California State University Sacramento
Electrical and Computer Science Department

Senior Design II – Team 2
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Clutching Leverage Arm for Wheelchairs

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Redefine the Possible

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I. EXECUTIVE SUMMARY

Senior design is a class that is the pinnacle of one's college career. The class takes everything that is learned and creates an environment to use the tools that one has acquired along the journey. The class is just as much about design as it is about documentation. In the field of engineering if you don't have documentation to back up your ideas than you are out of luck. This document will tell the story of four young students journey through senior design. It will describe the ups and downs and will prove that The CLAW is the best solution to the societal problem that is immobility.

There are millions of Americans that have trouble getting around in life. A lot of these people are confined to wheelchairs. This makes their daily life extremely hard. Just the simple act of getting a glass of water or reaching the button on the elevator can be all but impossible. There are not many solutions that can help a large portion of these people. The cost for a disabled person to get help from in house care is extremely high and can be demeaning for the person with the disability. Additional solutions such as helping dogs are cheaper but still do not completely solve the problem.

Before we could solve the problem there had to be research performed so we could set a list of features to design to. Through many hours of searching different Internet sites and ADA guidelines we were able to come up with a list of features that our solution needed to fit in order to solve the problem. As a group we decided that a robotic arm would be able to fit into our feature set. The team wanted an arm that is able to reach out and grasp an object off a typical table. The idea is to give just a bit of freedom to the user. This will help them with moral and make their life that much easier. The list of features also includes rotation that way the user can bring the object back to them. A video camera will be used to assist the user in finding the object that they desire. The grasping claw needs to be robust. It will need to at a minimum to be able to hold a glass of water. The arm will be attached to the chair and be controlled via a remote from the user. Our design will be able to meet all of these features and it is a solution to the problem of mobility in wheelchair bound people.

The design process is a tough one. The team did not have years to research and prepare for this project. The team only was equipped with a small budget and the tools that we have learned through school. This meant that we had to set up a time line that would guide us through the year. We broke the work up between us so that the parts we worked on would emphasize our skills. Each of the team members were able to complete the parts of the project and then work on the paperwork. Our team had a tight budget, this was both helpful and hurtful at the same time. The challenge was before us but we were able to succeed.

Once a basic prototype arm was completed during the first semester the arm needed to be tested. If the arm did not pass the testing phase the project would be sunk. The arm was not meeting our test criteria in January, but the team was able to solve the issues and the arm passed testing. The next hurdle that the team faced was is this project ready for market and if so what market would it do well in. This was a time consuming and saddening report. Our arm was not ready for market, but with some redesigning the arm has a good outlook for profits. The arm is extremely cost effective. And a redesign will not increase the cost to what the current competitors are selling their product for.

The CLAW is a product of hard work and dedication given by four undergraduate students that set out to solve a problem on a small budget and very little outside help. The team was able to meet all of the features set forth to solve the problem. The project was a success and if the opportunity presents itself to the team we will be moving forward to a secondary design and prototyping phase.

C.L.A.W. - End of Term Documentation

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***Abstract*—During the term year, our team has taken a societal problem and created a design. We proposed to solve a problem that affects millions of Americans, which is the mobility impairment of a wheelchair bound individual. Seeing the fact that those confined to a wheelchair only had forward reaching capacity of 48 inches[1] at best, we wanted to created an easier way for those who had ambulatory disabilities more freedom. We saw an opportunity to design a device that could help wheelchair bound individuals have the mobility closer to that of your average adult [1].**

The design idea revolved around the following: grasping a 1 pound object, the device is to be mountable, there will be an input system for the user to control it, a video feedback system to provide more of a view, the device will extend and retract, and the device will have horizontal rotation. We settled on this design to create a device that those with very limited mobility will be able to use it without much effort.

In order to accomplish our project very strict documentation was needed. We performed a multitude of different research and assessment projects, with those projects often overlapping in type but with different purposes and scope. This was key to developing our skills as good engineers who know how to document their work as well as implement solutions.

We had initially came up with a range of $540 - $1970, but were able to accomplish the project with spending only $321.52. This was achieved by focusing on a minimalistic design that we would be able to fully implement in the given timeline with the given budget of four college students. We were able to prototype an effective solution, as well as a cost efficient solution. We used our work breakdown structure to help guide us during the entire year. This allowed us to get a warning far in advance of the tasks ahead of us and helped us better balance our work/life/school workload. As seen in the task table we manage to chalk up 551 hours amongst the team over the entire year, which is less than most other teams in the same class.

Another important part of our project was the risk assessment and mitigation plan. We used these metrics to judge what the team should effectively spend their time to to ensure the project continued marching on. The few failures we foresaw in our assessment were remedied quickly or effectively mitigated through careful planning and redundancy.

Throughout the year our team has managed to create a function device, that with further development, could lead to a real impact in those confined to a wheelchair's life. The scope of this project has been limited to just this class for now but more discussion will be had on whether to continue with the project in the future. If this team were to continue with this project then drastic changes would be made to the design, but this class has served in purpose in helping us learn how to make, document, and implement these needed changes. This has been a learning experience that will set the stage for further development and design.

***Index Terms*—robotic arm, wheelchair, mobility, design, constraints, requirements, activities of daily living, risk assessment, mitigation, impact, likelihood, failure prevention, test plan, testing results**

Elevator Pitch: *We are enabling independence for wheelchair bound individuals through means of a robotic arm.*

II. INTRODUCTION

The purpose of Senior Design is to create a project that is aimed towards solving a societal problem. For our project, we chose one of the most prevalent societal problems of all - limited mobility. Millions of Americans every year are affected by limit mobility. For some, this is as simple as aches in the bones. For others, they are completely dependant on other people for all daily activities. Our team wanted to help solve the problem of limited mobility for the millions of Americans confined to wheelchairs. Wheelchair-bound disabilities are very prevalent, so our target audience is large and comes with varying degrees of immobility.

Being self-supported college students our budget is slim. In order to help with this problem of limited mobility we needed to come up with a very specific set of features that our project would aim to implement. Initially these features were defined based on what a person who is confined to a wheelchair could benefit from most. We wanted to go about solving the entire problem for that person with limited mobility. Once we had a very large set of features, we looked at our combined budget of money and time and narrowed the feature set down to what we could accomplish.

With a set of features defined, the next step was to consider our project schedule, milestones, and a work-breakdown structure. This was a very tricky process as we had many unknowns - what features would be most difficult, cost, mechanical issues, etc are all factors that play into the amount of time a feature takes to implement. Furthermore, the skill sets of all team members varied widely. There were some features that each member of the team could have implemented easily, and then there were others than no member of the team knew how to implement. It was a requirement of the project early on to break down the work for each feature amongst team members, and because of this skill differentiation this task proved difficult. Ultimately, being forced to come up with a concise schedule, milestones, and work breakdown structure served as an excellent guide on where to focus effort on which point in time.

While moving along with the design of the project and implementing features we needed to continue our research. In the fall semester, we performed a risk assessment and mitigation project. In order to perform this we had to break down each feature into smaller sub-features and then rank all of the sub features against one another in terms of probability and impact of failure. Performing this task was complicated as we had not properly implemented some of our features just yet, let alone broken them down into sub-features. Regardless, we were able to apply a ballpark-estimate to the unknown sub-features and our assessment could continue. With all of the sub-features having an quantified probability and impact of failure we were able to identify areas where we needed to be cautious and also areas in which failure would not have a catastrophic affect on the project.

With critical research and assessments performed and a prototypical design implemented, we began creating a test plan at the start of the second semester. The goal of the test plan was to come up with a quantifiable way to gauge the success of our prototyped design. This was probably the most enjoyable step for all team members as it gave us a lot of freedom. We came up with a formalized test plan, tested the device against that criteria, saw what the test didn't need or was missing, revised the test plan, and did it all over again. This process of laying out a formal criteria for a feature to meet was crucial in helping us understand the trouble spots in our design and also the spots that didn't need attention. All criteria was backed up by the problem statement so that if we were sure our test was "successful," then we could be sure that feature was contributing to solving the problem.

From both a technical and a documentation standpoint many of the tasks the team members faced were brand new. Furthermore, we had never worked on a team that was responsible for so much content and that stayed together for so long. The dynamics we faced here proved to be very challenging in the beginning because we had to grow so much so fast and were constantly changing the way we worked. This resulted in many learning experiences for all members of the team and we believe was key to our development that can contribute to larger solutions that require much larger teams.

This paper is a comprehensive look at all of the steps undergone in our senior design journey. A lot of the intermediate steps and revisions have been omitted to give the final results of our efforts. It is a culmination of the results of all of our research, design, and testing, and should give the reader an idea of what the problem is and how we tried to solve it.

III. SOCIETAL PROBLEM

Mobility is something that most people take for granted of, such as being able to turn a light switch on, open a door or grabbing a glass of water from the counter. Able bodied people never think twice about tasks like these, but for someone in a wheelchair these mundane daily tasks are all but impossible. A Colorado State website describes the reach of a wheelchair bound person by stating that "The average reaching distance of a seated adult: side reach maximum height overhead is 54 inches and the low side reach is 9 inches above the floor" shown in Figure 1 [2]. Also, the maximum forward reach is 48 inches above the floor and it does not include reaching over an obstacle. These are best case numbers, where as there are many people with more limiting disabilities. Not being able to reach out and grab or manipulate objects can create daily problems for them. Although limited mobility and ability to reach is not limited to the wheelchair-bound community, we wanted to focus on the current accessibility options for wheelchair-bound people, different physical ailments that are reach-compromised, and why we need an engineered solution to the problem.

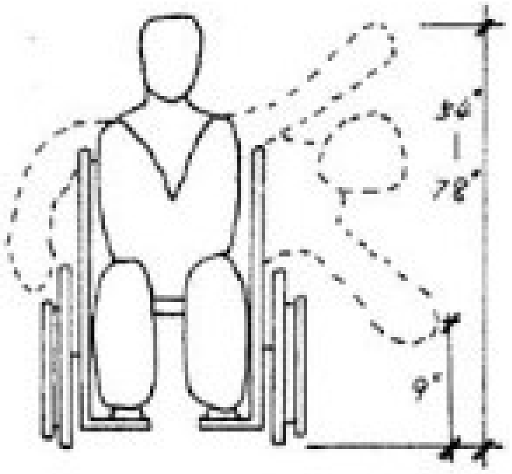


Figure 1: ADA Maximum Reach Sitting [2]

A. Brief History

The first milestone for people confined to a wheelchair was the amendment to the Fair Housing Act. The amendment reflected that multi-family homes would have to be accessible by wheelchair bound persons. This started a very big change in legislation for the disabled. The understanding of the limited mobility and accessibility of those bound to a wheelchair continued to be a focus of the public. In 1990 the Americans with Disabilities Act (ADA) became a publicly enacted law, which addressed the needs of the disabled community by prohibiting discrimination in employment, public services, public accommodations, and telecommunications. In this act there were specific requirements for those bound to a wheelchair.

B. ADA Requirements

Part of the ADA specific requirements were designated for entrances. These requirements were laid out in 1991, but amended in 2010. The original act laid out the minimum length required for a single wheelchair as 24 inches and the minimum width as 32 inches at the exit and 36 inches at the entrance shown in Figure 2 [3]. Along with basic minimum width and length, there are turning requirements. These requirements are in open space the needs to be at least 60 inches by 60 inches of clearing space for the wheelchair to maneuver. In the case of a T intersection there is a requirement of at least 36 inches down the hall, and from the wall to the exit there needs to exist at least 60 inches to shown in Figure 3 [3]. The demand of mobility is not limited to that square footage, but rather the ability to maneuver in tight spaces. As a part of these minimum requirements for entrance, there exist exceptions. Exceptions create a need that has not yet been met. For example registered historic monuments reserve exception from the entrance requirements outlined in the ADA [3]. Another

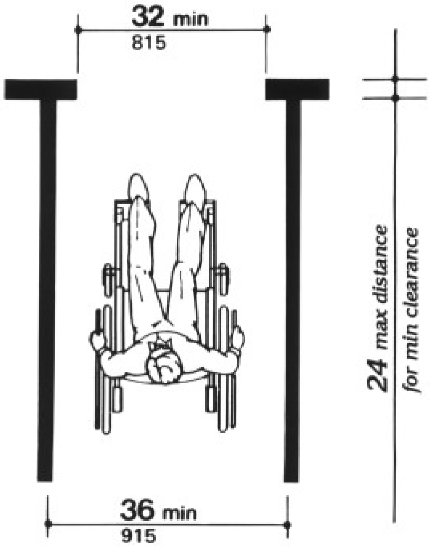


Figure 2: ADA Entrance Requirements [3]

important focus of the ADA was to keep paths accessible. The ADA set minimum requirements for ground clearance space as a clearing width of 36 in and must have a clearing route without any obstruction.

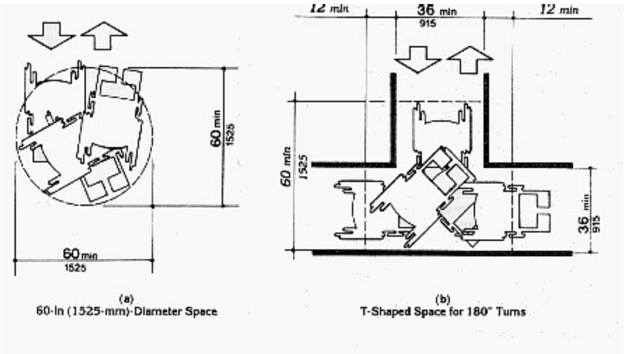


Figure 3: ADA Open Space Requirements [3]

The final portion of the ADA that will be covered is the forward and side reach requirements. The forward reach requirement has a minimum requirement of a high reach of 48 in of the cleared forward approach. Additionally, the low reach must be no lower than 15 inches Figure 4 [3]. The side requirements are defined where the individual may have a parallel approach and the maximum height would be 54 inches, and the lowest height as 9 inches. In addition to these standards the reach is also over an obstruction, the obstruction can be no lower than 34 inches, no higher than 48 inches, and cannot exceed 24 inches in depth shown in Figure 5 [3].

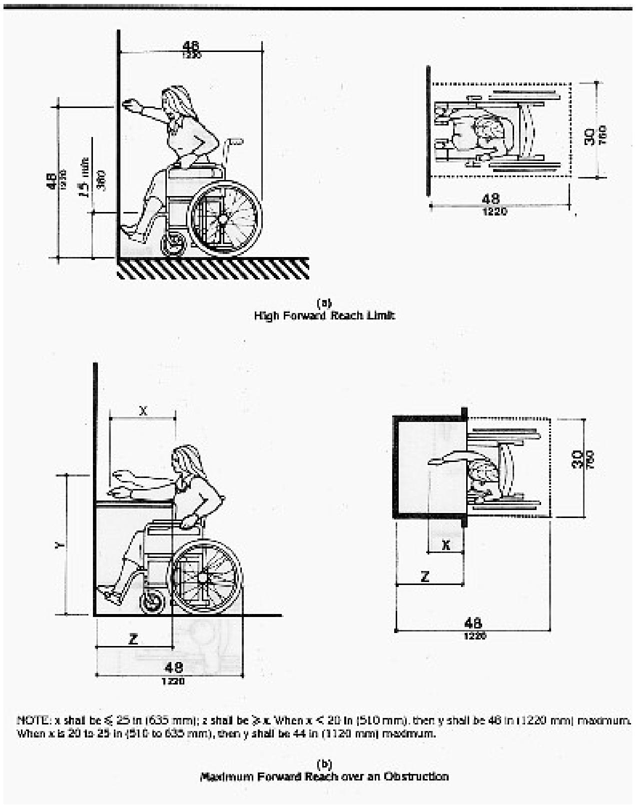


Figure 4: ADA Forward Reach Requirements [3]

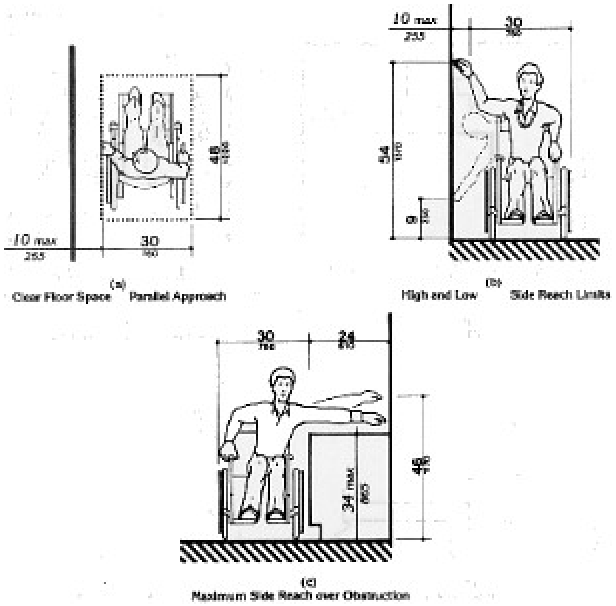


Figure 5: ADA Side Reach Requirements [3]

Even with the revision of the ADA in 2010 there still exists exceptions to the outlined requirements. As mentioned before this creates a need for something to help cope in the situations where exceptions exist. For example, registered historical landmarks have a particle set of rules for ADA compliance, which may limit a wheelchair-bound individual and potentially become a safety hazard when visiting those spots.

An important note to make is that even though the ADA has put regulations in place to aid individuals in the outside world, this does not take into account the impracticalities of everyday life, which will be discussed in a later section. In order to fully define the problem, we need to take into account how large it is.

C. Scope of the Problem

In 2010 U.S. Census Bureau data showed that approximately 3.6 million people used a wheelchair [4]. Considering that the US population was 303.9 million, that means that 1 out of every 100 American's suffers from the limited mobility that comes from a wheelchair. There are many causes of disabilities that require a wheelchair but the largest one is spinal cord injuries which can be categorized as traumatic and non-traumatic.

1) Non-Traumatic Spinal Cord Injuries: Non-traumatic spinal cord injury is a damage to the spinal cord by some disease, condition, or illness and not by a major trauma. Some of these include cerebral palsy, muscular dystrophy, and amyotrophic lateral schlerosis.

Cerebral Palsy (CP)
"The term cerebral palsy refers to any one of a number of neurological disorders that appear in infancy or early childhood and permanently affect body movement and muscle coordination but don't worsen over time. Even though cerebral palsy affects muscle movement, it is not caused by problems in the muscles or nerves, it is caused by abnormalities in parts of the brain that control muscle movements [5]. The CDC estimates that 4 out of every 1000 children born have some form of CP [6]. There are different degrees of CP and some children can have more movement than others. The CDC estimates that 30.6% of children with CP have little to no ability to walk [6]. Not being able to walk requires some sort of assistance through a wheelchair. Once confined at a wheelchair their range of movement is greatly decreased and requires some type of aid in reaching for and grabbing objects. For someone with CP being confined to a wheelchair is not the only set back they face. The ability to hold objects and manipulate them with accuracy can be very difficult. One type of CP causes muscles to be weakened, this type of CP is called hypotonia this is where muscles have lower than normal tone. A child afflicted with hypotonia CP needs assistance when holding objects. Children with CP also have impaired motor control. Normally muscle movement can occur in any joint at any time, but a child with CP cannot move a single joint without involuntarily moving another joint. CP has other conditions that have negative effects on the body like contracture and poor balance that require a wheelchair or need of some sort of assistance from a care giver [7].

Muscular Dystrophy (MD)
As stated by the Mayo Clinic "Muscular dystrophy is a group of diseases that cause progressive weakness and loss of muscle mass. In muscular dystrophy, abnormal genes (mutations) interfere with the production of proteins needed to form healthy muscle" [8]. The evolution of the disease will cause the affected person to lose the ability to walk and cause a need for a wheelchair. The most affected population is boys and MD can come on at any time in life with most cases being diagnosed at a young age between birth and teen years. The most common type of MD is Duchenne muscular dystrophy. Some of the symptoms are frequent falls, trouble running and jumping and Muscle pain and stiffness which will increase in severity overtime. Facioscapulohumeral (FSHD) is a type of MD that causes weakened upper body muscles. This makes it hard for a person to lift and hold heavier objects. This disease requires a wheelchair and assistance from others. MD greatly reduces the range and ability of the afflicted to reach/grab objects and manipulate them.

Amyotrophic Lateral Sclerosis (ALS)
ALS does not affect a large number of people but it is a debilitating disease that takes over the body of the affected person. "Amyotrophic lateral sclerosis, is a progressive neurodegenerative disease that affects nerve cells in the brain and the spinal cord" [9]. This disease almost always will require a wheelchair and some form of assistance. The most affected population is men over forty. The onset of ALS is a gradual process starting with daily tasks becoming harder to accomplish and then progressing into a much worse condition. Some of the other symptoms are dropping things, abnormal fatigue of the arms and/or legs, slurred speech, and muscle cramps [9]. ALS creates a problem for the affected because their muscles are too weak to grab and manipulate objects. ALS also restricts the range of motion of the afflicted.

2) Traumatic Spinal Injuries: The University of Iowa states "The most common cause of traumatic injury in the United States is motor vehicle accidents (MVA's). MVA's account for 44% of all spinal cord injuries [10]. Some of the results can vary from each accident but some examples are Ischemia: decreased blood flow to the spinal cord, bruising of the spinal cord, broken bones (vertebrae) and, dislocation or misaligned vertebrae. We will further examine how becoming paralyzed limits your mobility.

