o = 0.63 \]

\[ A_s = \pi \cdot d_r \cdot w_o \cdot p = 1.442 \frac{\text{in}^2}{\text{m}} \]

\[ \tau_s = \frac{|P|}{A_s} = 1.831 \times 10^4 \frac{\text{kg}}{\text{m}} \]

Factor of safety
\[ N_s = \frac{0.577 \cdot \gamma_{iy}}{\tau_s} = 2.593 \times 10^{-2} \frac{1}{\text{m}} \]

torsional stress
\[ \tau_u = \frac{(16T_u)}{\left(\pi \cdot d_r^2\right)} = 5.852 \frac{\text{m-kg}}{} \]
\[ \tau_d = \frac{(16T_d)}{\left(\pi \cdot d_r^3\right)} = 3.953 \frac{\text{m-kg}}{} \]
4.0 Arm Statics

Grabber Arm Assembly

Units

<table>
<thead>
<tr>
<th>Unit</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newton</td>
<td>N</td>
<td>1 newton</td>
</tr>
<tr>
<td>MPa</td>
<td>( \text{MPa} )</td>
<td>( 10^6 \text{Pa} )</td>
</tr>
<tr>
<td>GPa</td>
<td>( \text{GPa} )</td>
<td>( 10^9 \text{Pa} )</td>
</tr>
</tbody>
</table>

Length of Grab-bot

\( L_x := 34.79 \text{in} \)

\( S_u := 70 \text{MPa} \)

Distance to Object Weight

\( a := 23.47 \text{in} \)

\( G := 2.6 \text{GPa} \)

Distance to distributed load

\( b := 4.5 \text{in} \)

\( F_{\text{obj}} := 0.34 \text{lb} \)

Thickness

\( t := \frac{1}{8} \text{in} \)

\( h := 1.00 \text{in} \)

\( w := 2.5 \text{in} \)

\( \text{psi} := 6.9 \times 10^6 \text{GPa} \)

Applied force

\( F := 8 \text{lb} \)

\( F_{\text{obj}} := 4 \text{lb} \)

\( W_{\text{object}} := F_{\text{obj}} \)

Modulus of Elasticity

\( E := 400000 \text{psi} \)

Moment of Inertia

\( c := 0.5h = 0.5 \text{in} \)

\( M_x := 32.0 \text{lb-in} \)

\( I_z = 0.208 \text{in}^4 \)

Sum of forces in Z

\(-W_{\text{object}} + F_{\text{hand}} - F_{\text{forearm}} = 0\)

\( F_{\text{hand}} = W_{\text{object}} + F_{\text{forearm}} \cdot \epsilon \)

Sum of moments

\( M_x = -W_{\text{object}} \cdot a - F_{\text{forearm}} \cdot \frac{6 \cdot b}{2} \)

\( F_{\text{forearm}} := \frac{M_x + W_{\text{object}} \cdot a}{6 \cdot (b) \cdot 2} = 16.279 \text{lb} \)

\( F_{\text{hand}} := W_{\text{object}} + F_{\text{forearm}} \cdot \frac{(b)}{\text{in}} = 81.253 \text{lb} \)
5.0 Gripper Stress Analysis (Z Forces)

\[ N = \text{newton} \quad \text{MPa} = 1 \times 10^6 \text{ Pa} \]

\[ t = 0.75\text{in} \quad h = 2.656\text{in} \]

\[ l = 8.31\text{in} \quad w = 0.9\text{in} \quad N = 0.225\text{lb} \]

\[ \text{applied force} \quad F_x = F_y = 37.533\text{lb} \]

\[ F_{\text{max}} = 4\text{lb} \]

\[ \text{modulus of elasticity} \quad E = 68.90\text{GPa} \quad \text{aluminum} \]

From the free body diagram of the cam follower

\[ M_{\text{max}} = 33.24\text{lb}\cdot\text{in} \]

\[ q_t = 0.5\cdot h = 1.328\text{in} \]

Moment of Inertia

\[ I_z = \frac{w\cdot h^3}{12} \]

\[ I_z = 1.405\text{ in}^4 \]

Bending Stress

\[ K_t = 1 \]

\[ \sigma_{Z\Delta} = \frac{K_t \cdot M_{\text{max}} \cdot q_t}{I_z} = 31.413\text{ lb in}^2 \]

Asume torsion is negligible

Shear stress due to Transverse loading

cross section area

\[ A_x = (h \cdot w) = 2.39\text{ in}^2 \]

Maximum Shear

The highest peak in shear indicates the maximum shear value (occurs at load)

\[ V_{\text{max}} = 4\text{ lb} \]
Max Shear Stress

Rectangular Beam

\[ \tau_{\text{max}} = \frac{3}{2} \left( \frac{\psi_{\text{max}}}{A} \right) = 2.51 \frac{\text{lb}}{\text{in}^2} \]

Principle Stresses at Outer Surface (A)

Stress Components

\[ \sigma_{zA} = 31.413 \frac{\text{lb}}{\text{in}^2} \]

\[ \sigma_{zA} = 0 \frac{\text{lb}}{\text{in}^2} \]

\[ \tau_{xz} = 0 \frac{\text{lb}}{\text{in}^2} \]

\[ \sigma_1 = \frac{\left( \sigma_{zA} + \sigma_{zA} \right)}{2} + \sqrt{\left[ \frac{\left( \sigma_{zA} - \sigma_{zA} \right)}{2} \right]^2 + \tau_{xz}^2} = 31.413 \frac{\text{lb}}{\text{in}^2} \]

\[ \sigma_2 = 0 \frac{\text{lb}}{\text{in}^2} \]

\[ \sigma_3 = \frac{\left( \sigma_{zA} + \sigma_{zA} \right)}{2} - \sqrt{\left[ \frac{\left( \sigma_{zA} - \sigma_{zA} \right)}{2} \right]^2 + \tau_{xz}^2} = 0 \frac{\text{lb}}{\text{in}^2} \]

\[ \tau_{13} = \frac{(\sigma_1 - \sigma_3)}{2} = 15.707 \frac{\text{lb}}{\text{in}^2} \]