Quadriplegia
As with all of the diseases we have discussed there are many levels of this injury. Spinal injury network describes Quadriplegia as a "Cervical (neck) injuries usually result in four limb paralysis. This is referred to as Tetraplegia or Quadriplegia. Injuries above the C-4 level may require a ventilator or electrical implant for the person to breathe. This is because the diaphragm is controlled by spinal nerves exiting at the upper level of the neck [11]. The different levels are classed from C-1 to C-7 with C-1 being the most severe class level. Someone with a C-1 injury will, "Require assistance for all personal care, turning, and transfer functions. Head rests, troughs or a lapboard, for the upper extremities, and lifts may be necessary. Bed surfaces with two or more segments that are alternately inflated and deflated may be indicated for patients who do not have assistance for turning [11]. These people remain immobile for the rest of their lives. On the other end someone with C-7 have more mobility but daily tasks are still very difficult. Someone with C-7 classification is able to be more independent. "C-7 patients have functional triceps, they can bend and straighten their elbows, and they may also have enhanced finger extension and wrist flexion. As a result, they have enhanced grasp strength which permits enhanced transfer, mobility, and activity skills. They can turn

and perform most transfers independently. They can propel a manual wheelchair on rough terrain and slopes, and may therefore not need a powered wheelchair. They may drive with a van and specialized equipment. They can perform most daily activities, they can cook and do light housework, and therefore they may live independently. They may, however, require assistance for bowel care and bathing [11]. Although they will not require 24 hour care, they still will require a wheelchair and some form of assistance.

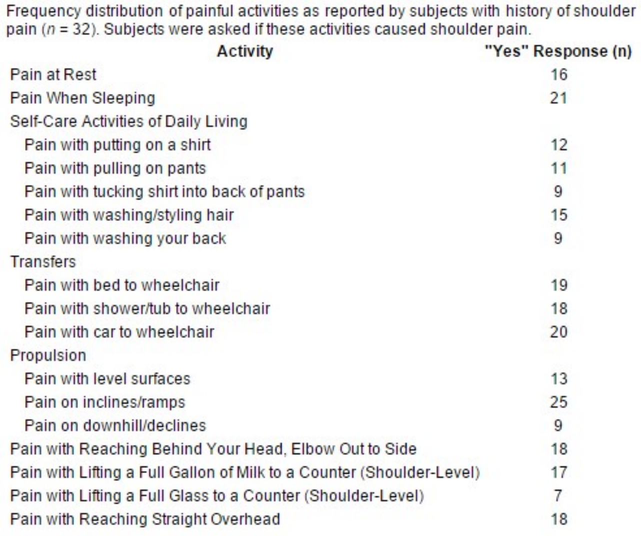
Paraplegia

"Paraplegia describes complete or incomplete paralysis affecting the legs and possibly also the trunk, but not the arms. The extent to which the trunk is affected depends on the level of spinal cord injury. Paraplegia is the result of damage to the cord at T1 and below" [12]. While some people with paraplegia don't require a wheelchair many do. Similar to Quadriplegia there is different classes of paraplegia with T-1 to T-12. These numbers are based on what part of the spine is affected. Some people maintain function over the upper body and have a range of motion similar to the numbers stated in the introduction. In more severe cases movement is more restricted. There are even some cases where a patient is able to walk again but this is rare and heavily supervised by doctors.

It is clear that most injuries that confine people to wheelchairs are not negligible in size and have serious life altering consequences. Most of the injuries listed above come with some sort of limited arm mobility as well, so while the ADA has defined minimum regulations to aid these individuals there is still no doubt that day to day life is a struggle.

D. Why We Need a Solution

Studies show that there are pain associated with activities of daily living (ADL) on a wheelchair. This includes sleep, chore, work, exercise, and other daily activities reference [13]. From a study conducted by the University Of Maryland School Of Medicine, there were associations of shoulder pain included with manual wheelchair usage reference [1]. Several of the sample that there were pain from resting or sleeping. However, majority reported pain with activities such as propulsion such as moving on an incline or ramp or transferring from bed, shower, or car to wheelchair. Moreover, pain was also prevalent in self-care activities such as change of clothing and cleaning. Mainly reaching objects overhead and from the ground level to shoulder level showed inflicted pain on the individual as well as self-care activities shown in Figure 6 [1].


Frequency distribution of painful activities as reported by subjects with history of shoulder pain (n = 32). Subjects were asked if these activities caused shoulder pain.

Activity	"Yes" Response (n)
Pain at Rest	16
Pain When Sleeping	21
Self-Care Activities of Daily Living	
Pain with putting on a shirt	12
Pain with pulling on pants	11
Pain with tucking shirt into back of pants	9
Pain with washing/styling hair	15
Pain with washing your back	9
Transfers	
Pain with bed to wheelchair	19
Pain with shower/tub to wheelchair	18
Pain with car to wheelchair	20
Propulsion	
Pain with level surfaces	13
Pain on inclines/ramps	25
Pain on downhill/declines	9
Pain with Reaching Behind Your Head, Elbow Out to Side	18
Pain with Lifting a Full Gallon of Milk to a Counter (Shoulder-Level)	17
Pain with Lifting a Full Glass to a Counter (Shoulder-Level)	7
Pain with Reaching Straight Overhead	18

Figure 6: Table of Pain associated with ADL [1]

Furthermore, tests were performed on the strength and range of motion of the arms [1]. The range of motion were tested by degrees of rotation of the arm including flexion, extension, abduction, external rotation and internal rotation. Examples of the range of motion can be seen in Figure 7 [14]. Along with the results of the tests of the thirteen individuals that participated are shown in Figure 8 [1]. Comparing this with the average range of motion, the manual wheelchair users are limited than the average person besides flexion, achieving a range of greater than 60°.

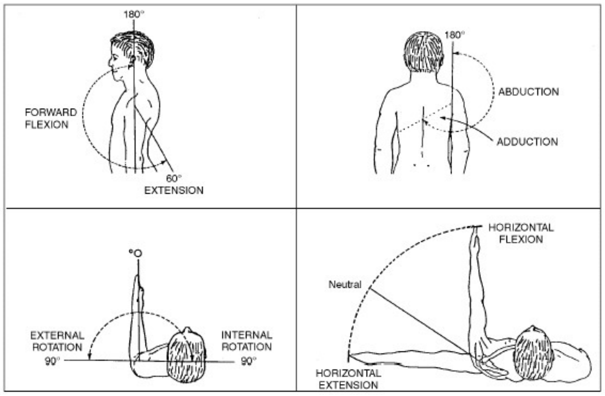
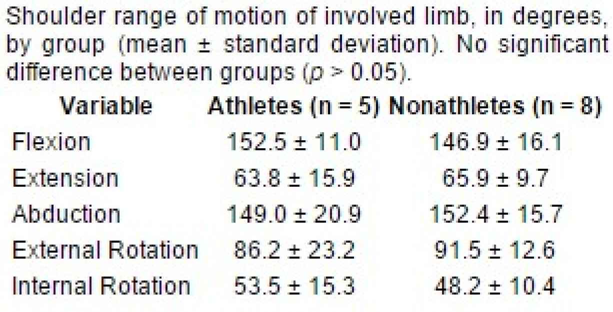


Figure 7: Average Range of Arm Motion [14]


Shoulder range of motion of involved limb, in degrees, by group (mean ± standard deviation). No significant difference between groups ($p > 0.05$).

Variable	Athletes (n = 5)	Nonathletes (n = 8)
Flexion	152.5 ± 11.0	146.9 ± 16.1
Extension	63.8 ± 15.9	65.9 ± 9.7
Abduction	149.0 ± 20.9	152.4 ± 15.7
External Rotation	86.2 ± 23.2	91.5 ± 12.6
Internal Rotation	53.5 ± 15.3	48.2 ± 10.4

Figure 8: Range of Motion Test [1]

Furthermore, inability to perform ADL may lead to increased dependence on others such as family and also lead to depression. According to a study supported by a grant from the National Institute on Disability and Rehabilitation Center, 177 individuals with spinal cord injury (SPI) were put to a life satisfaction and depression test [15]. Using the Geriatric

Depression Scale and the Older Adult Health and Mood Questionnaire, approximately 24% of the individuals with SPI were tested with depression, while 17% were probable. The individuals tend to rely on their family for assistance or resort to hiring in-home care. Seeking help from spouses can also impose depression on them as well [16].

IV. DESIGN IDEA AND THE FEATURE SET

The entire problem of limited mobility cannot be solved with one single engineering solution, the scope of the problem is simply too large. For our project, we decided to focus on those who have trouble reaching out from the wheelchair to those distances that ADA requires. This includes persons who can only move their arms between the armrests to persons who can reach only a few inches out from the arm rests for seated adults. A perfect example of this is a person with a medium severity Quadriplegia. In this case the person does not have control of their arms, but can move their hands enough to grab objects.

A. Requirements

Our design focuses on creating an affordable solution to those with limited mobility. The Colorado State website states that "The average reaching distance of a seated adult: side reach maximum height overhead is 54 inches and the low side reach is 9 inches above the floor. This does not include reaching over an obstacle such as a counter. The maximum forward reach is 48 inches above the floor, also not over an obstacle" as shown in Figure 5 [3]. This means for the average wheelchair height of 30 inches the arm should be a minimum of 24 inches to reach the 54 inch average overhead reach of an adult. The design extends the reach of the wheelchair bound person to at least these average reaches. The design solution has the flexibility to be used on either side of the wheelchair so that if a person has use of one hand more than the other they can use this solution with the better hand. The user is able to control this solution with a joystick from small movements of the wrist. Furthermore, the user can control the device well enough to distinguish between two objects next to each other. Lastly, this design can bring the object into the boundary defined by the arm rests and the front of the wheelchair seat.

B. Constraints

The design is built to work within certain constraints, which are real world limits to what it can actually do. First, the weight limit of the solution is 1 pound with dimensions of height, width, and length of one to three inches. Similarly, the maximum size of at least one of the dimensions of the object to be retrieved will be 3 inches. The design cannot be allowed to interfere with the normal functions of the wheelchair, specifically the user should not be able to touch any wheelchair controls with the arm to cause an accident and the extra weight of the arm should not create a risk of tipping. The solution will soon have built in protections against driving the arm into the user. Finally, as this is a project completed by college students the price of parts and materials used on the arm should not cost more than $800, and we are on track with this.

C. Previous Solutions

Figure 9: Service Dog [17]

To solve the limited mobility a viable solution would have been service dogs. Service dogs are highly trained dogs capable of servicing basic needs to their attendee as one is shown in Figure 9 pressing a crosswalk button [17]. Typically, service dogs are trained for the disabled who are not vision or hearing impaired. These dogs go through extensive training including 120 hours of schooling of a period of 6 months or more [18]. The standards presented here are from IADDP (International Association of Assistive Dog Partners), and include the following: obedience training, manners, and disability related tasks. These dogs are trained to service people on needs specific to them depending on their disability. Now, these standards listed vary from group to group that certify dogs as assistive. There does not exist a central organization that oversees all training requirements of these dogs. Additionally, these dogs are limited to specific training. They do as they are instructed which limits the flexibility of solution for someone who is impaired. Another consideration to a service dog is according to The Foundation for Service Dog Support the average cost to raise and train a service dogs is in excess of $15,000 [19]. Though some of the cost is defrayed by fund raising, an individual trying to obtain a service dog could cost as much as $6000. That number does not include fees associated with keeping the dog's training up or health costs. This sum adds up quickly. Service dogs are a viable solution for those who can afford one, or obtain one for that matter. There is an application through most trainers, which brings to light the individual may not even qualify for one. Our solution works more broadly and is more affordable than this though.

A more engineering focused solution to the problem could have been purchasing a premade design robotic arm, such as the JACO assistive robot arm as shown in Figure 10 [20]. The JACO arm can be mounted on wheelchairs and assist individuals with activities of daily living (ADL). It helps users pick up items around the user, prepare meals, eat and drink with the control of an analog stick [21]. The arm itself has been tested on individuals with upper extremity disabilities and have shown that majority of the users can definitely perform the given tasks assigned to them [22]. The results have shown that it is possible to reduce time in performing such activities such as preparing meals, eating, drinking and changing clothes. The perks of a buying a premade robotic arm on the market is that it has gone through testing, redesigning, and accounts

Figure 10: JACO Robot Arm [20]

for many of the safety issues regarding the use of the arm. However, the cost of the JACO assistive robot arm can be extensive for many users. The price ranges from \$35,000 to \$50,000 with a two year warranty [21]. This may be seen as a cost efficient for relying on self-service and reducing the need for care giving costs, but it is still an investment and cannot guarantee that the product will last several years. Moreover, health care programs may not cover or support the cost of assistance items since individuals have to be assessed for a manual wheelchair necessity of the different types of wheelchairs [23]. The product that we have implemented is more cost efficient and able to perform similar tasks even though limited.

A more extreme solution that we could have tried would be to connect a sensor to the afflicted person's brain. The sensor would then send the information to a computer to have the gathered information analyzed. The information would be sent to a robotic arm the complete the task the person desired. This solution has already been done by Brown University and citation [24]. There are some problems that made this solution not a viable option for us. The first is that implanting a sensor in someone's brain is not realistic for us. No one in the group has any medical background or the money to pay a doctor to do the surgery. The next problem that we would not have been able to accomplish is creating a program that would interpret the data received. No one in the group has ability to deliver brain functions making all but impossible to create a program for the robotic arm. The final issue that made this solution not viable for our problem is that this is not a mobile device. It would take a large computer and an arm that is anchored into the ground.

Similar to a robotic arm, we considered building an exoskeleton. An exoskeleton would assist disabled people with the strength to move their arms with the full range of motion and strength than an average human being could. One example of an exoskeleton can be seen in Figure 11 [25]. While an exoskeleton that works as described would ultimately be a better solution for the end user, it was not implemented for a variety of reasons. The design would have simply taken too long to design and implement as the motions, sensors, and controls would be much more complicated and dangerous than our simple arm. The exoskeleton will require many more sensors and parts that would have been too expensive for us to afford.

Figure 11: Exoskeleton [25]

D. Design Idea

For our solution, we felt that we had the ability to build a low-cost electric robotic arm that can be attached to a wheelchair. Our goal was to make the claw be able to grasp an object 32 inches away at countertop level. In order for the arm to bring an item back to the user, it is able to extend and retract via a telescoping motion on the horizontal axis. To maximize flexibility, the arm has a single point of rotation that allows it to rotate along the horizontal axis, with a varying range dependent upon where the arm is mounted so that the user is not able to push the arm into themselves. This horizontal rotation provides enough resolution for us to be able to distinguish between two objects, up to our design constraint of 3 inches apart.

The user controls for this arm is a combination of joysticks or buttons, which made sense for the ergonomics. These controls are routed to an Arduino Microcontroller with a 16Mhz Atmel Atmega 2560 Microprocessor as shown in Figure 12 [26]. It will then perform any necessary trigonometric and algebraic calculations and adjusts the position of the arm accordingly. There was a lot of math involved and we thought maybe the Arduino Microcontroller does not provide enough power and we would have to move to something like the Max32 Prototyping Platform which uses the 80Mhz MicroChip Pic32for its processing. The arm joint actuators are stepper motors, which provided the right amount of power and resolution for us to meet our requirements.

Figure 12: Atmel Atmega 2560 Microprocessor [26]

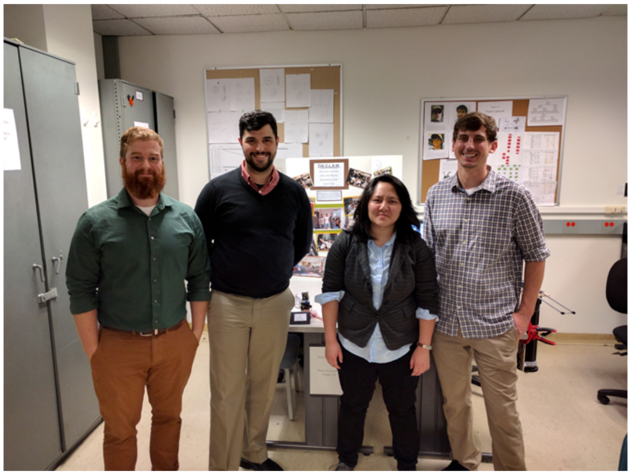


Figure 13: Team C.L.A.W. [27]

To maintain cost, function, simplicity and efficiency the mechanical design was made as light and minimal as possible. The claw is a two-finger pincher that is able to apply enough force to pick up an item of the specified weight of one pound. To help those who only have limited use of their neck, we have mounted a small camera on the claw with a live video feed to a small TV that a user can then control the claw with. As a team we agreed on this solution as it was cost effective and simple while at the same time providing users with the functionality they need. Simple elements such as the live video feed were simple to implement but add a unique aspect to the user experience that we have seen other places. Keeping the weight limit to one pound, we gave ourselves room to innovate in the space of compactness and simplicity based on area of space available on the wheel chair, while still giving the user the ability to grab most objects that they would want to grab.

E. Feature Set

1) ***Grasping Objects****:* The major feature of our design is the claw attached to the end of the arm. This claw has the ability to grasp and hold a one pound object. The grasping capabilities are limited to the vertical plane, I.E. the claw is not able to rotate, but is fixed with its opening and closing movement on the horizontal axis. The maximum opening capability will is about four inches wide, and it is able to close the fingers. Therefore, the object to be picked up needs to weigh a maximum of one pound and be two to four inches wide in one of its vertical dimensions. These requirements were developed with an object such as a glass of water in mind, implementing a claw that could grab a much large range of shapes, sizes, and weights was above the scope of this project.

2) ***Mountable****:* In order for a person in a wheelchair to use our robotic arm, we gave them the ability to take it with them. The arm is mountable on an item such as a wheelchair. We say mountable because right now during the development stage we have it mounted on a table and will soon come up with the design to meet an individual wheelchairs style. Since we are keeping a broad “mountable” feature in mind, we will have kept the base of the arm smaller than a 16 inch cube. This of course does not take into consideration batteries, microcontrollers, and any other components that are not fundamentally integrated into the movement of the arm and that can be mounted elsewhere.

3) ***Physical Input System****:* In order for the arm to be controlled, we have developed a control system that takes small physical inputs and converts them to something the arm can understand. This feature allows the user to move the robotic arm to a location they would like and grab an object they want to grab with just a few movements of their hands.This has been realized in the form of a joystick and two buttons. The buttons allow you to open and close the claw, while the joystick controls the movement of the arm. Movement for the arm, camera, and claw are all done with these three elements.

4) ***Point-of-View Video Feedback System****:* Since many wheelchair-confined people are suffering from many other physical limitations besides the ability to walk, we have added a video feedback system that provides imagery from the point of view of the claw. With this feature, the user does not need to turn their head to see what the claw is grabbing. Rather they can monitor the claw movement on a camera to grab the items that they choose. To achieve this feature we found a tiny camera that has a fish eye lens to allow users to get more of the peripheral vision. This camera is mounted on a servo that moves left when the arm is moving left and right when the arm is moving right. When the arm is idle or extending, it looks forward. The video signal is then be fed from the camera to a small display that can either be mounted on the wheelchair or resting in the users lap, wherever the user prefers.

5) ***Extend and Retract****:* The feature that is key to the use of a robotic arm is the arm motion. In the horizontal axis, our arm has the ability to extend and retract.This means that the arm is able to extend out and grab items from its mounted height. In the same manner that this arm extends, it also can retract to its starting position. This feature will be one of the key components of making the arm helpful to a disabled person as it allows them to bring an item back in closer to the base of the arm. For the second semester we may add the ability for the arm to tilt but we have not fully discussed this yet.

6) ***Horizontal Rotation****:* The arm also features a single point of rotation on the horizontal axis. By keeping all horizontal movement centralized in one place the mechanical design is much simpler. The user is able to control the horizontal rotation to at least a 1.8° resolution. Considering that our arm will have a maximum reach of 32 inches, the arc length of 1.8° is 1.1 inches, which is more than enough resolution to distinguish between two water glasses on a table.

V. FUNDING

At the beginning of our project, we anticipated on spending a minimum of $540 to a maximum of $1970 as seen in Table I. The reason for all these costs was that we wanted to implement a more complex design. However, a few weeks in towards the semester, we realized that we needed to redesign due to the complexity of mechanics. This resulted in reducing our costs to $321.52 as seen in Table II. Overall, we reduced the need for high torque servos, cut out costs for pulleys, materials for the arm, and the need for a CNC machine.

Table I:
Estimated Budget [28]

Item	***Quantity***	***Price***	***Min SubTotal***	***Max SubTotal***	***Min Total***	***Max Total***
Wheelchair	1	$0-$250	$0	$250		
Stepper motors	3	$30	$90	$90		
Stepper motor drivers	3	$10-$30	$30	$90		
High Torque Servos	3	$20-$100	$60	$300		
Drive reduction gears	3	$0-$120	$0	$360		
Belt pulleys	10	$0-$20	$0	$200		
Belts	5	$10	$50	$50		
G10 for arm material	2	$45	$90	$90		
3D Printing Filament Reels	2	$50	$100	$100		
Microcontroller	2	$10-$50	$20	$100		
CNC Costs (hours)	4	$0-$60	$0	$240		
Misc Hardware	1	$100	$100	$100	$540	$1,970

VI. WORK BREAKDOWN/PROJECT TIMELINE

During our project we were able to maintain a tight schedule during the fall semester. During the design phase we were able to narrow our vision on an obtainable model to meet our feature set. This section of will evaluate the time line of our project, as well as where the project stands.

A. Mountable Arm

To deliver a viable option for the disabled, we had to come up with a design that would add accessibility to the inaccessible. The idea of mounting the arm was an essential part to this goal. To achieve this we had to first understand what were the space requirements of the potential user. We went through measuring all members in the wheelchair that was available to establish and average space in the chair. After the chair dimensions were established, we then began to research what is the best option for mounting our apparatus. We settled on a mounting system that was both cost effective and usable. The mount was then modeled in solid works and built. The mount was built in such a way as to keep the center of gravity low in the arm, as to not interrupt normal use of the chair. Doing the fall we will be diving into testing to ensure both safety of the user, and the usability of the apparatus.
Milestone: Design Completion

Table II:
Actual Budget [29]

ITEM	**QUANTITY**	**PRICE**	**SUBTOT**
STEPPER MOTOR NEMA 17	2	$ 14.98	$ 29.96
TOWER PRO MG995 SERVO	1	$ 6.99	$ 6.99
LM2596 BUCK CONVERTER	2	$ 5.96	$ 11.92
4.3" TFT LCD	1	$ 15.55	$ 15.55
WIDE ANGLE BOARD CAMERA	1	$ 14.99	$ 14.99
THERMAL ADHESIVE	1	$ 6.72	$ 6.72
DRV8825 STEPPER DRIVER 5 PACK	1	$ 14.59	$ 14.59
LINEAR MOTION ROD 8mm 30"	2	$ 22.44	$ 44.88
JOYSTICK	1	$ 1.98	$ 1.98
LINEAR MOTION BEARING	1	$ 10.97	$ 10.97
3M GRIPPING MATERIAL	1	$ 18.93	$ 18.93
TB6560 STEPPER MOTOR DRIVER	1	$ 14.99	$ 14.99
LAZY SUSAN BEARING	2	$ 4.46	$ 8.92
MECHANICAL ARM PAW GRIPPER	1	$ 17.59	$ 17.59
MISC HARDWARE	1	$ 40.00	$ 40.00
CLAMPS	2	$7.99	$ 15.98
3D PRINTER FILAMENTS	1	$23.95	$ 23.95
		Total:	$ 298.91
PREVIOUSLY OWNED ITEMS	**QUANTITY**	**PRICE**	**SUBTOT**
ARDUINO UNO	1	$ 12.00	$ 12.00
3D PRINTED PARTS	1	$ 15.00	$ 15.00
14.8V LIPO BATTERY 4Ah	1	$ 40.00	$ 40.00
NEW JOYSTICK	1	$23.45	$ 23.45
NEW PUSH BUTTONS	2	$3.45	$ 6.90
		Total:	$ 97.35
ACTUAL TOTAL			**$ 396.26**

B. Extend and Retract

To create a useful utility of our design the ability to bring an object from its stable position to the user is key. The safety of the user was first in foremost in our design. We had to create a way for the user to grasp and object and not be allowed to tip over, or injure his or herself during operation. We used the data captured during the measurement stage of the last section to calculate the moment arm of the apparatus on the wheelchair. We used the arm at full extension as it provides the most force on the chair, to achieve a safety check. We will be diving further into testing in the spring to ensure we have ensured safety of the user. We also implemented step counters to ensure the user is unable to drive the apparatus into his or herself. The next stage of the extend and retract was to settle on a design of usability. We settled on a design that met our feature set of extension and retraction. We were able to fully extend to the design parameters with a linear motion with rods and bearings. The arm was able to fully extend the rods using a stepper motor pulley through the bearings. In the spring we will be going through further testing to ensure we have met our design features.
Milestones: Assembled Linear Action

C. Horizontal Rotation

The arm will need to rotate to gain access to the outside and inside of the chairs frame. The rotator will be able to swing within an angle range of -45° and 135° of the arm rest with the arm rest being the reference axis. The rotation axis will

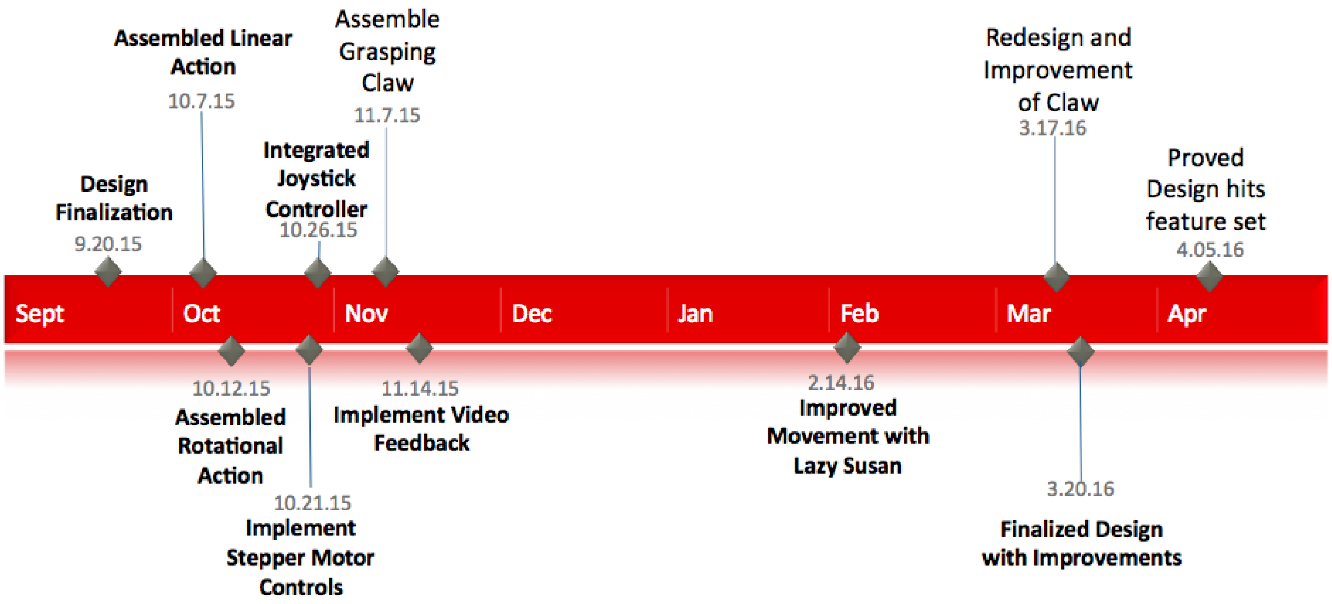


Figure 14: Timeline [30]

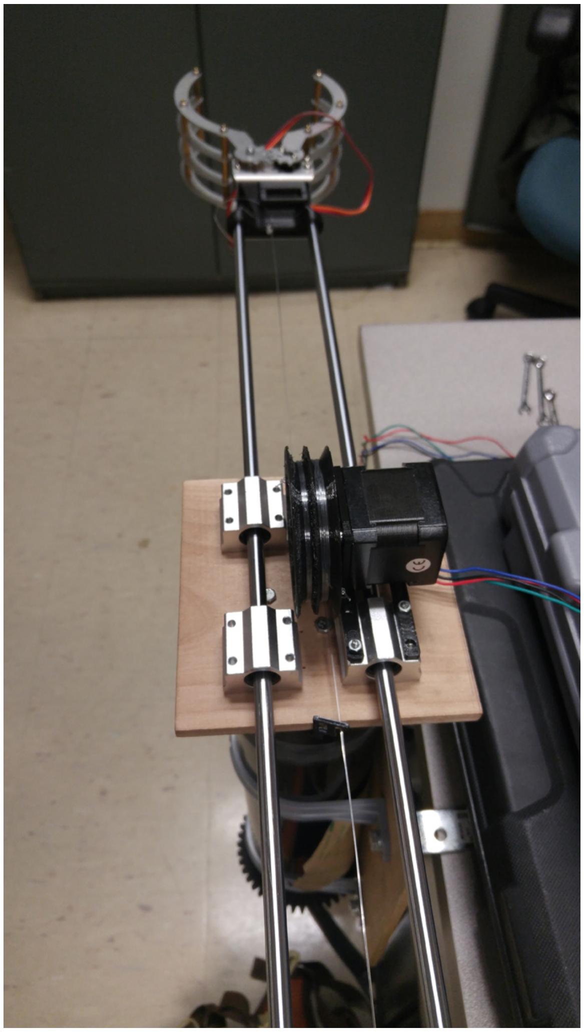


Figure 15: Linear Action Assembled [31]

be the vertical axis that is parallel to the back of the chair. One of the obstacles of the rotation was the strength of the stepper motor in regards to the torque it would undergo. This was tested with the gear implementation we choose to use in our design. Additionally, we implemented step counting to ensure the safety of the user during this stage. Another subtask for this section was to create a base for the connection of the rotating base, and the base which mounts to the chair. We completely assembled the design at this point and began testing. We found there was a deficiency in our design in regards to horizontal rotation, which a plan has been arrived at. We shall shrink down the shaft where the rotation occurs, and create a more frictionless environment next semester. We believe this discovery has an appropriate plan for the next semester that will allow for smooth rotation and full design feature expectation.

Milestone: Assembled Rotational Action

D. Input Control System

For our design we picked a relatively simple solution for our control system. We implemented a two axis joy stick to control both the linear actuation, as well as the horizontal rotation. Out of all the controller types we explored this simple solution seemed the most appropriate for our design. The requirements of our design were kept in mind while deciding on this particular controller. To have the arm move the way it needed to move, we needed a solution that was simple to use based on the needs of the user, and also a durable solution with plenty of documentation. Additionally, the size of the joystick also helped make the decision as a small area that it will occupy on the end user's wheel chair. The last subtask of this section was to decide on the microcontroller for our design. The micro controller needed to have enough pins for the input and output of our system. We picked a micro controller

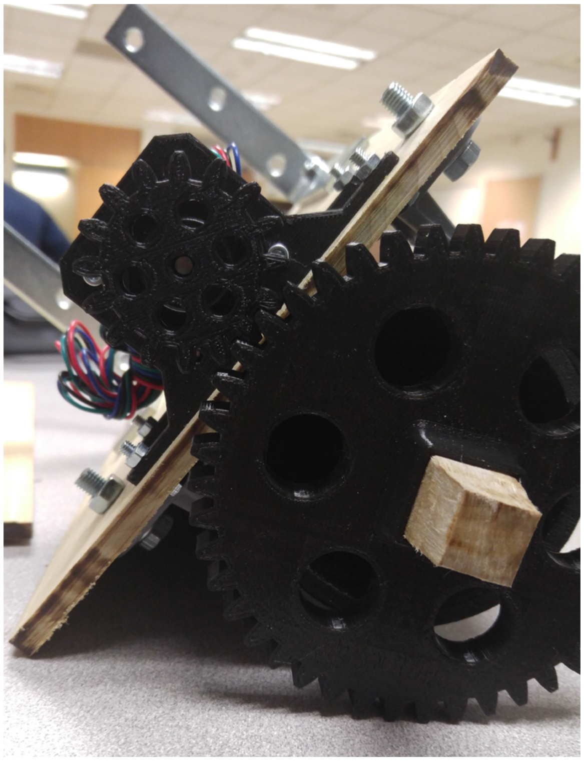


Figure 16: Gears Assembled for Rotation [32]

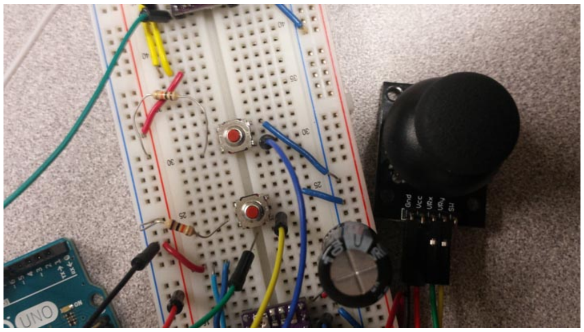


Figure 17: Input Controls [33]

that suited our needs. After, the micro controller was picked, we programmed it to fit our feature set. Finally, we tested the components individually to test both the programming and hardware individually, before the complete assemble was made.

Milestone: Implemented stepper controls and Integrated Joystick

E. Claw for Grasping Objects

The claw design will be able to grasp an object with a weight of one pound. The dimension of such objects will also vary of height, length, and width from one to 3.5 inches. The design of the claw will account for the actuators used, control speed of actuators, size and style of the claw, gripping materials, and attachable to the robotic arm. There were numerous tasks which we completed to complete the grasping apparatus. The first task we accomplished was determining the motor actuation type that was used in our design. We decided on a particular servo that had the strength to grasp our punch list requirement. After deciding on the servo, we then researched premade grasping claws. We decided on a premade model to help reduce the non-electrical engineering aspects in our project, since we have embarked on a project with a lot of mechanics involved. Another subtask of the claw decision was using a gripping material to help stabilize the grasping and holding of the claw. Implementing a grasping material prevented the slipping of the object out of the claws grasp. Additionally, the micro controller also came into play when deciding on the claw. With only a certain number of I/O pins, we had to be conscious of the requirements of the servo-motor. Power was also a consideration on the claw. The servo current draw was accounted for in the final power decision. The final subtask of the claw was how it was attached to the arm. The additional weight of the claw did affect the final operation of the arm. The horizontal rotation will be modified to take into account the added weight.

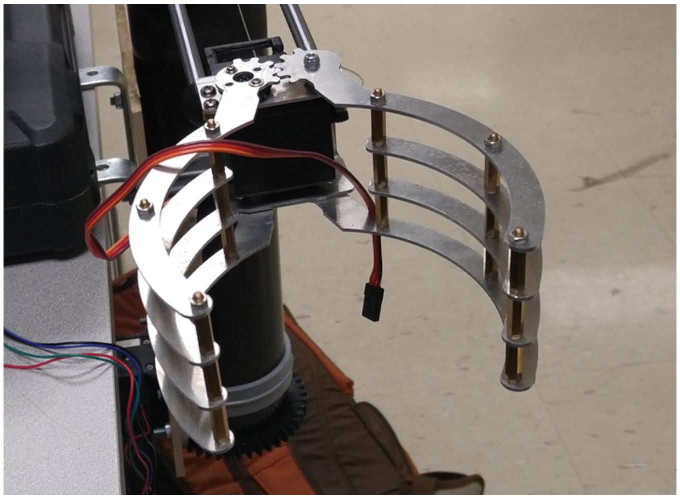


Figure 18: Claw Assembled [34]

Milestone: Assembled Claw

F. Visual Aid

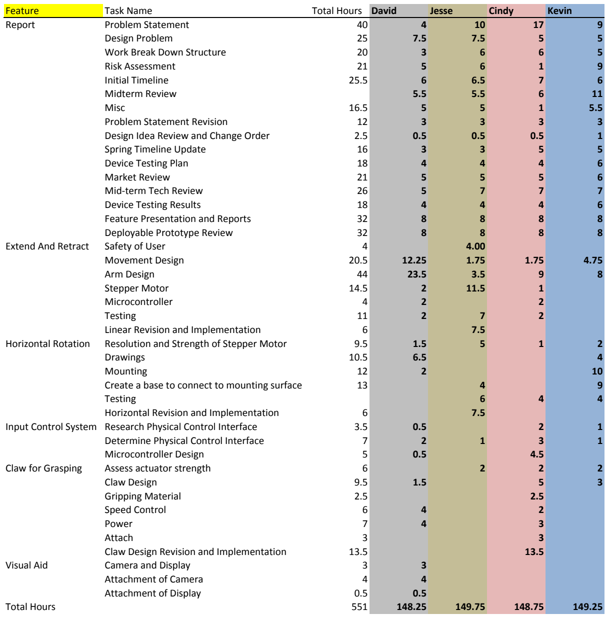
A point of view display will be provided to the user as a visual aid to grasping an object. It will help the user to determine how the claw is orientated to the object and be able to grasp the item. The visual aid will include the camera and display as well as the attachment to the arm. We decided on a low power camera and display to keep the power consumption as low as possible. The camera ended up being mounted on a servo which rotated as the arm moved horizontal to add additional vision for the user.

Milestone: Implemented Video Monitor

VII. TASK ASSIGNMENTS

Our team spent approximately 551 hours on the project this year. This included the documentation and building of our project. Each person spent at least 148 hours on the project. The breakdown of the hours can be seen on Table III.

Table III:
Team C.L.A.W. Task Hours [35]



Feature	Task Name	Total Hours	David	Jesse	Cindy	Kevin
Report	Problem Statement	40	4	10	17	9
	Design Problem	25	7.5	7.5	5	5
	Work Break Down Structure	20	3	6	6	5
	Risk Assessment	21	5	6	1	9
	Initial Timeline	25.5	6	6.5	7	6
	Midterm Review		5.5	5.5	6	11
	Misc	16.5	5	5	1	5.5
	Problem Statement Revision	12	3	3	3	3
	Design Idea Review and Change Order	2.5	0.5	0.5	0.5	1
	Spring Timeline Update	16	3	3	5	5
	Device Testing Plan	18	4	4	4	6
	Market Review	21	5	5	5	6
	Mid-term Tech Review	26	5	7	7	7
	Device Testing Results	18	4	4	4	6
	Feature Presentation and Reports	32	8	8	8	8
	Deployable Prototype Review	32	8	8	8	8
Extend And Retract	Safety of User	4		4.00		
	Movement Design	20.5	12.25	1.75	1.75	4.75
	Arm Design	44	23.5	3.5	9	8
	Stepper Motor	14.5	2	11.5	1	
	Microcontroller	4	2		2	
	Testing	11	2	7	2	
	Linear Revision and Implementation	6		7.5		
Horizontal Rotation	Resolution and Strength of Stepper Motor	9.5	1.5	5	1	2
	Drawings	10.5	6.5			4
	Mounting	12	2			10
	Create a base to connect to mounting surface	13		4		9
	Testing			6	4	4
	Horizontal Revision and Implementation	6		7.5		
Input Control System	Research Physical Control Interface	3.5	0.5		2	1
	Determine Physical Control Interface	7	2	1	3	1
	Microcontroller Design	5	0.5		4.5	
Claw for Grasping	Assess actuator strength	6		2	2	2
	Claw Design	9.5	1.5		5	3
	Gripping Material	2.5			2.5	
	Speed Control	6	4		2	
	Power	7	4		3	
	Attach	3			3	
	Claw Design Revision and Implementation	13.5			13.5	
Visual Aid	Camera and Display	3	3			
	Attachment of Camera	4	4			
	Attachment of Display	0.5	0.5			
Total Hours		551	148.25	149.75	148.75	149.25

A. Spring Semester Plan

Our project underwent changes to create a practical prototype. The horizontal rotation is now fully rotatable, so in the spring semester we were able to create a more functional rotation. Additionally, our Claw starts open then shuts immediately as a start up sequence, so we adjusted to create a smoother transition during power on. Finally, we are altered the linear motion to create a more precise movement.

Rotation Adjustment

For the spring semester the biggest overhaul to our prototype was the horizontal rotation. We expected to get friction on rotation, but we did not expect it to be such an issue, but we be implemented changes to the base, as well as the mounting surface to create a more fluid movement. For the base we implemented a bearing assembly to help with direct friction. This helped elevate the friction of the cap on the tube. This to took approximately 7.5 hours for this alteration. The mounting apparatus will be adjust such that it provides a more static environment. Additionally, we implemented a bearing at the gear in the bottom as well. It create a more static condition to keep the bearings in mesh with one another. We were able to achieve this in 7.5 hours.

Claw Adjustments

An additional change we made this spring semester was be the Claw start up. Currently, the claw was snapping up then shut on power up. We were using the native libraries in Arduino to run the claw currently, so we will be added a start up sequence to adjust this reaction. This will provided a more confident operating claw to our design. It does not affect the operation of the claw, but has a certain psychological play, as it appears unexpected. This adjust to took approximately 4 hours. Another adjustment we made to the claw was adding material to allow a better grip on a wider array of objects. This took approximately 13.5 hours to implement.

Linear Motion Adjustment

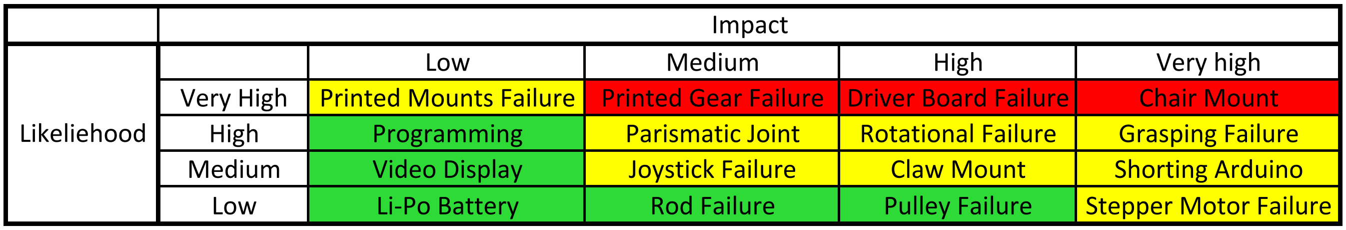
The finally change to our project was the linear adjustment. The linear motion worked, but we tightened the strings on the pulley to better achieve motion. By fighting the string, there will be less play in the line as the pulley moves. Additionally, we were experiencing a slight catch where the string attaches to the pulley. We adjusted such that when the pulley is moving, the string will not hit the motor on rotation. This will be a minor adjust and we completed it in less than half an hour.