Von Mises Effective Stress

\[ \sigma_{\text{von}} = \sigma_1 = 31.413 \frac{\text{lb}}{\text{in}^2} \]
6.0 Gripper Fatigue Analysis

For Ductile Steel: \( \sigma_{max} = 10^3 \text{ psi} \)

Tensile strength \( S_{ut} = 45000 \text{ psi} = 45 \text{ ksi} \)

Shape \( \) rectangular

Surface finish \( \) surface = 'machined'

Loading \( \) load = "bending"

\( T = 72 \)

\( R = 0.999 \)

\( S_{c1} = \begin{cases} 0.4 S_{ut} & \text{if } S_{ut} \leq 45 \text{ ksi} \\ 100 \text{ ksi} & \text{otherwise} \end{cases} \)

\( S_{c1} = 18 \text{ ksi} \)

\( C_{load} = \begin{cases} 1 & \text{if load = "bending"} \\ 1 & \text{if load = "tension"} \\ 0.7 & \text{if load = "axial"} \end{cases} \)

\( C_{load} = 1 \)

\( A_{95} = A \)

\( d_{equiv} = \frac{A_{95}}{0.0766} = 0.142 \text{ in} \)

\( d = d_{equiv} \)

\( C_{size} = 0.869 \left( \frac{d_{equiv}}{\text{in}} \right)^{-0.097} \)

\( C_{size} = 0.735 \)

\( A_{\infty} = \begin{cases} 1.34 & \text{if surface = "ground"} \\ 2.70 & \text{if surface = "machined"} \\ 2.70 & \text{if surface = "cold rolled"} \\ 14.4 & \text{if surface = "hot rolled"} \\ 39.9 & \text{if surface = "forged"} \end{cases} \)

\( A_{\infty} = 2.7 \)
\[
b = \begin{cases} 
-0.085 & \text{if surface = "ground"} \\
-0.265 & \text{if surface = "machined"} \\
-0.265 & \text{if surface = "cold_rolled"} \\
-0.715 & \text{if surface = "hot_rolled"} \\
-0.995 & \text{if surface = "forged"}
\end{cases}
b = -0.265
\]

\[
C_{surf} = A \left( \frac{E}{\sqrt{\nu}} \right)^2
\]

\[
C_{surf} = 0.985
\]

\[
C_{temp} = \begin{cases} 
1 & \text{if } T \leq 840 \\
(1 - 0.0003(T - 840)) & \text{otherwise}
\end{cases} \quad C_{temp} = 1
\]

\[
C_{relab} = \begin{cases} 
1.000 & \text{if } R = 0.50 \\
0.897 & \text{if } R = 0.90 \\
0.814 & \text{if } R = 0.99 \\
0.753 & \text{if } R = 0.999 \\
0.733 & \text{if } R = 0.9999 \\
0.659 & \text{if } R = 0.99999
\end{cases} \quad C_{relab} = 0.733
\]

\[
S_f = C_{load} C_{size} C_{surf} C_{temp} C_{relab} \quad S_{f1} = 9.215 \times 10^3 \frac{N}{m^2} \quad N_w = \frac{S_f}{\sigma_{vmax}} = 312.4GPa
\]

Principal Stress at highest transverse stress (neutral axis-E)

\[
\tau_{max} = 0
\]

\[
\sigma_{SB} = 0 \text{MPa}
\]

\[
\sigma_{BY} = 0 \text{MPa}
\]

\[
\tau_{gy} = \tau_{max} - \tau_{vmax} = -2.21 \frac{N}{m^2}
\]
Appendix C: Informed Consent Form

Informed Consent Agreement for Participation in a Research Study

Investigators: Meaghan Busteed, Amanda Rinaldi

Contact Information:
Meaghan Busteed (978) 987-7597 mbusteed@wpi.edu
Amanda Rinaldi (617) 759-1314 amanda_rita88@wpi.edu

Title of Research Study: Design of the Grab-bot

Sponsor: WPI Department of Mechanical Engineering

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 test the “Grab-bot” device for comfort, functionality, effectiveness and ergonomics. The results and suggestions we receive from this study will help in making further improvements to the Grab-bot.

Procedures to be followed: The user will attach the Grab-bot to their arm and will be asked to pick up 3 objects: a 1-pound object, a 3-pound object, and a 5-pound object. After taking the grab-bot off, the participant will be asked to complete the survey on their experience.

Risks to study participants: There is a possible risk of dropping an object while using the Grab-bot or experiencing discomfort at points of attachment due to the weight of the object. You should discontinue the test if you experience substantial discomfort.
Benefits to research participants and others: None

Record keeping and confidentiality: All records will be kept confidential. A single list associating your name with a survey number will be destroyed at the end of the project on May 3, 2011. Participants will remain anonymous, as their names will not be written down at any point. 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 locked password. The two student investigators will have the only access to this 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 Grab-bot is 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- Michael J. Curley, Tel. 508-831-6919, Email: mjcurley@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: __________________

Signature of Person who explained this study