These adjustments took approximately 31 hours to complete. These adjustments were the horizontal base, linear motion pulley, mount, and claw to achieve the goal of adding accessibility to the wheel chair confined. We discovered once the adjustments are made a more usable prototype resulted. The smooth operation is imperative to the end user. Having smooth operation will ensure they have a usable tool to help them more easily grasp objects they would not have access to otherwise.

VIII. RISK ASSESSMENT

With every project we must assess the risks that will be involved with the project. The risks will be divided up in to sections as can be seen in the Table IV. The table categorizes the risk with two metrics, likelihood and impact. The impact of a risk has a wide range from low impact, which will not affect the project that much, to very high impact, which could possible end the project entirely. Similarly the likelihood is categorized with the range of low likelihood, which means it probably will not happen, to very high likelihood which means it will happen. Each risk will be addressed to better understand what causes the risk and what the team will due to mitigate the risk and possibly prevent it. Not all risks can be accounted for because there are different types of risks. Some risks are foreseen and others are not but will still be accounted for, because these unforeseen risk will come up without notice and the team will have to adapt to the situation. The arm has multiple parts that will be integrated to make a functioning arm. Each of the integrated parts have sub parts. The combined parts have a risk associated with them, which can become quite complicated. So it is best to break them down into sections first will be the 3D printed parts, next we will discuss both of the joints. The arm uses two different

Table IV:
Risk Assessment Table [36]



		Impact			
		Low	Medium	High	Very high
Likeliehood	Very High	Printed Mounts Failure	Printed Gear Failure	Driver Board Failure	Chair Mount
	High	Programming	Parismatic Joint	Rotational Failure	Grasping Failure
	Medium	Video Display	Joystick Failure	Claw Mount	Shorting Arduino
	Low	Li-Po Battery	Rod Failure	Pulley Failure	Stepper Motor Failure

printed circuit boards such as the microcontroller and driver boards have a similar risk and also will be discussed. Last the team will talk about the hardware and the risks that come with them. The likelihood of the 3D parts breaking and / or failing in some way is very high, the impact on the other hand is very low. We are using 3D printed for mounting the motor. We have already broke two different mounts confirming the high likelihood for failure. This was anticipated by the team and we have access to a 3D printer and making new parts. Another risk that the 3D printed parts have is design is the fact that they may not be able to hold up to the torque that is required to spin the arm. To prevent this we printed the gears with a 40% core the more robust core will mitigate the risk for failure of the 3D printed parts.

The arm is comprised of two joints a rotational and prismatic joint. Both joints have their own risks, but they have the same likelihood for risk of failure. Each of the joints have significant impact on the project and failure of either one would set the team back. A prismatic joint has the action of extending and retracting in a linear form. There are some risks associated with this type of joint. The joint may have too much friction in the bearings and may not slide smoothly. The joint may also not extend to the full length as desired. The rotational joint also has risks associated with it, some of which even that we did not foresee. A case in point is the torque that the motor places on the gear is not being translated completely and therefore the arm is not turning smoothly. Another risks is that both joints being handmade and not purchased as a unit. We are not mechanical engineers so the build may not be perfect. The joint will have a lot of friction in the rotational movement. The rotational joint is constructed using gears and a stepper motor, therefore too much friction will cause stress on the motor and gears. We have made plans to do a redesign of the rotational joint for the spring semester to address the rough rotation.

We will be using an Arduino microcontroller and two stepper diver boards. The likelihood levels for the PCB's are much different. The motor drivers have a very high likelihood of failure unlike the Arduino. As for the Arduino the major risk that the team must be cautious of is the not short circuit the Arduino. To prevent this the team will double check each other's work to ensure the wiring is correct. The impact to the project is very high because the Arduino is the main microcontroller that we are using. The other risk associated with the Arduino is the programing of it. The likelihood of the programing failing is high but the impact is low. There is many resources both at school and on the internet that the team will use to solve any issues that may come up during programing. The mitigation to programing is to start early and be as clear as we can be with our comments. The motor drivers, on the other hand, are much more prone to failure. The failure is not because of construction but due to user error, the team has already blow two drivers boards. To overcome this risk we bought a 5 stepper motor drivers, that way we have backups for when we blow them.

The other hardware that we are using is stepper motors and Li-Po batteries. Both of these have risk that are associated with them. The stepper motors are a very robust component and have a very low likelihood of failure. The only way the team foresees a motor failure would be if the motor was dropped or damaged is some other physical way. Similar to the motors the batteries are not prone to failure other than if not handled properly. Our team members have done sufficient research to have a strong understanding to properly maintain and handle the batteries and motors.

IX. TESTING RESULTS

A. *Linear Extending*

The linear extending arm is a vital component to the project. The extension is what reaches out and put the claw within reach of an object to grab. This component needs was tested for reliability and operation. The reliability pertained to the arm extending every time the joy stick moved while the arm moved forward and backward with the corresponding joy stick movement. The operation of the extending arm is the range the arm moves. The arm extended a determined distance based on the time that the joystick is being actuated.

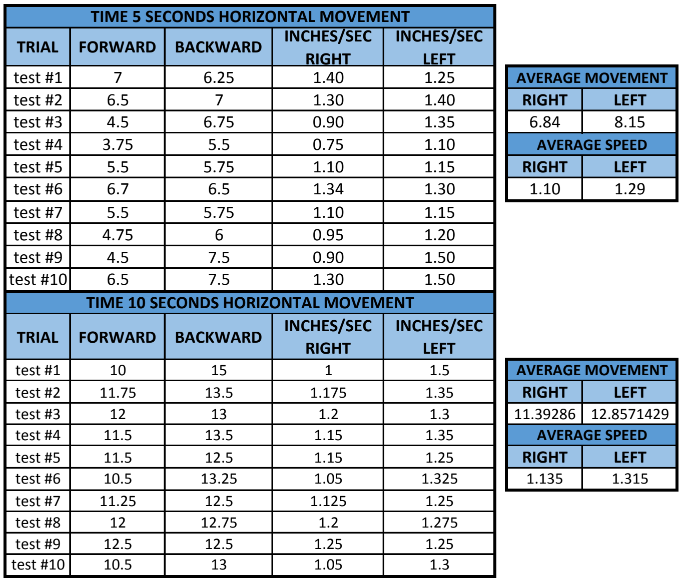
The Test:
For reliability the arm shall was observed no less than 10 times for both forward and backward movement. The joystick was actuated in forward mode. Ff the arm moved forward, the arm was a passing trial. If the arm did not move forward, it would be considered a fail. For each trail, there were observations made to describe the actions of the arm. If the joystick was actuated in the backwards mode and if the arm moves backwards, the trial was a pass. If the arm did not move backwards, the trail was considered a fail. Observations were made to describe the actions of the arm. To perform this test, the arm was moved forward and then

then backwards completing one trail. If the arm failed any trails, the observations shall be discussed to determine the cause of failure.

To test the arm, it was extended for 1 seconds, 2 seconds, and 3 seconds and the length was recorded. This test determined the length for extension based on the time that the joystick was held in the forward position. For each time frame, there were three trails to determine the average distance. A yard stick was used to measure the extension and a stopwatch was used to measure time. If the arm did not move, the trail will be considered a fail and the trail will need to be repeated. If the trail could not be repeated, the entire test was considered a fail. Observations and notes were taken during each trail to help determine the failures or to conclude an optimal time holding the forward position. Optimal was considered where the arm will have the greatest extension without saturation. Saturation occurred when the arm is fully extended and the joystick is still in forward position. If the arm did not reach maximum extension during these trails, the time frames needed to be extended.

The Results:
Upon the beginning of testing, the team has decided that the previous test would not provide enough data to accurately represent the actions of the arm. The test that were performed were changed much from what was previously stated. The decision to change the duration of the holding time was determined from running the slower time and not finding sufficient results. The duration was changed to five and ten seconds. The team decided to go with two times rather than three to save time and the results that we were able to achieve were expected to our standards. The linear actions produced a speed of about 1 inches per second. The arm did rotate at different speeds from forward to backwards. We found that the arm although had different speeds it was consistent though out the test. The arm at full extension will reach an object at 30 inches. The tip of the claw will reach 32 inches as set forth by the team's feature set. The data can be seen in the Table V.

Table V:
Translation [37]



TIME 5 SECONDS HORIZONTAL MOVEMENT				
TRIAL	FORWARD	BACKWARD	INCHES/SEC RIGHT	INCHES/SEC LEFT
test #1	7	6.25	1.40	1.25
test #2	6.5	7	1.30	1.40
test #3	4.5	6.75	0.90	1.35
test #4	3.75	5.5	0.75	1.10
test #5	5.5	5.75	1.10	1.15
test #6	6.7	6.5	1.34	1.30
test #7	5.5	5.75	1.10	1.15
test #8	4.75	6	0.95	1.20
test #9	4.5	7.5	0.90	1.50
test #10	6.5	7.5	1.30	1.50

AVERAGE MOVEMENT	
RIGHT	LEFT
6.84	8.15
AVERAGE SPEED	
RIGHT	LEFT
1.10	1.29

TIME 10 SECONDS HORIZONTAL MOVEMENT				
TRIAL	FORWARD	BACKWARD	INCHES/SEC RIGHT	INCHES/SEC LEFT
test #1	10	15	1	1.5
test #2	11.75	13.5	1.175	1.35
test #3	12	13	1.2	1.3
test #4	11.5	13.5	1.15	1.35
test #5	11.5	12.5	1.15	1.25
test #6	10.5	13.25	1.05	1.325
test #7	11.25	12.5	1.125	1.25
test #8	12	12.75	1.2	1.275
test #9	12.5	12.5	1.25	1.25
test #10	10.5	13	1.05	1.3

AVERAGE MOVEMENT	
RIGHT	LEFT
11.39286	12.8571429
AVERAGE SPEED	
RIGHT	LEFT
1.135	1.315

B. Rotational Movement

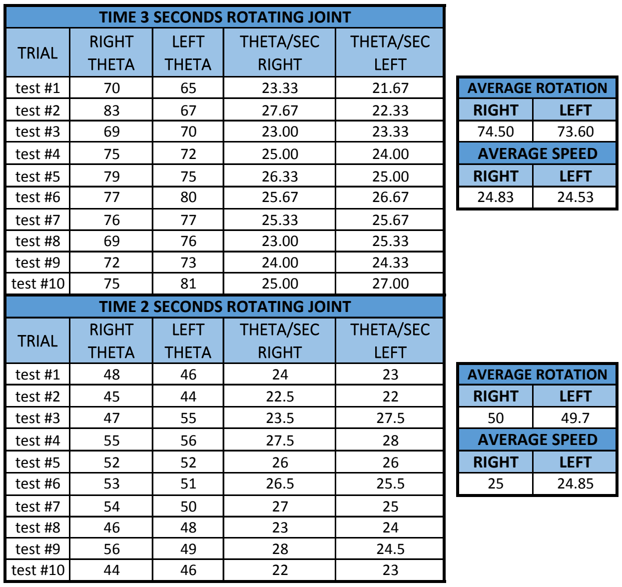
The rotational joint is a vital component to the project and must be tested to ensure its reliability and operation. The reliability of the rotational joint can be described as the repeatable operation based on the input from the joystick. The operational of the rotational joint can be described as the arm rotating no less than 180°. If the rotational joint is not able to function properly the project will be a failure. The arm was tested to rotate from within the area of the wheelchair and outside the wheelchair area to position the claw in such a way that the extending arm will be in place to reach the object that is desired to be grabbed.

The Test:
For reliability the arm was observed no less than 10 times for both right and left movement. The joystick was actuated towards the right. If the arm moves right, that shall be a passing trial. If the arm did not move forward, that will be a fail. For each trial there shall be observations made to describe the actions of the arm. The joystick shall be actuated in the left mode if the arm moves left the trial will be a pass. If the arm does not move left the trail will be a fail. Observations shall be made to describe the actions for the arm. To perform this test, the arm will be moved right and then then left completing one trail. If the arm fails any trails the observations shall be discussed to determine the cause of failure.

For the operation testing the arm shall be rotated for 1 seconds, 2 seconds and 3 seconds. This test determined the degree of rotation based on the time that the joystick is held in the right and left positions. For each time frame there were three trials to determine the average degrees rotated. A protractor was used to measure the degrees of movement and a stopwatch will be used to measure time. If the arm did not rotate the trial was considered a fail and the trial was repeated. If the trial cannot be repeated the entire test was considered a fail. Observation shall be taken during each trail to help determine any failures or to help conclude an optimal holding time for the right and left positions. Optimal is considered where the arm will have the greatest turning radius without saturation. Saturation will occur when the arm is fully rotated and the joystick is still in the right or left positions. If the arm did not reach maximum rotation the time frames may need to be extended.

The Results:
The rotational joint provided a hard time for the team. There have been a few fixes to the joint before the team began testing. Two lazy Susan's have been added to the joint to ensure proper rotation with the least amount of friction. A lazy Susan is a joint that utilizes a ball bearing race to

Table VI:
Rotational [38]



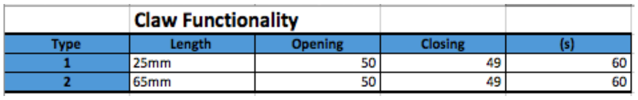
TIME 3 SECONDS ROTATING JOINT				
TRIAL	RIGHT THETA	LEFT THETA	THETA/SEC RIGHT	THETA/SEC LEFT
test #1	70	65	23.33	21.67
test #2	83	67	27.67	22.33
test #3	69	70	23.00	23.33
test #4	75	72	25.00	24.00
test #5	79	75	26.33	25.00
test #6	77	80	25.67	26.67
test #7	76	77	25.33	25.67
test #8	69	76	23.00	25.33
test #9	72	73	24.00	24.33
test #10	75	81	25.00	27.00

AVERAGE ROTATION	
RIGHT	LEFT
74.50	73.60
AVERAGE SPEED	
RIGHT	LEFT
24.83	24.53

TIME 2 SECONDS ROTATING JOINT				
TRIAL	RIGHT THETA	LEFT THETA	THETA/SEC RIGHT	THETA/SEC LEFT
test #1	48	46	24	23
test #2	45	44	22.5	22
test #3	47	55	23.5	27.5
test #4	55	56	27.5	28
test #5	52	52	26	26
test #6	53	51	26.5	25.5
test #7	54	50	27	25
test #8	46	48	23	24
test #9	56	49	28	24.5
test #10	44	46	22	23

AVERAGE ROTATION	
RIGHT	LEFT
50	49.7
AVERAGE SPEED	
RIGHT	LEFT
25	24.85

Table VII:
Claw Functionality [39]



	Claw Functionality			
Type	Length	Opening	Closing	(s)
1	25mm	50	49	60
2	65mm	50	49	60

distribute the friction evenly throughout the whole ring. This provides a smooth rotation for joint. The new additions to the joint have greatly improved the reliability of the rotating joint. The test was modified in a similar way as the previous test. The test consisted of two times 3 sec and 3 sec. The team decided that these times were able to meet the testing needs for the team. The arm rotates at about 25° per second with the arm being able to rotate a full 360°.The data can be seen in the Table VI. Through the many trials the arm performed every constantly and predictably.

C. *Claw Functionality*

For the arm to be an effective assistive device, the claw must have a reliable grasping. During this test the claw what be monitored opening and closing in one minute. Repeat the introduction to the other tests.

The Test

This test involved monitoring the opening and closing for 60 seconds. This test was to prove a consistent number of opening closing of the arm.

The Results

The results of the test showed two identical results. In 60 seconds the arm opened 50 times and closed 49 times. These results were sufficient enough for our application to show reliability without too much time investment.

D. *Ability to Grasp Objects*

The ability to grasp objects is one of the most important aspects of our arm. As part of our problem statement and feature set, we want to be able to grasp objects of at least two to four inches of width, length, and height. With this in mind, we want to be able to grasp the objects and bring it back towards the user without the object slipping. When purchasing the claw, we knew that we would have to redesign the claw due to the way it was built as seen in Figure 18. The surface areas on the claw is minimal, in which objects would most likely slip through. So within our testing plan, we used three different shaped objects. These three include a tennis ball, Rubik's Cube, and a paper coffee cup. These objects can be seen in Figure 19.

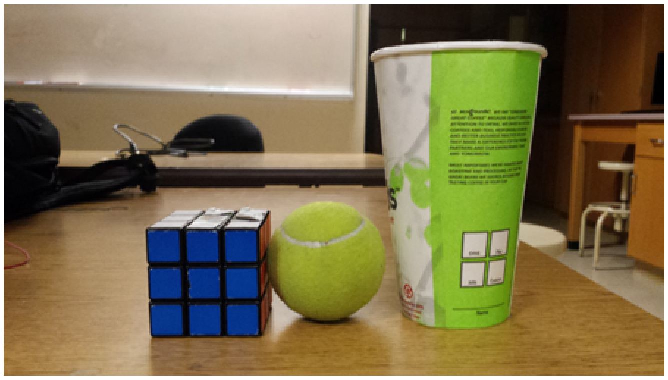


Figure 19: Different Shaped Objects [40]

The Test:

The grasping was tested on each object ten times without being attached to the arm due to the fact that redesigning was still being performed during the testing. To test, the claw was set on the table and the object was put randomly somewhere in between the claw in grasping range. The close button was pressed and by holding the back of the claw, it was pulled off the surface of the table. Observations were needed to see if the claw was able to grasp the item while being pulled off the table. If the claw was able to grasp the object with no or minimal slipping after being pulled away from the table, it was counted as a successful grasp.

The Results:

The grip was first tested on the tennis ball. The curvature of the claw was able to account for a decent grip onto the tennis ball (57 grams). The claw was also able to grasp onto a paper coffee cup with a weight of 72 grams. However, when performing the test on a Rubik's Cube, there was clearly not enough surface area to actually hold onto the cube itself. The test was performed onto the Rubik's Cube ten times, and out of those two times it was successful due to the fact that the claw was able to slip into the grooves of the cube.

To improve the aspect of grasping the Rubik's Cube, six foam padding was incorporated onto the claw to add surface area. With that, 3M gripping material was applied to help to create friction. This can be seen in Figure 20 and 21.

Performing the grasping test on the Rubik's Cube, the claw was only able to grasp it for 50% of the time. Observing how the Rubik's Cube was being grasped, there was not that many surface area near the tips of the claw, which seemed to be the issue. After applying another two strips of foam padding with gripping material, one on each side, the Rubik's Cube was successfully being grasped off the table. The eight foam padding can be seen in Figure 22. Notes and weights can be seen in Table VIII.

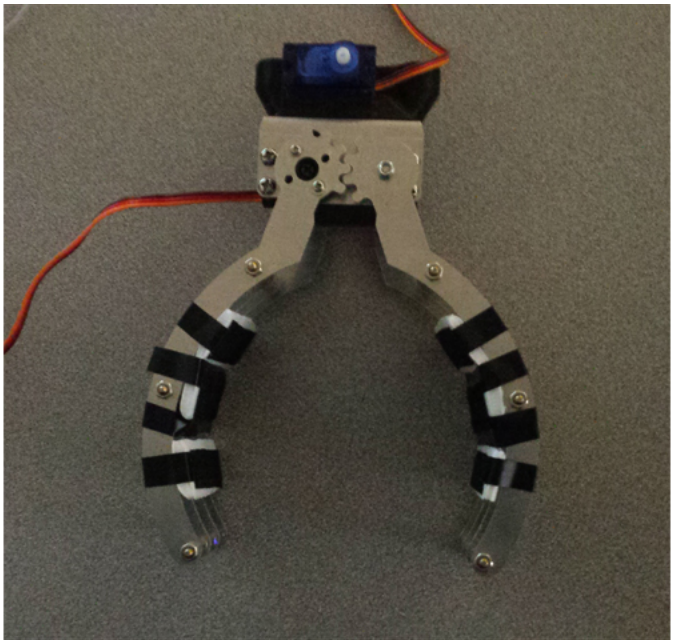


Figure 20: Six Foam Padding Attached to Claw (Top) [41]

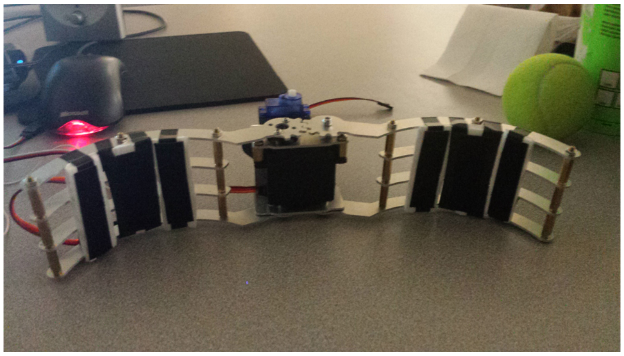


Figure 21: Six Foam Padding Attached to Claw (Side) [42]

E. Ability to Grasp One-Pound

As part of the feature set, our objective was to be able to grasp a one-pound object. For this test, a paper coffee cup was used to be able to vary the weight for testing. The coffee cup can be seen in Figure 19. For this test, we evaluated a successful grasp as being able to still hold the object when retracting from the table with minimal slipping and tilting. However, if the object was continuously slipping, it would be listed as an unsuccessful grasp.

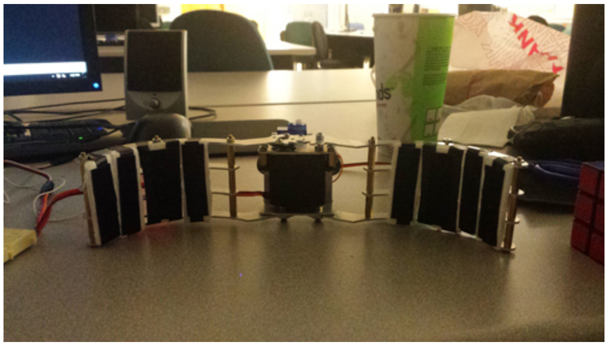


Figure 22: Eight Foam Padding Attached to Claw [43]

The Test:
For the testing, weight would be continuously added until there seems to be an issue with how much weight the claw can handle. Some examples include tilting when being pulled off the surface as well as continuous slipping. From there, redesigns were necessary to take into account to make sure we can reach the objective of grasping one pound.

The Results:
Testing how much weight the claw could hold was conducted the same time as testing the various shaped objects. From the claw that was bought with no redesigns, the claw was having issues grasping up to 180 grams. It was noted that the cup will initially slip upon retracting from the table, but would eventually halt and be considered a successful grasp. This would be problematic if more weight would be continously applied.

After applying the six foam padding as shown in Figure 20, the grasp was more secured. The cup would not slip until it stops, but one thing that was observed was that the cup will tilt upon leaving the surface. From there on, the eight foam padding as seen in Figure 22. The two extra strips of foam padding did not affect the outcome and realized that there needs to be something that conforms to the object. This lead to the idea of adding some sort of tension that will help grasp the objects. This resulted in adding wristbands to one side of the claw to be able to grasp the object while leaving the other side to have a good amount of surface area and friction to hold the object. This claw was able to grasp up to one pound (460 grams) with minimal slipping and no drastic tilts. The test was then stressed to 870 grams in which there were continuous slipping observed for half the time. It was stressed up to 1 kilogram in which there were continous slipping in which we felt that it was not viable to test more than needed. The final result of our claw can be seen in Figure 23. Notes and weights can be seen in Table VIII.

F. User Input Control

The user input controls are a vital part of any control system. While they are technically the simplest parts of the design, they are the sole interface for the user to the device and therefore have a large impact on the user experience. For our device,

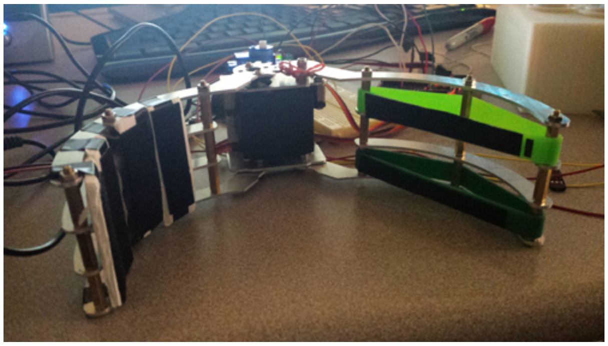
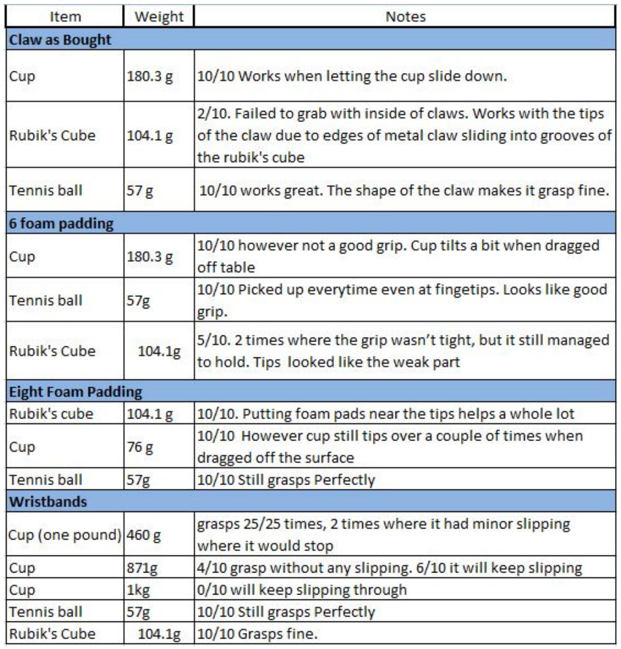


Figure 23: Claw with Wristbands [44]

Table VIII:
Grasp Results [45]



Item	Weight	Notes
Claw as Bought		
Cup	180.3 g	10/10 Works when letting the cup slide down.
Rubik's Cube	104.1 g	2/10. Failed to grab with inside of claws. Works with the tips of the claw due to edges of metal claw sliding into grooves of the rubik's cube
Tennis ball	57 g	10/10 works great. The shape of the claw makes it grasp fine.
6 foam padding		
Cup	180.3 g	10/10 however not a good grip. Cup tilts a bit when dragged off table
Tennis ball	57g	10/10 Picked up everytime even at fingetips. Looks like good grip.
Rubik's Cube	104.1g	5/10. 2 times where the grip wasn't tight, but it still managed to hold. Tips looked like the weak part
Eight Foam Padding		
Rubik's cube	104.1 g	10/10. Putting foam pads near the tips helps a whole lot
Cup	76 g	10/10 However cup still tips over a couple of times when dragged off the surface
Tennis ball	57g	10/10 Still grasps Perfectly
Wristbands		
Cup (one pound)	460 g	grasps 25/25 times, 2 times where it had minor slipping where it would stop
Cup	871g	4/10 grasp without any slipping. 6/10 it will keep slipping
Cup	1kg	0/10 will keep slipping through
Tennis ball	57g	10/10 Still grasps Perfectly
Rubik's Cube	104.1g	10/10 Grasps fine.

the users are people with physical ailments and therefore it is even more important that the user input controls are simple and easy to use.

The Test:
In order to test that the user input controls are simple and easy to use we developed a practical criteria for testing. To test the joystick, the tester sat on a raised chair and placed their dominant arm flat on the table with the user input controls in their dominant hand. This environment setup was meant to mimic a user in a wheelchair with their arm on the arm rest. A disabled user may have limited use of their wrist, fingers, and arms, so we had the user attempt to use all possible operations of control. While they were operating the controls, we took measurements of the angles and amount of travel required to activate the controls. In taking these measurements we are able to quantify the usability of the different types of controls. Aside from quantified results, we asked the tester to be mindful of what they felt in their fingers, wrists, and arms while performing the tests. If they felt any stress, this meant that we may need to modify the controls as a person with limited mobility may not be able to perform these stressful movements.

The Results:
Early on in the testing of our user input controls we realized that our initial setup was going to need to be changed in order to be feasibly used by a person with disabilities. As we we're fortunate to see this early, we were able to develop a completely new and improved set of controls. As we had the old and new controls, we were able to measure and quantify the difference between the two.

Joystick:
With our initial design we used a PlayStation 2 Joystick. This joystick is only 25mm(1 inch) tall, which a circular grip of 20mm. It's the maximum travel of this joystick is 18mm, at which time it has an angle of 50 degrees. It begins registering a reading of movement at 20 degrees, which means the user has to tilt it to at least 20 degrees before the microcontroller can start making a decision with it. After observing the tester using the joystick and questioning them about the stress in their fingers, wrist, and arm we found that there was simply too much dexterity required to operate this joystick. The short height and large movement angles meant that a user will need to be able to manipulate their hand to extreme angles to operate the device - a task that is almost impossible for someone with limited mobility in their fingers, wrist or arm.

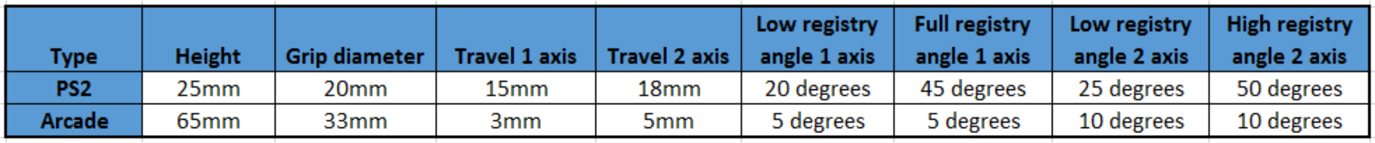
The revised joystick was one taken out of an arcade machine. This joystick was much larger with a height of 65mm. It had a large grip of 33mm, and it's travel was significantly less than the PS2 Joystick - 5mm max. For one axis of movement the joystick only needs to be moved 5 degrees to register, and for two axis it needs to be moved 10 degrees. This resulted in a joystick that was larger and easier to grip, yet only needed to be moved minimal amounts to control the device. When observing the tester, it was clear that very minimal finger, wrist, and arm movement was needed, resulting in little to no stress.

The measurements for these two joysticks can be seen in Table IX.

Button:
With our initial design we used some very cheap microcontroller push buttons. These buttons only had a diameter of 2mm, and required a weight of 42oz (almost 3 pounds) to register a button press. When we observed the tester, it was clear they had to place their finger on the perfect spot on the button and then had to deliberately exert downward force in order for the button to register a click. Clearly, this caused stress in the fingers and wrists of the tester and would be worse for a person with limited dexterity.

Similar to the joystick, our revised buttons were sourced from an arcade machine. These buttons were 26mm in diameter - 13x larger than the previous ones. Furthermore they took only 8oz of pressure to activate, which can almost be obtained by the weight of your fingers. It was clear when we observed the tester that there was no problem finding the buttons and

Table IX:
Joystick Results [46]



Type	Height	Grip diameter	Travel 1 axis	Travel 2 axis	Low registry angle 1 axis	Full registry angle 1 axis	Low registry angle 2 axis	High registry angle 2 axis
PS2	25mm	20mm	15mm	18mm	20 degrees	45 degrees	25 degrees	50 degrees
Arcade	65mm	33mm	3mm	5mm	5 degrees	5 degrees	10 degrees	10 degrees

fully activating them.

The measurements for these two buttons can be seen in Table X.

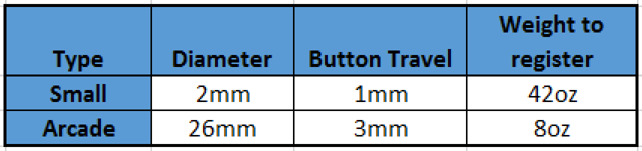
G. Video Feedback

The video feedback system was intended to be a complimentary feature for those users who have limited movement in their neck. Using this feature, they would be able to operate the arm solely through a LCD screen in their lap. This would allow them to keep their head pointed straight forward instead of turning it to try and control the arm. While this feature was an extra, controlling a device through an LCD screen can be complicated if not implemented correctly and needed to be tested to ensure it reached a certain standard.

The Test:
In order to declare the video feedback system as successful it needed to meet two criteria: 1. An object can be successfully picked up and returned through only the use of the camera and LCD screen. 2. LCD screen needed to provide assistance for all functions of the arm, meaning that the user would still need to be able to rotate, extend and retract the arm safely through the use of the LCD screen. We had the tester sit in a position where they could not see anything but the LCD screen, with the user input controls in their hand. We placed a cup to be retrieved approximately 90 degrees to the rotational axis of the arm, and told the tester to attempt to rotate to the cup, extend to it, grasp it, and return it to himself.

The Results:
As we had programmed the camera to move to point in the direction that the arm is rotating, the user was able to rotate the arm and see where it was rotating through the use of the LCD screen. Once they saw they had rotated to where the arm could be extended, they started extending the arm. Through the use of the LCD screen they could see that they were extending straight to the cup, and they moved the claw right up to where the cup was in clasping range. They used the buttons to close the claw, retract the arm, and rotate back to themselves to drop the cup off. Each member of the team took place in this test (as it was exciting,) and we all found that the arm was simpler to operate than we originally projected. Conclusively we found that the arm can be fully operated through the use of the LCD screen, though in the future we would need to add more safety features to take care of the corner cases for this usage model.

Table X:
Button Results [47]



Type	Diameter	Button Travel	Weight to register
Small	2mm	1mm	42oz
Arcade	26mm	3mm	8oz

H. Mounting Test

As requirement by our punch list, we had to ensure our device was capable to be mounted onto a surface. The following test was performed to ensure that requirement was met.

The Test:
This test was relatively simple. We simply mounted the device to a flat surface and attached a cup to the closed claw with a 1 kg weight in it at full extension.

The Results:
Due to the simple nature of our design, our product passed the mounting test. There were no signs of distress of the device with the 1 kg weight at full extension. The robust adaptive nature of arm has proved its viability on multiple surfaces.

X. CONCLUSION

During the term year, our team has taken a societal problem and created a design. The Executive summary describes our entire project in the perspective of a simplified summary for all to read. Creating a simplified version allowed us to describe our vision of the solution to our societal problem. To help the physically disabled, we really had to pull a lot of ideas out to try and decide on the best one. We understood through our research that with we wanted to help those confined to a wheelchair. Seeing the fact that those confined to a wheelchair only had forward reaching capacity of 48 inches[1] at best, we wanted to created an easier way for those who had ambulatory disabilities more freedom. We sat out to follow the ADA's lead by providing a way for those confined to a wheelchair to have more freedom. After more research on those confined to a wheelchair, we further defined our target audience as those with ambulatory confinement, meaning those who did not have full function of there upper body. We came to our design idea through this research and settle our final punch list. The design idea revolved around the following: grasping a 1 pound object, the device is to be mountable, there will be an input system for the user to control it, a video feedback system to provide more of a view, the device will extend and retract, and the device will have horizontal rotation. We settled on this design to create a device that those with very limited mobility will be able to use it without much effort. The claw attachment provided the grasping feature. The claw feature was tested in reliability of opening, as well as the ability to grasp an object. To test the reliability of opening, the device was opened and closed for 60 seconds. The test proved a reliable 50 openings and 49 closings on a consistent basis. The object grasping test proved more challenging. Using three different shaped objects, the claw was tested in its ability to grasp onto an object after it was pulled off the table. We discovered a deficiency with the ability to grasp square objects. After some brain storming we were able to devise a plan which was able to conquer the square. The final design included some added gripping material to allow us to grasper the elusive square Rubik's Cube. The linear extension would through a reliability test as well. The linear extension was found to move at an average of 1.30 inches per second, and 1.29 inches per second backwards. The horizontal movement went through similar testing yielding an average speed of 1.135 inches per second right, and 1.315 left. Examining the code we realized we had set the duty cycle differently for the two so we corrected the software to resolve that particular issue. We tested those two movements ten times to ensure a reliable average could be determined. The joystick underwent testing as well after the change was made. We originally started out with a PlayStation 2 style joystick, but decided on a change in the spring semester. We decided by providing a simple arcade style joystick we allowed for more error in movement. The PlayStation 2 style joystick was to precise for our end users, and did not account enough for accidental movements. We measured the difference in "registry" of the two units, and decided the arcade style was more useful for our particular application. The test results confirmed the this idea because it only took 5 degrees of movement to register a button movement with the arcade, while the PlayStation 2 style device took 20 degrees. The user would have to move less to accomplish the desired movement with the arcade style joystick. The final feature test results was the video feedback system. The test was as simple as using only the video feedback only to identify an object, and attempt to retrieve it. We discovered that not only could we effectively grasp objects, but other users who had no knowledge of our product could as well.

All of the features met by our device came with a monetary cost. We had initially came up with a range of $540 - $1970. Luckily for use we only ended up spending approximately $321.52. We were able to prototype an effective solution, as well as a cost effective solution. With all the objectives of our project we had budget our time as effectively as our money. During the semester we enjoyed our share of milestone moments from our design finalization to proving the the design hitting the feature set. We took time to bask in the milestones as they came, but we also kept our eyes forward. We used our work breakdown structure to help guide us during the entire year. We divided up the tasks based on strengths and knowledge to help use stay focused. As seen in the task table we manage to chalk up 551 hours throughout the entire year.

Another important part of our project was the risk assessment and mitigation plan. We divided up the risk with two metrics, likelihood and impact. We used these metrics to judge what the team should effectively spend their time to to ensure the project continued marching on. We created a table and looked into what could cause the failures and effectively decided on a plan of action to help mitigate those risks. We were very fortunate in that we were able to avoid catastrophic failure, and we give credit to our risk assessment. The few failures we foresaw in our assessment were remedied quickly or effectively mitigated.

Throughout the year our team has managed to create a function device, that with further development, could lead to a real impact in those confined to a wheelchair's life. From the initial problem statement to the final roll out of our design, we have manage to overcome obstacles to achieve what we set out to do, create a robotic arm capable of bringing in a one pound object controlled by the user, and mounted to a wheel chair in so that the user can experience more freedom. This has been a learning experience that will set the stage for further development and design.

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XI. GLOSSARY

3D Printer - A three dimension printer that uses plastic filaments, and prints on the x-y-z axis planes.

ADL - Activities of Daily Living are daily activities that able-bodied people do without trouble or stress. Disabled persons may have trouble performing such tasks or may be time consuming.

Arduino IDE - Arduino microcontroller integrated developer environment is the software used to program Arduino microcontrollers.

CNC machine- Computer numerical control machining uses computers to control machining tools.

LCD- Liquid Crystal Display is a video display that using modulation of light in the liquid crystal.

Linear Actuators- A device that moves in one direction using electro-mechanical forces in a linear fashion.

Lithium Polymer Battery (Li-Po) - a type of lightweight rechargeable battery.

Microcontroller- single chip computer with built-in memory, and programmable input and output pins.

PID – Proportional, Integral, Derivative. This is a cybernetics algorithm that has 3 different approaches to the problem of "we are here, and we want to be there." It is primarily used to reduce jitter in control systems.

PVC - Polyvinyl chloride is a type of plastic polymer commonly used in piping.

Stepper Motors- DC motors which rotate with phase control with discrete steps. The steps are computer controlled yielding adequate accuracy.

APPENDIX A
USER MANUAL

1. Start by connecting the JST(battery connector) to the battery. Wait approximately 5 seconds for device to stabilize.

2. To move extend the device forward, press the joystick in the forward direction. To retract the device, pull the joystick in the backward direction.

3. To move the arm left or right, press the joystick in the left or right direction.

4. When device is grasping distance of the object, press the left button on the controller platform.

5. Use the motion control joystick to retard the desired object to desired location, and press the right button to open the claw.

Table XI:
C.L.A.W. Functionality [48]

Action	Response
Left pushbutton push	Claw opens 1 degree
Left pushbutton hold	Claw opens at a constant rate until fully
Right pushbutton push	Claw closes 1 degree
Right pushbutton hold	Claw closes at a constant rate until fully
Joystick left on X axis	Retract the claw in the linear motion.
Joystick right on X axis	Extend the claw in the linear motion.
Joystick left on Y axis	Rotate the arm left. Camera will turn to look left.
Joystick right on Y axis	Rotate the arm right. Camera will turn to look right.
Joystick centered on Y axis.	Camera will look forward.

4. To power down the arm. Simply remove the Lithium Polymer battery from the power distribution harness.

APPENDIX B
HARDWARE

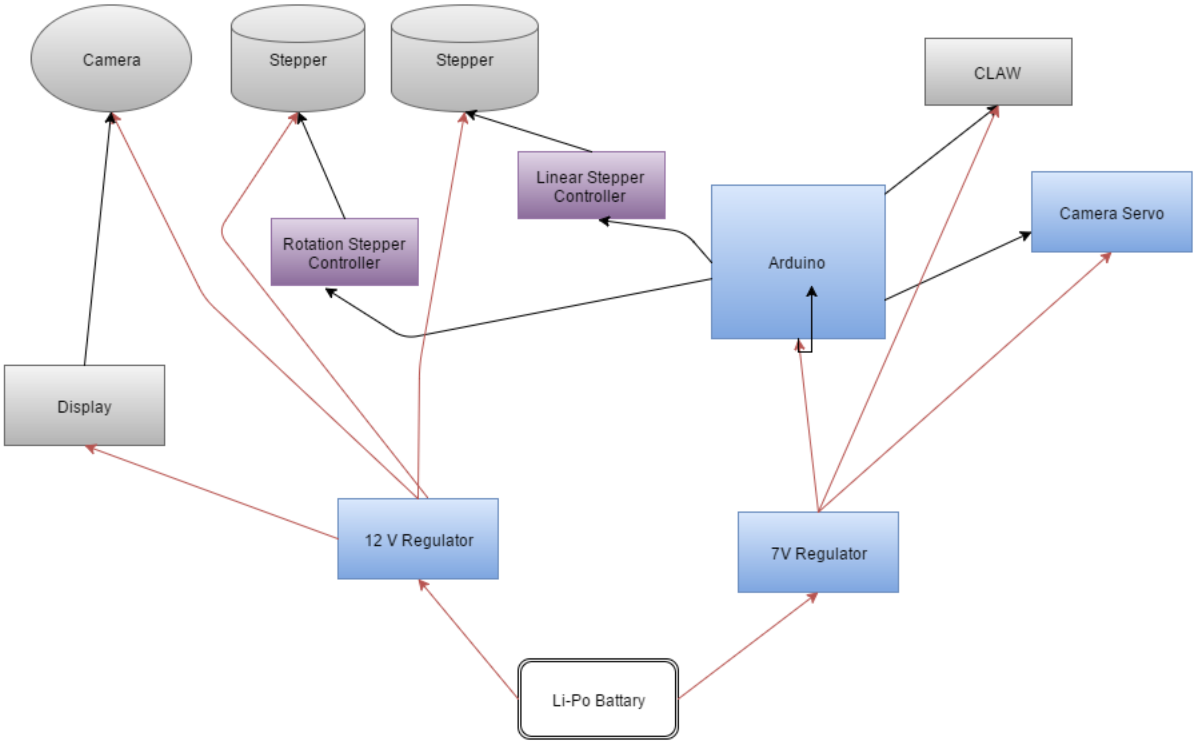

Figure 24: The C.L.A.W. Diagram [49]

Our project, the C.L.A.W, is built up of both electronic and not electronic parts. We unitized what we either had on hand or found a cheap substitute. The team is not funded form any outside sources so the team aid for everything ourselves. This limited the choice of materials that we were able to use. We first looked at what the team had on hand which was the Arduino microcontroller and that was about it. We decided that wood and plastic part were the lightest and most economical. The claw was also researched and chosen for the weight and price. The motors were the highest cost item and were chosen because we needed the power and control that they could supply. We used servos for controlling the claw and camera based on the size and weight of them. This section will discuss the hardware that was used, why we used it and how it was used.

The joints are made from wood and plastic parts. The parts were obtained from Home Depot and local hardware stores. The decision to go with wood and plastic is due to the low cost and ease to work with. Drawing were made up in SolidWorks and then translated to the wood pieces. The wood is five inches wide and a foot and a half long with the depth of a quarter inch. The wood was cut and drilled to fit the needs of the project. Next team decided to use PVC piping; the pipe is a three inch in diameter and one and a half foot long. The team chose the pipe size because of the agreed upon design for the linear bearings. Once the pipe was sanded and connected to the cap that holds the liner bearings. The pipe is connected to the board with U-clamps and bolted together. The PVC and wood make up most of the structure of the arm.

The team had to find the best way to create linear motion. After some research we found that there was a rod and bearing apparatus that is both cheap and strong. The team then needed to design a mounting structure for the linear bearing that was done is SolidWorks and described in the previous paragraph. We needed to use two rods and four bearings for the arm the rods are thirty-two inches long and the bearings are a linear type that the rods fit into and glided with little resistance.

We chose to use stepper motors for our project because we can control the amount of movement without having to have a feedback system. This not only helped with the coding of the microcontroller but it also cut down on cost. The stepper motors we chose is the NEMA 17. The NEMA class of stepper motors are very popular and has a lot of information on the internet another reason we chose the motors. The 17 is a specific model that fits the project requirements. The motor take 1.5 Amps per phase and only 7 volts, because the arm will one day be place on a wheelchair power consumption is a factor. The motors are bipolar and are controlled with a driver for forward and reverse operation. The driver that was chosen was theDRV8825 stepper motor driver. We chose this driver because it is able to supply the 1.5 amps that the motor needs. The driver also has the ability to step the motor at different intervals like half and quarter stepping. We need this for our project to accurately rotate the motors to control the joints. The motors are mounted in two places one at the bottom of the board and the other on top off the rotating tube.

We utilized a 3D printer for a few parts of our project. We need mounts for each motor. The mounts were designed in SolidWorks and then printed with a printer owned by a team member. We also needed gears and a pulley to translate the rotation of the motor to the linear actuation and the rotation for each joint.The team designed a mount for the claw and the servo for the camera. The mount mates up with the two rods and is held in place with the fishing line that is attached to the motor.

Our team decided to buy a claw from eBay. We went with store bought because it was cheap and much better than anything that we could have design. The claw we got needed a servo motor.The data sheet for the claw called for a specific servo motor that fit inside the claw. We also needed a servo for the rotation camera one of the team members had an extra servo so we chose that. The camera we picked out was a package that came with a monitor. The camera is small and located on a PCB that is one inch square and it is attached to the monitor with an AV cable the monitor is a five inch screen with a 240 resolution. The monitor is large enough for the user to see the surrounding area and small enough to be portable for the wheelchair.

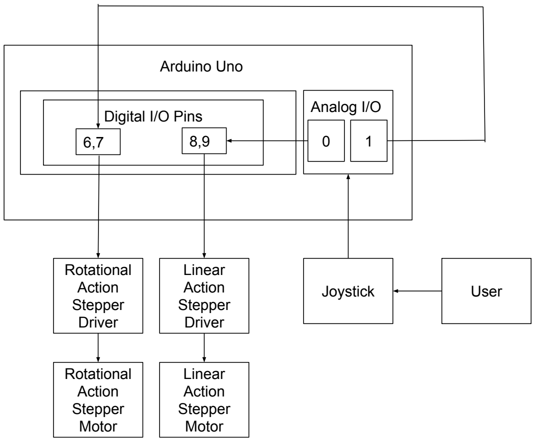

Figure 25: Arduino Uno Diagram [50]

The joints are to be controlled by an input from the user. We have decide to use a toggle style thumb stick. We chose the Breakout Module Shield PS2 Joystick. There are two reasons why we chose this joystick the first is the compatibly with the Arduino and the second is the cost of the board, it was cheap. The platform or mounting place for the joystick will be created in the spring semester.

APPENDIX C
SOFTWARE

The software used in our project was limited to the Arduino Integrated Developer Environment. The Arduino Uno was the only programmable device in our project, so it provided a limited software requirement. Our code did undergo quite a few revisions as the project was developed and obstacles address.

Stepper Motor Software Upon start up, the software would begin to loop through the main function calling the stepper functions we designed for our project. Within the stepper functions, it would take a read from the analog pin, which in our case would take a reading from the joystick, and perform an action. The action for the linear and rotation actions were the same in regards to the code. In this document they are interchangeable with one another in software operation. The micro controller would take the analog read and decide which stepper motor to engage or both stepper motors. The axis on the joystick would determine the stepper motor. The multi-axis read then would determine which direction the steppers needed to turn. The joystick is a 10k potentiometer with a static point at around 5k in both directions, which allows for two directions on each axis. For example, at the static buffer in the software, the analog read will return the position and the if else statement will execute a command. In this example will it output not action is necessary. If the joystick is pushed past the buffer, the Uno will output the direction pin to the stepper driver as well as the pulse speed. We then implemented if else statements with a buffer to decide which direction the individual stepper motors would turn using the direction pin on the stepper motor driver. The micro controller would then send a pulsed digital signal to the stepper motor driver to get them to turn. To provide safety for the user we implemented a counter to count the total number of steps each motor was making. Anytime the direction pin was enabled the counter would count the other direction to keep track of the position in regards to the user. For example, if the counter reached the limit set in the code, it will only able to move in the opposite direction. As the apparatus moves in the opposite direction the counter will decrement thus allowing for movement again. The code can be seen in Appendix C. **Servo Control** To control the grasping on the claw, we broke out another function to control the servo on the claw. We used the native servo libraries built into the Arduino IDE to control the servo's closing and opening. The Arduino would take two digital inputs from two buttons, and perform a digital write on the pins connecting the servo. We implemented if else statements to decide whether to close or open the claw using the servo libraries. The code also accounts if both buttons are pushed preventing any over current condition. Finally, the claw code also has a closing limit to not allow any crushing to occur. This limit also creates a current limiting condition to protect the entire system. The code functioned by entering the main loop and checking for a read from each button. If button 1 is high the claw would open until the limit was reached. If the limit was reached the claw would no longer move, but the Arduino would not rentered the main loop. Once button 1 goes to logic low, the Uno would then return to main a call the servo function again. If the read returned a logic high on button 2, the Uno would output a signal to close the servo using the servo library.

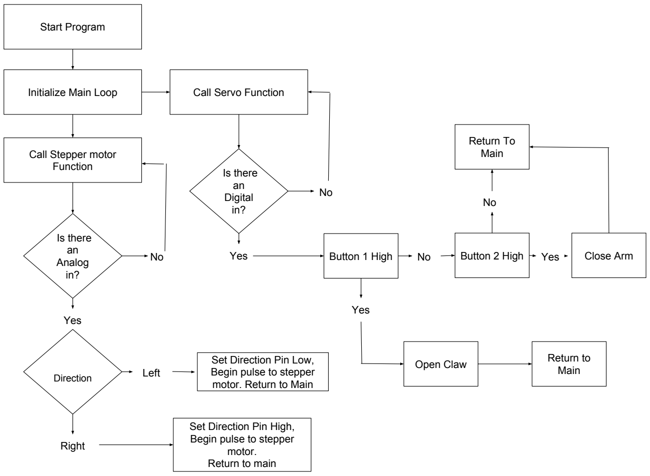

Figure 26: Software Flow Chart [51]

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Arduino Code

```
//*****************************************************
//* Control code for Senior Design Team 2's Robotic Arm
//* Authors:
//*   David Stark
//*   Cindy Chao
//*   Jesse Graham
//*   Kevin Hartman
//*
//* Sacramento State, Fall 2015
//* Professor Russ Tatro
//*
//* Main loop calls function that check joystick and button
//* input and adjusts stepper motors and servos accordingly
//*
//*****************************************************


//**********************Includes**********************
#include <Servo.h>

//Print every PRINTINTERVAL seconds
#define PRINTINTERVAL 500

//********************PINDeclarations********************
//Linear movement pins
#define LINDIR     12//controls direction
#define LINSTEP    11 //pulse control
//Rotational movement pins
#define ROTDIR     10
#define ROTSTEP    9
#define OPENBUTT  7
#define CLOSEBUTT 6
//Boundaries for the claw
#define MAXCLAWDEG     62
#define MINCLAWDEG     0
//Servo pins
#define CLAWPIN    8
#define CAMPIN     13
//Joystick Pins
//{UP, DOWN, LEFT, RIGHT} so if left/right is reversed swap index 2 and 3
int jPins[4] = {5, 2, 3, 4};
int camDirs[3] = {100, 190, 50};
//Don't change the order of these directions
enum jDirections {UP, LEFT, RIGHT, DOWN};
```

```
//********************Global Variables********************
//Servo objects
Servo clawServo;
Servo camServo;

//Position trackers for the servos and stepper motors
int clawPos = MAXCLAWDEG;
int camPos = 1; //0 = Left, 1 = Middle, 2 = Right
int linCounter = 800;
int rotCounter = 0;

//Variable that holds the next time to print
unsigned long nextPrint = millis();






//******************************************************
//********************Setup Function********************
//******************************************************
void setup(){
 pinMode(LINDIR, OUTPUT);
 pinMode(LINSTEP, OUTPUT);

 clawServo.attach(CLAWPIN);
 camServo.attach(CAMPIN);

  clawServo.write(clawPos); //Move the claw to it's initial position.
  camServo.write(camDirs[UP]); //Point the camera straight forward

 pinMode(OPENBUTT, INPUT);
 pinMode(CLOSEBUTT, INPUT);

 Serial.begin(9600);
}


//*********************************************************
//********************MainControl Loop********************
//*********************************************************
void loop(){
   int joystickPressed = checkJoystick();
  //Serial.println(joystickPressed);
   if (joystickPressed != -1){
```

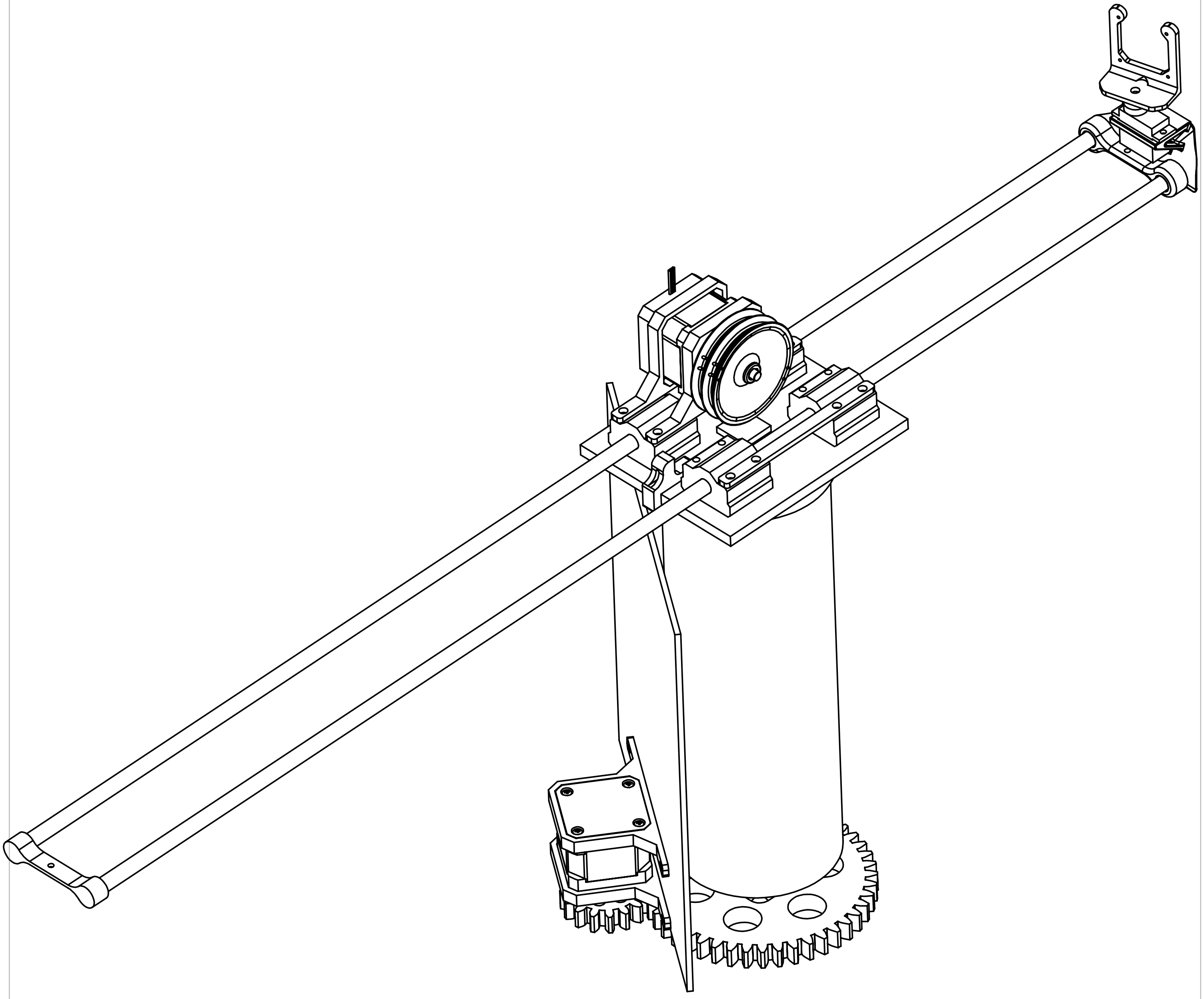
```
    startMotor(joystickPressed);
    }
   //stepLin(xanalog); //Check linear motion input
   //stepRot(yanalog); //Check rotational motion input
   checkClaw();      //Check to see if we need to move the claw

   //Print if it's time
   if (millis() > nextPrint){
      //Do printing as we need it.
     Serial.print("clawPos");
     Serial.print(clawPos);
     Serial.print(", camPos");
     Serial.print(camPos);
     Serial.print(", linCounter");
     Serial.print(linCounter);
     Serial.print(", rotCounter");
     Serial.println(rotCounter);
     nextPrint = millis() + PRINTINTERVAL;
   }
}





//************************************************************
//********************Helper Functions********************
//************************************************************

//******************stepLinFunction**********************
int checkJoystick(){
  int i = 0;
  for (i = 0; i < 4; i++){
    if (digitalRead(jPins[i]) == LOW){
      return i;
    }
  }
  return -1;
}

//******************stepLinFunction**********************
void startMotor(int numDirection){
 switch(numDirection){
    case UP:
      stepLin(UP);
```

```
    break;
    case DOWN:
      stepLin(DOWN);
    break;
    case LEFT:
      stepRot(LEFT);
    break;
    case RIGHT:
      stepRot(RIGHT);
    break;
  }
}

//******************stepLinFunction**********************
void stepLin(int num){
  int speed1 = 2500;
  if (num == UP){
    digitalWrite(LINDIR, HIGH);
    while(digitalRead(jPins[UP]) == LOW){
      //if (linCounter < 800){
        digitalWrite(LINSTEP, HIGH);
        delayMicroseconds(speed1);
        digitalWrite(LINSTEP, LOW);
        delay(20);
        //linCounter++;
      //}
    }
  }
  else if(num == DOWN){
    digitalWrite(LINDIR, LOW);
    while(digitalRead(jPins[DOWN]) == LOW){
      //if (linCounter > 0){
        digitalWrite(LINSTEP, HIGH);
        delayMicroseconds(speed1); //THE LONGER THE DELAY THE SLOWED THE TURNS
        digitalWrite(LINSTEP, LOW);
        delay(20);
        //linCounter--;
      //}
    }
  }
  else{
    digitalWrite(LINSTEP, LOW);
  }

}
```

```
//********************stepRot Function********************
void stepRot(int num){
  int speed1 = 3000;
  if (num == LEFT){//left.
    digitalWrite(ROTDIR, HIGH);
    checkCam(LEFT);
    while(digitalRead(jPins[LEFT]) == LOW){
      digitalWrite(ROTSTEP, HIGH);
      delayMicroseconds(speed1); //THE LONGER THE DELAY THE SLOWED THE TURNS
      digitalWrite(ROTSTEP, LOW);
      delay(35);
      rotCounter++;
     }
    }
  else if(num == RIGHT){
    digitalWrite(ROTDIR, LOW);
    checkCam(RIGHT);
    while(digitalRead(jPins[RIGHT]) == LOW){
      digitalWrite(ROTSTEP, HIGH);
      delayMicroseconds(speed1); //THE LONGER THE DELAY THE SLOWED THE TURNS
      digitalWrite(ROTSTEP, LOW);
      delay(35);
      rotCounter--;
     }
   }
  checkCam(UP);
}

//********************checkCam Function********************
//Checks the position of the camera versus the value passed in.  If the value passed
in is not equal to the current position, move to the desired position.
void checkCam(int dir){
  switch(dir){
    case LEFT: //Check if camera is left
        if (camPos != LEFT){
          Serial.println("Moving camera left.");
          camServo.write(camDirs[LEFT]); //60 degrees from 90 left
           camPos = LEFT;
        }
       break;
   case UP: //Check if camera is centered
        if (camPos != UP){
          Serial.println("Moving camera center.");
          camServo.write(camDirs[UP]); //straight forward
           camPos = UP;
        }
```

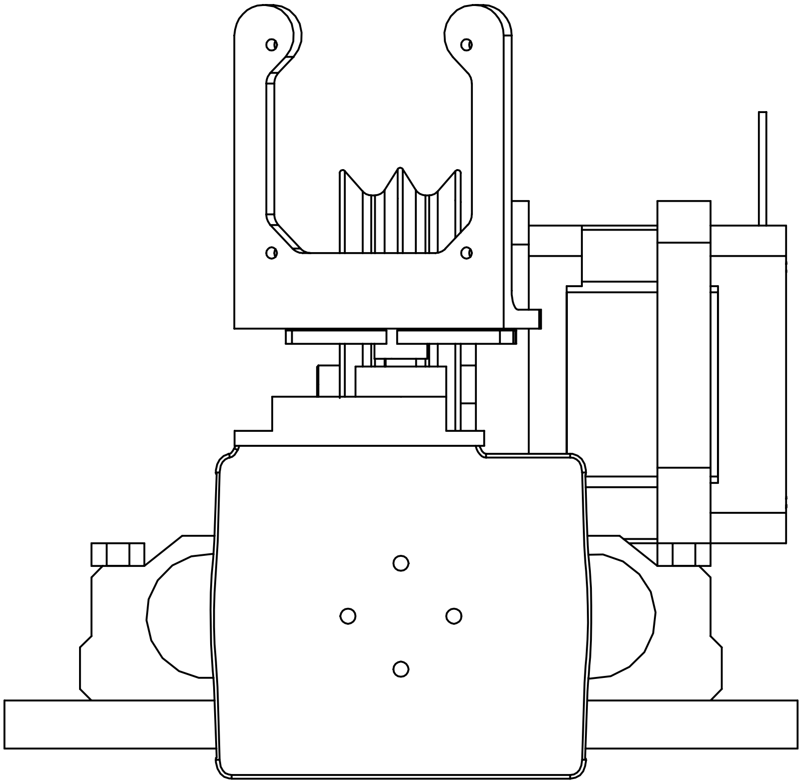
```
      break;
   case RIGHT:  //Check if camera is right
        if (camPos != RIGHT){
          Serial.println("Moving camera right.");
          camServo.write(camDirs[RIGHT]); //60 degrees from 90 right
          camPos = RIGHT;
        }
      break;
  }
}

//********************checkClaw Function********************
//CLAW SERVO STUFFS
void checkClaw(){
  int openB = digitalRead(OPENBUTT);
  int closeB = digitalRead(CLOSEBUTT);

  if (openB == HIGH){
    if (closeB == LOW){
      if (clawPos > MINCLAWDEG){
        clawServo.write(clawPos--);
        delay(10);
      }
    }
  }
  else if (closeB == HIGH){
    if (openB == LOW){
      if (clawPos < MAXCLAWDEG){
        clawServo.write(clawPos++);
        delay(10);
      }
    }
  }
}
```

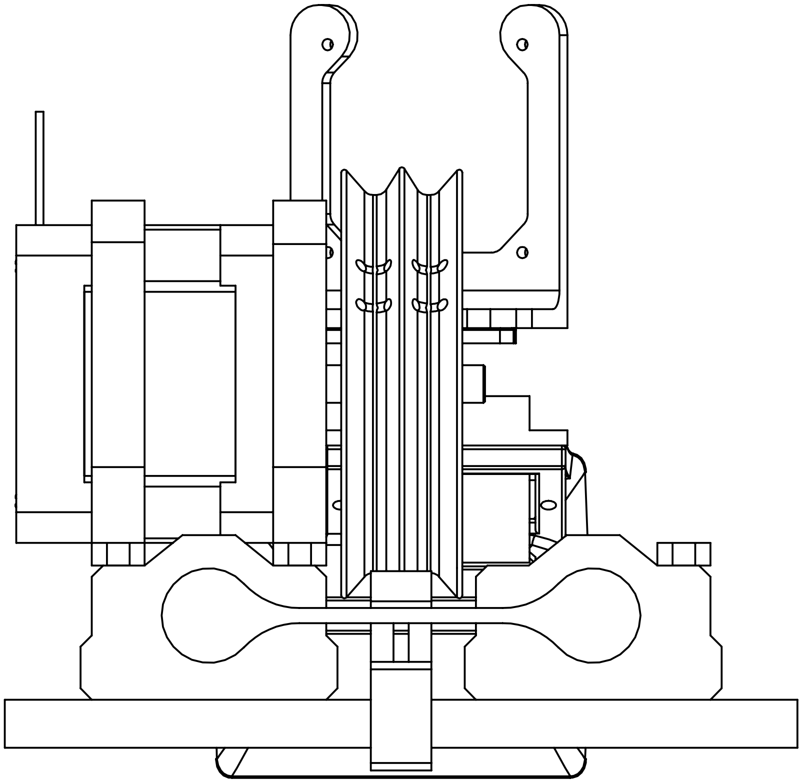
APPENDIX D
MECHANICAL DRAWINGS



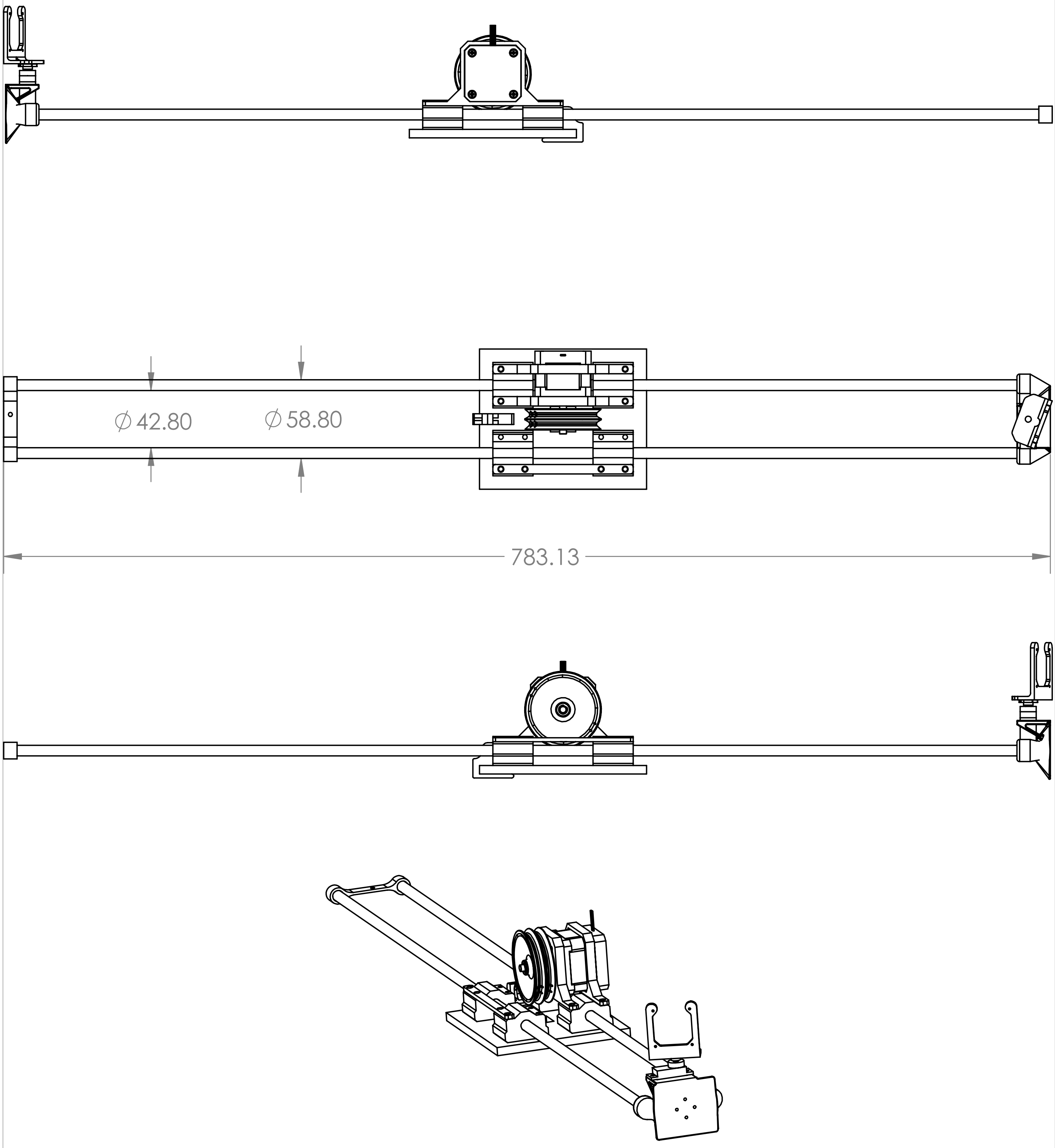
SIZE	DWG. NO.	REV.
A	Whole thing assembled	

SCALE:1:3	WEIGHT:	SHEET 1 OF 1

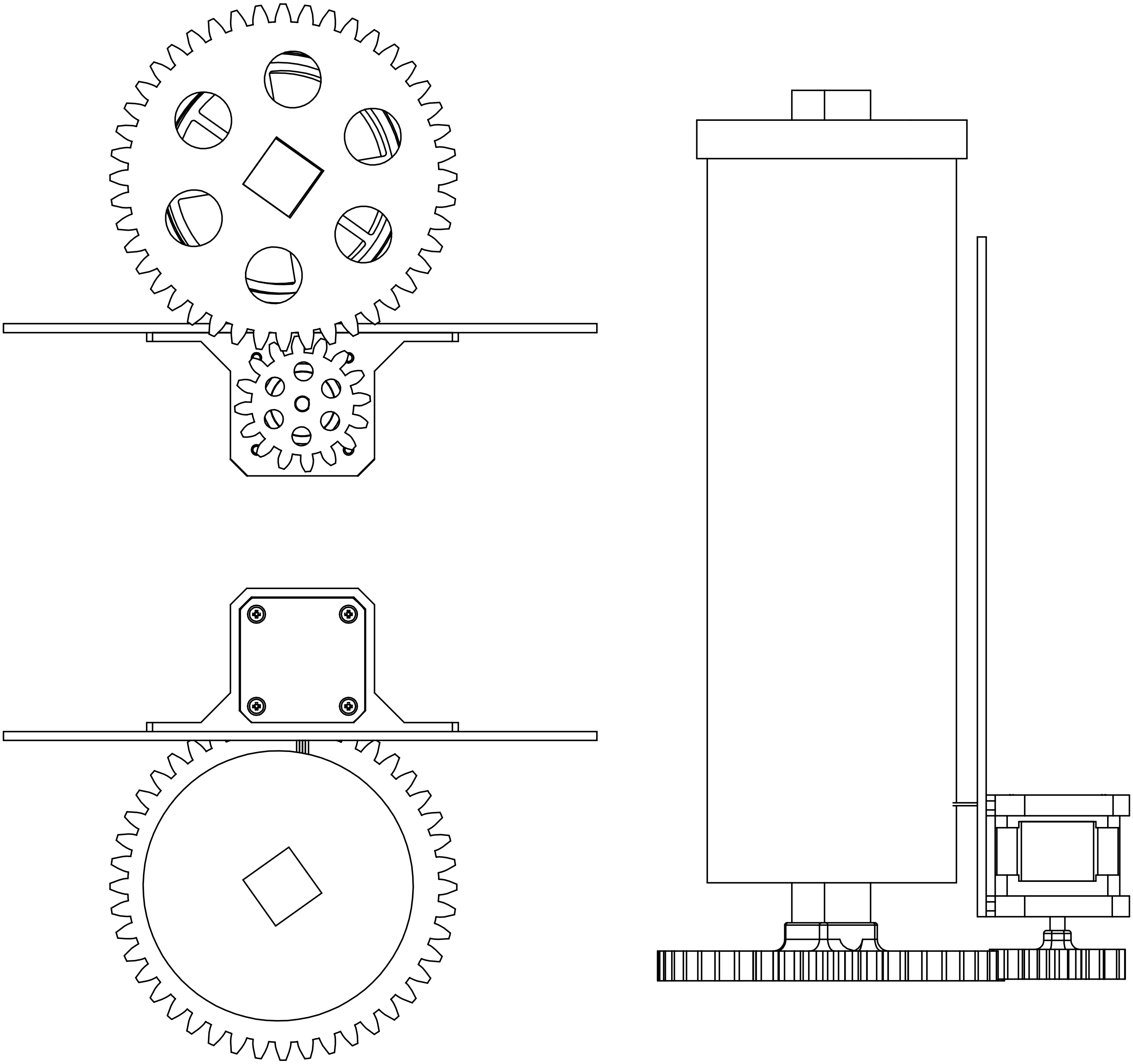




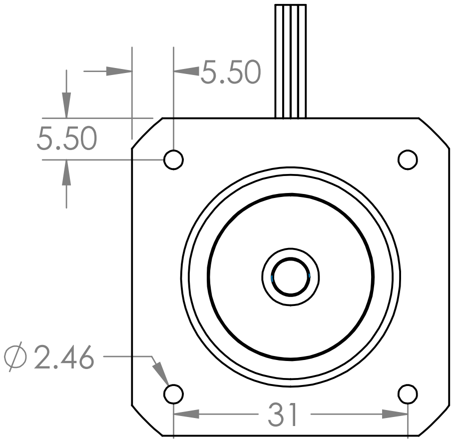
SIZE A	DWG. NO. Linear Motion 1	REV.
SCALE:1:1	WEIGHT:	SHEET 1 OF 1

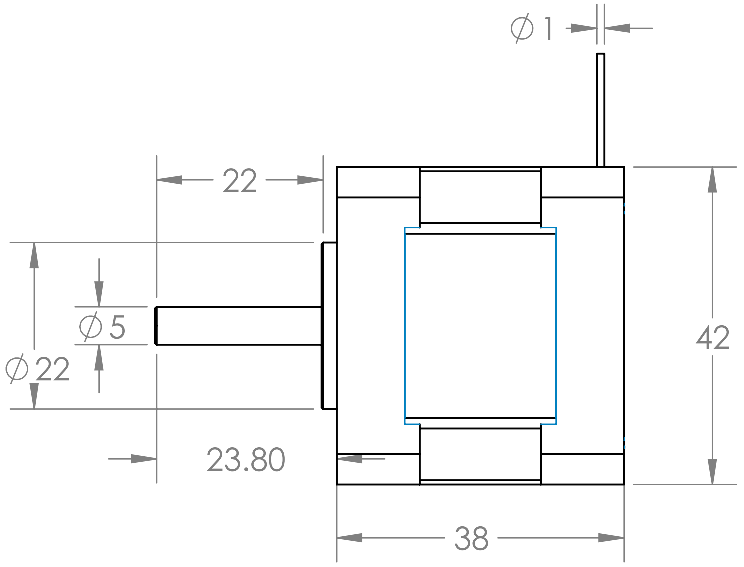


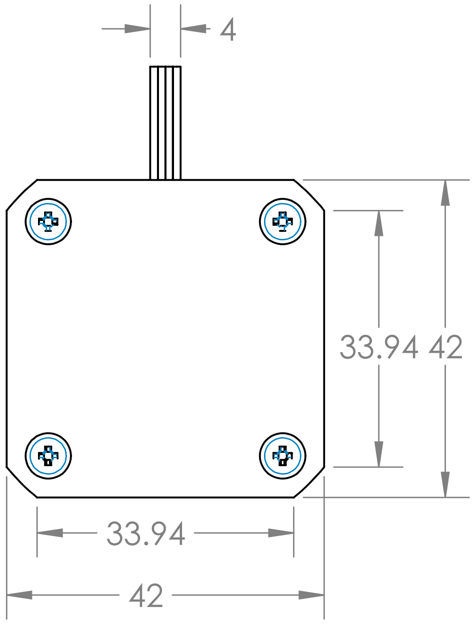
SIZE	DWG. NO.		REV.
A	Linear Motion 2		
SCALE:1:4	WEIGHT:	SHEET 1 OF 1	

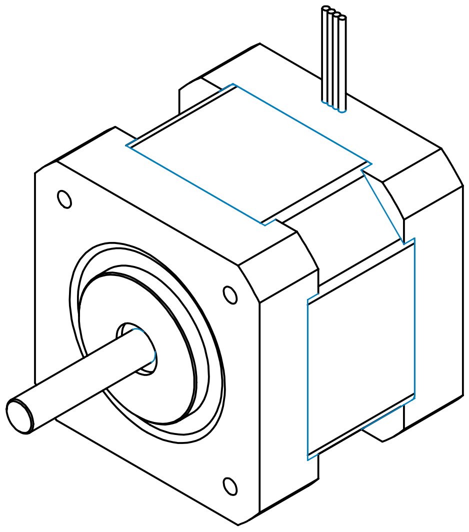


SIZE	DWG. NO.		REV.
A	Rotating mount assembled		
SCALE:1:2	WEIGHT:		SHEET 1 OF 1

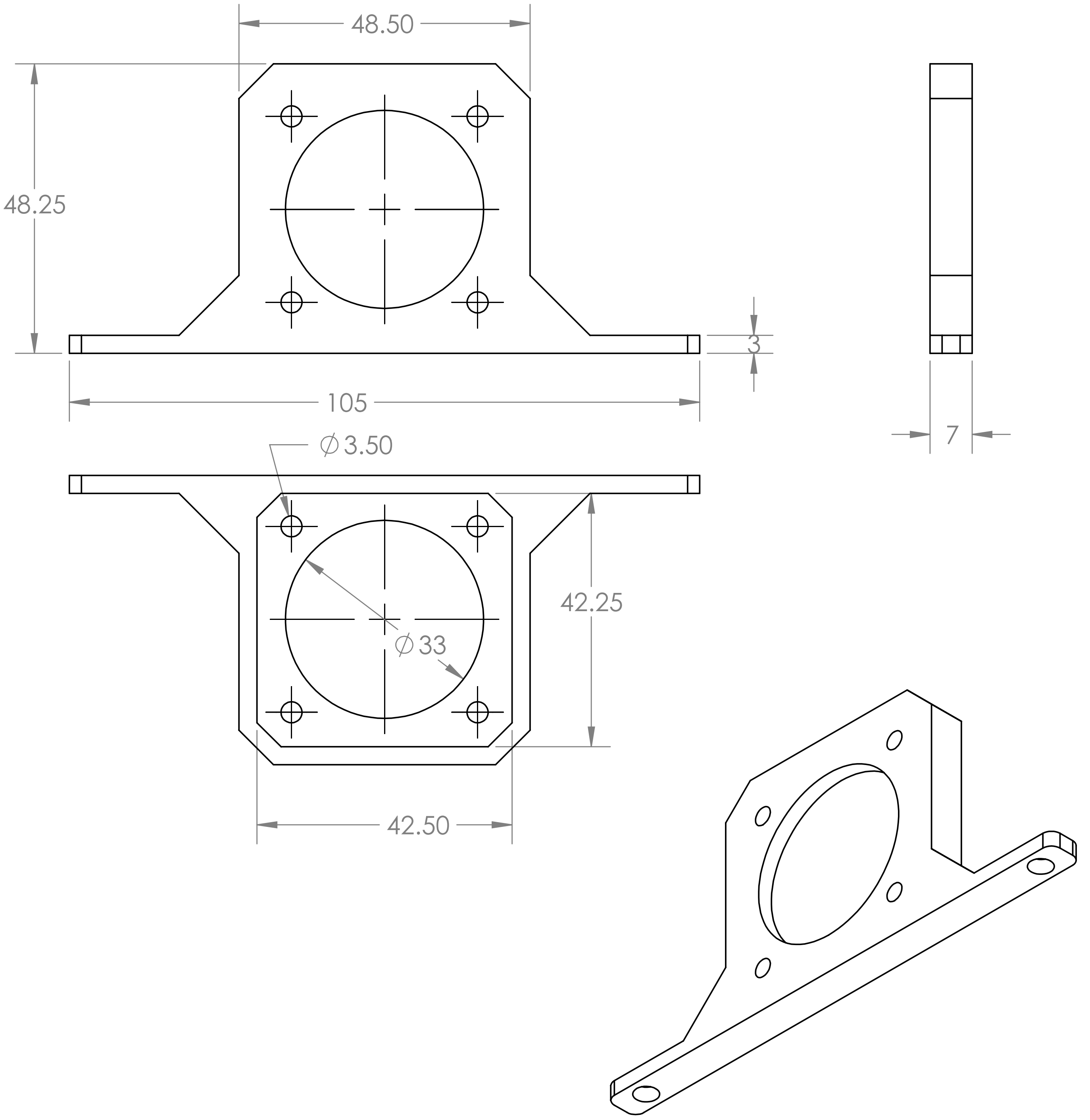








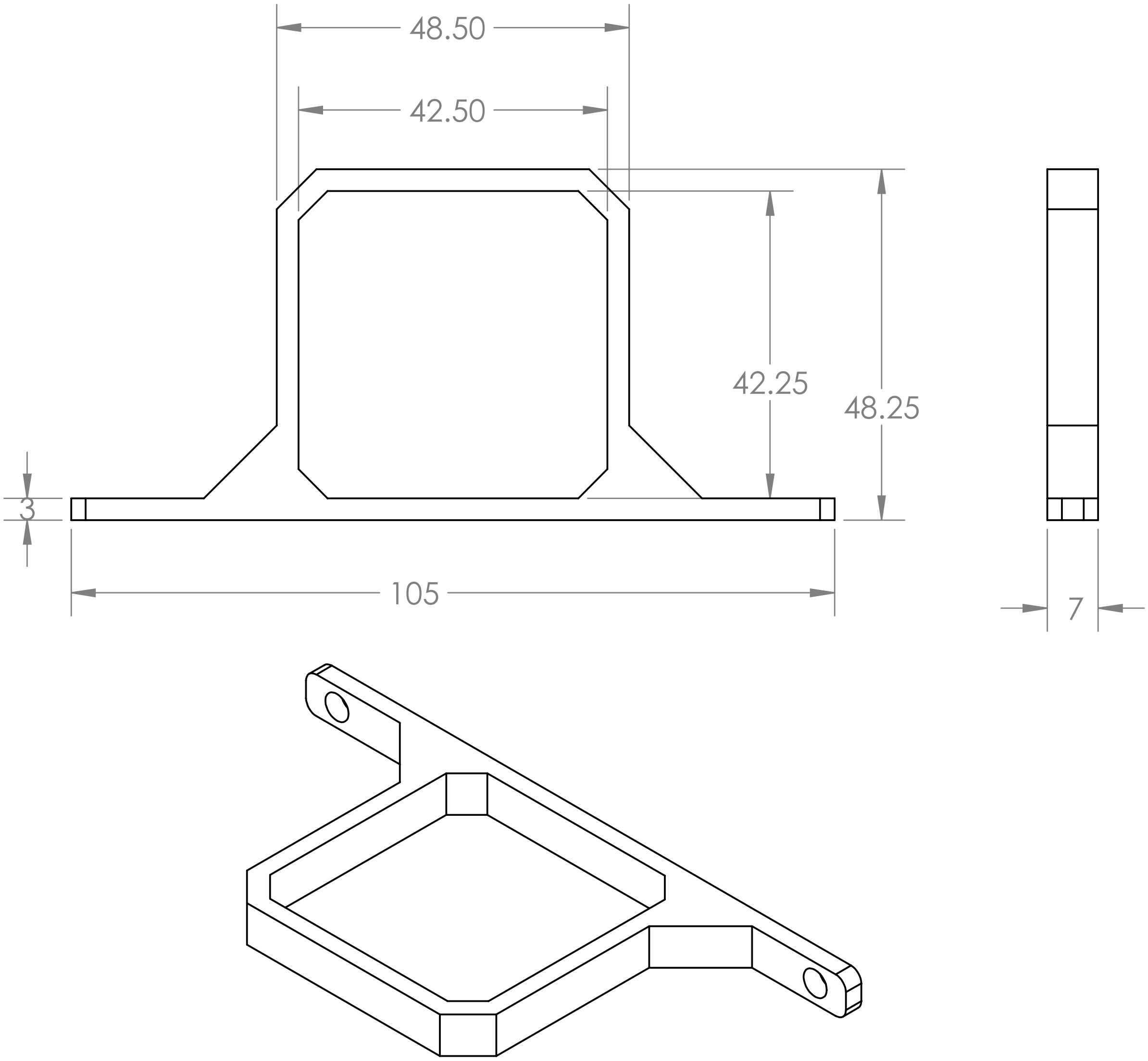
SIZE A	DWG. NO. Nema17 Motor		REV.
SCALE:1:1	WEIGHT:	SHEET 1 OF 1	



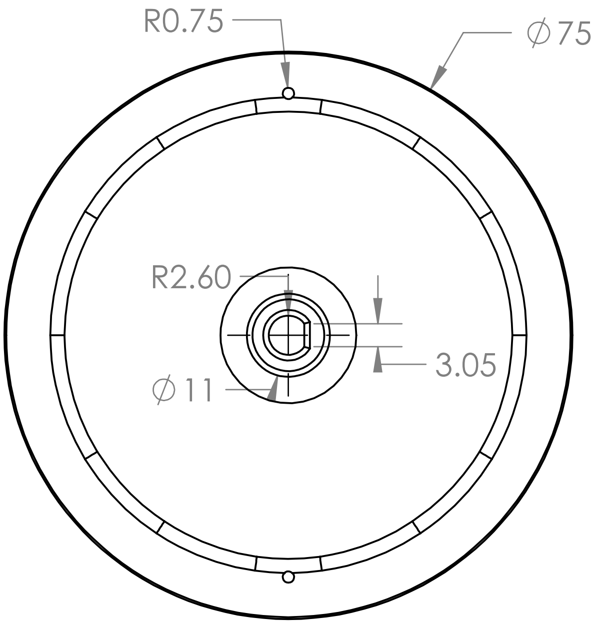
SIZE DWG. NO. REV.

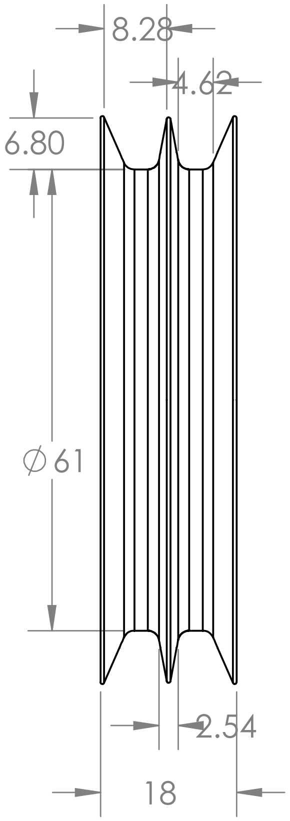
A Motor Mount Wrap Around

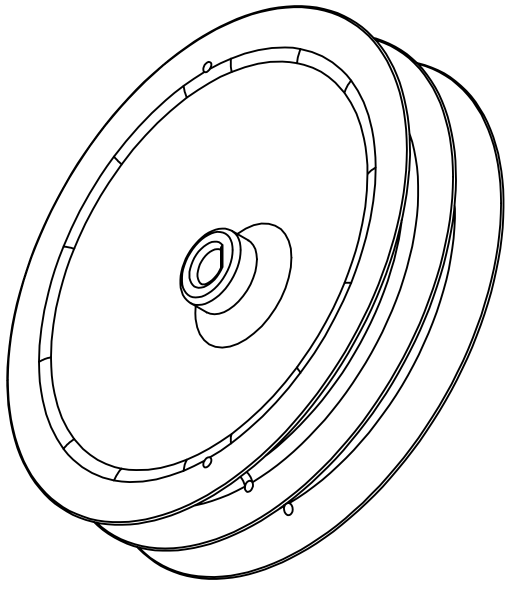
SCALE:1:1 WEIGHT: SHEET 1 OF 1



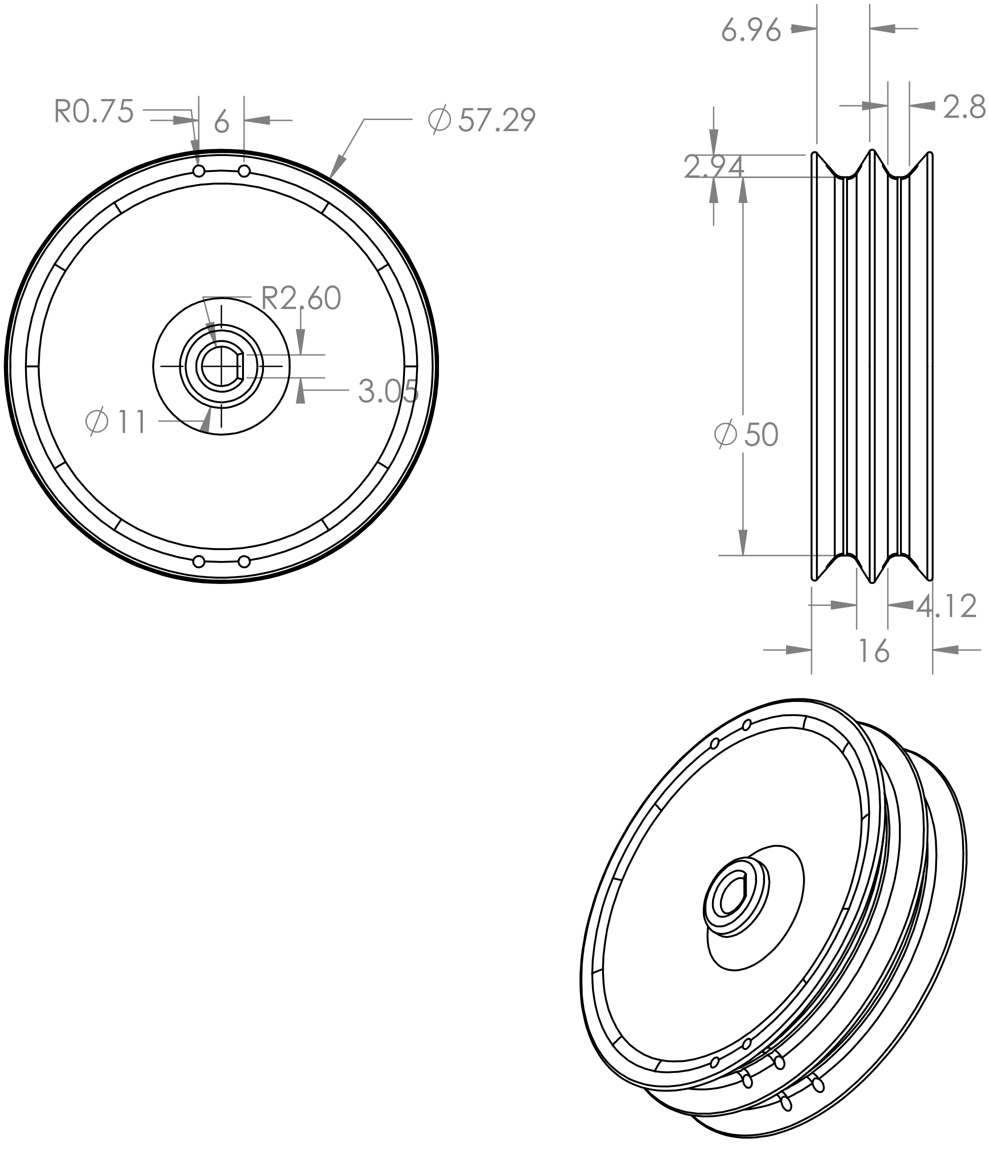
SIZE A	DWG. NO. Motor Strap		REV.
SCALE:1:1	WEIGHT:		SHEET 1 OF 1



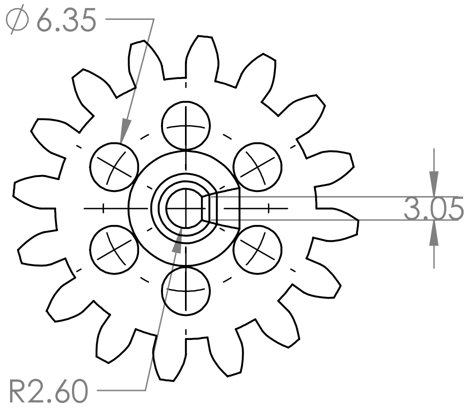


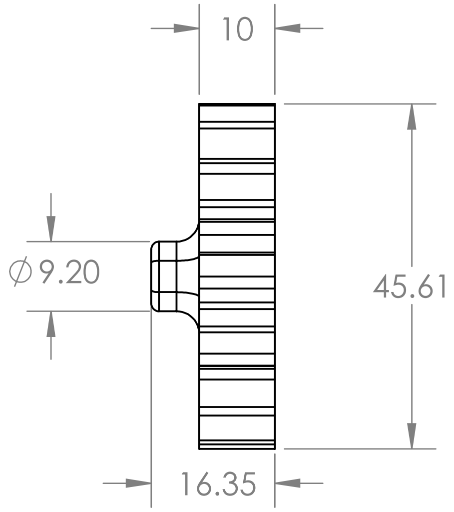


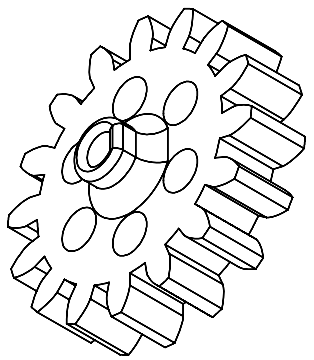
SIZE **A**	DWG. NO. Pulley	REV.
SCALE:1:1	WEIGHT:	SHEET 1 OF 1



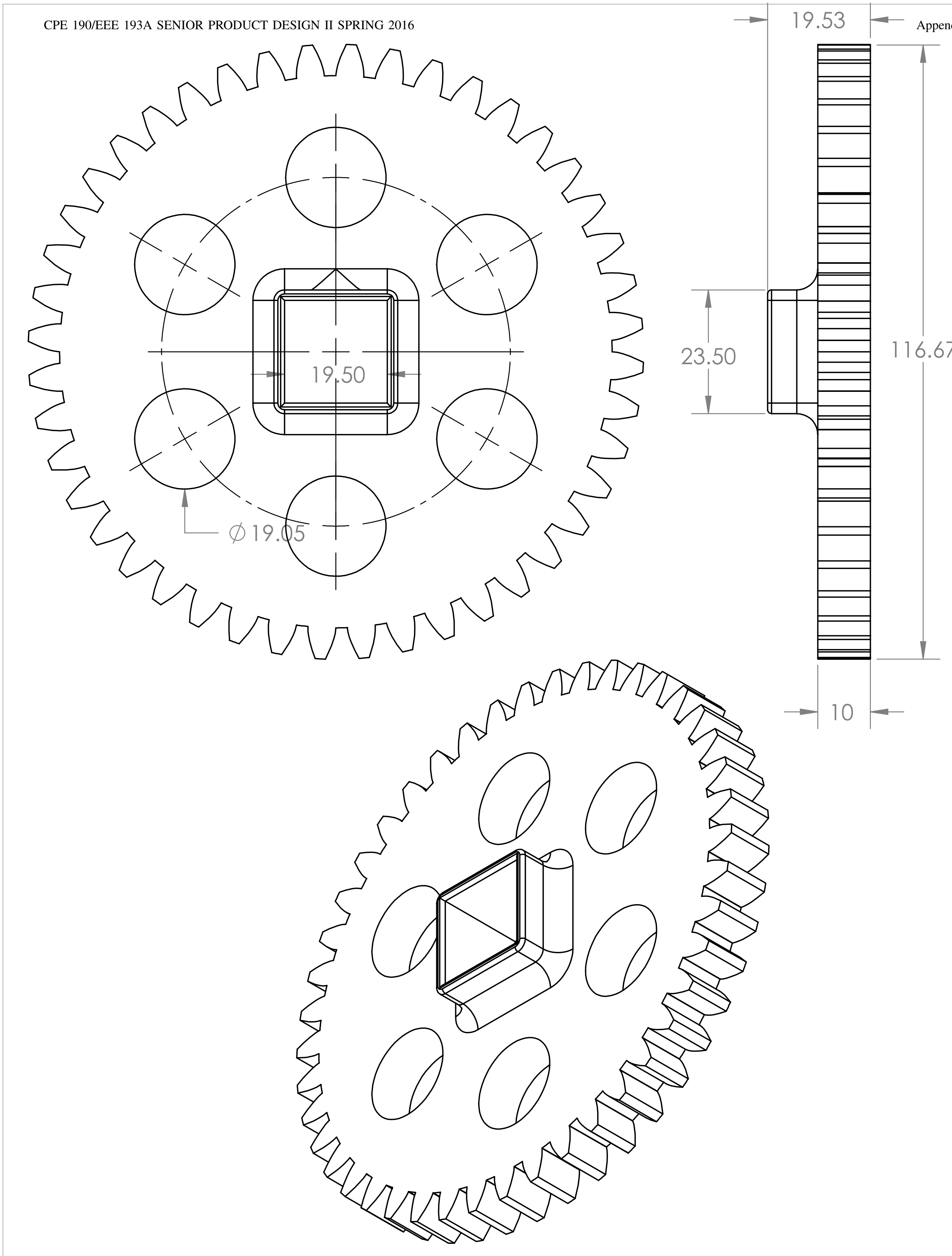
SIZE A	DWG. NO. Pulley Smaller		REV.
SCALE:1:1	WEIGHT:		SHEET 1 OF 1



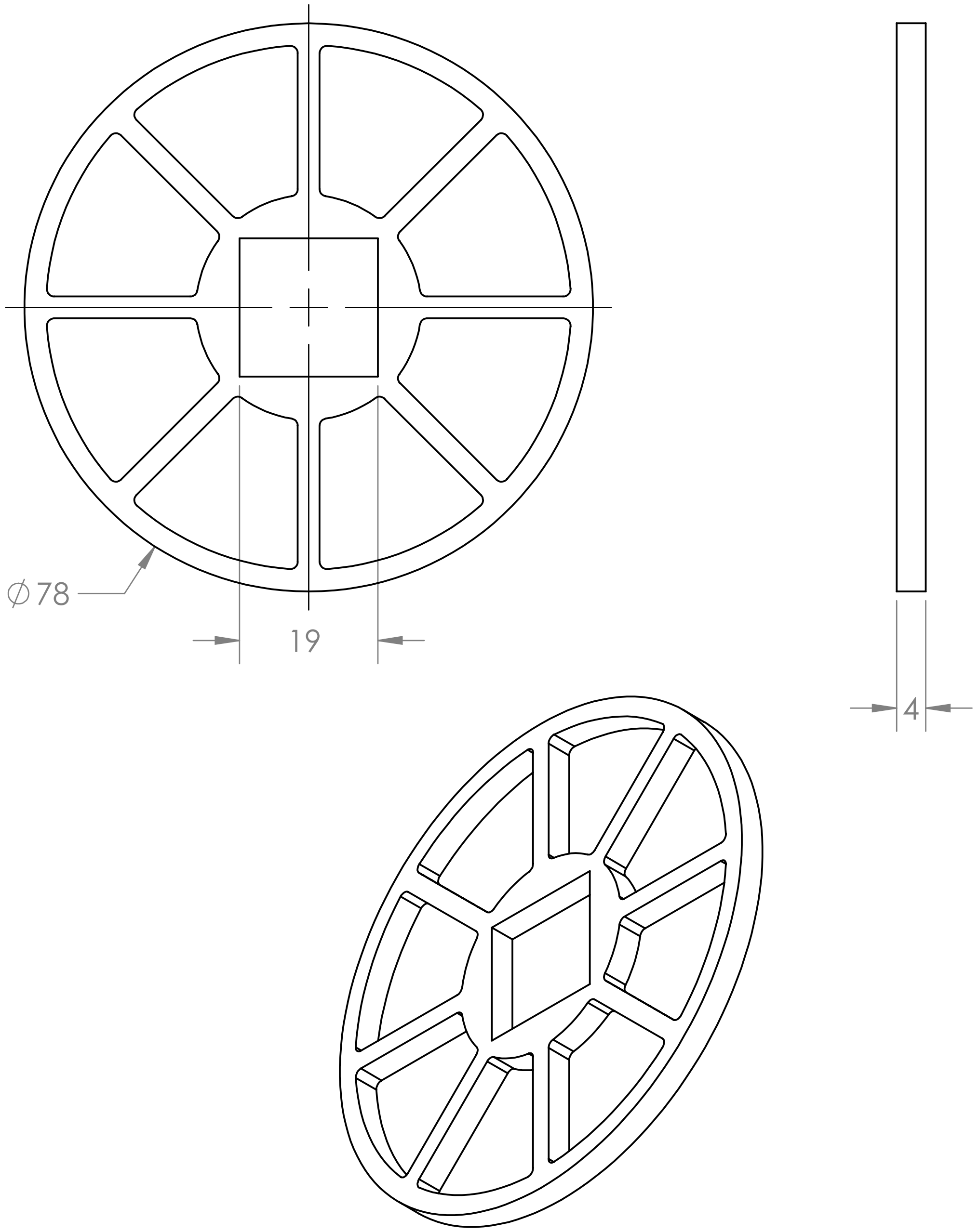




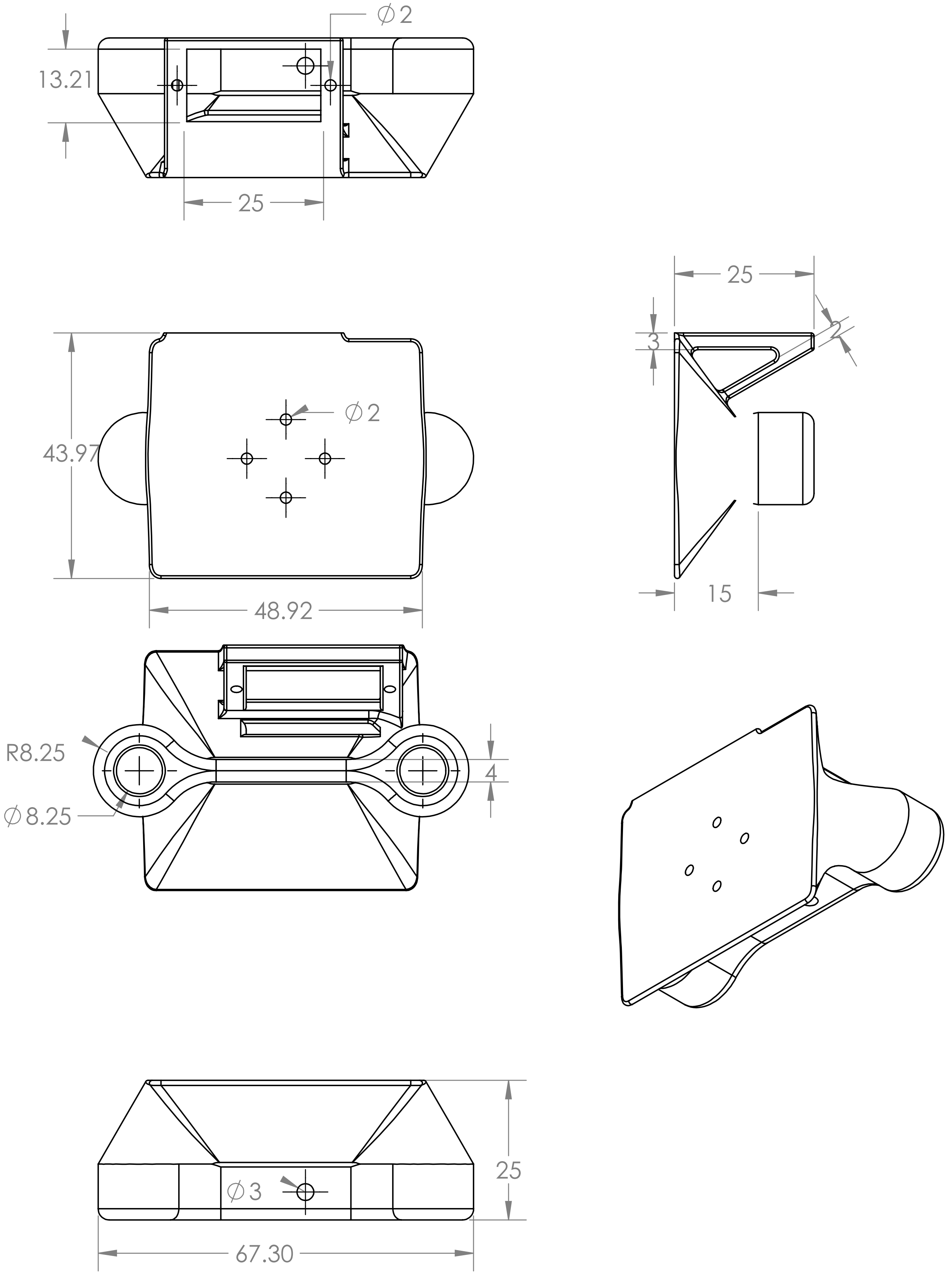
SIZE A	DWG. NO. Motor gear 10p		REV.
SCALE:1:1	WEIGHT:	SHEET 1 OF 1	



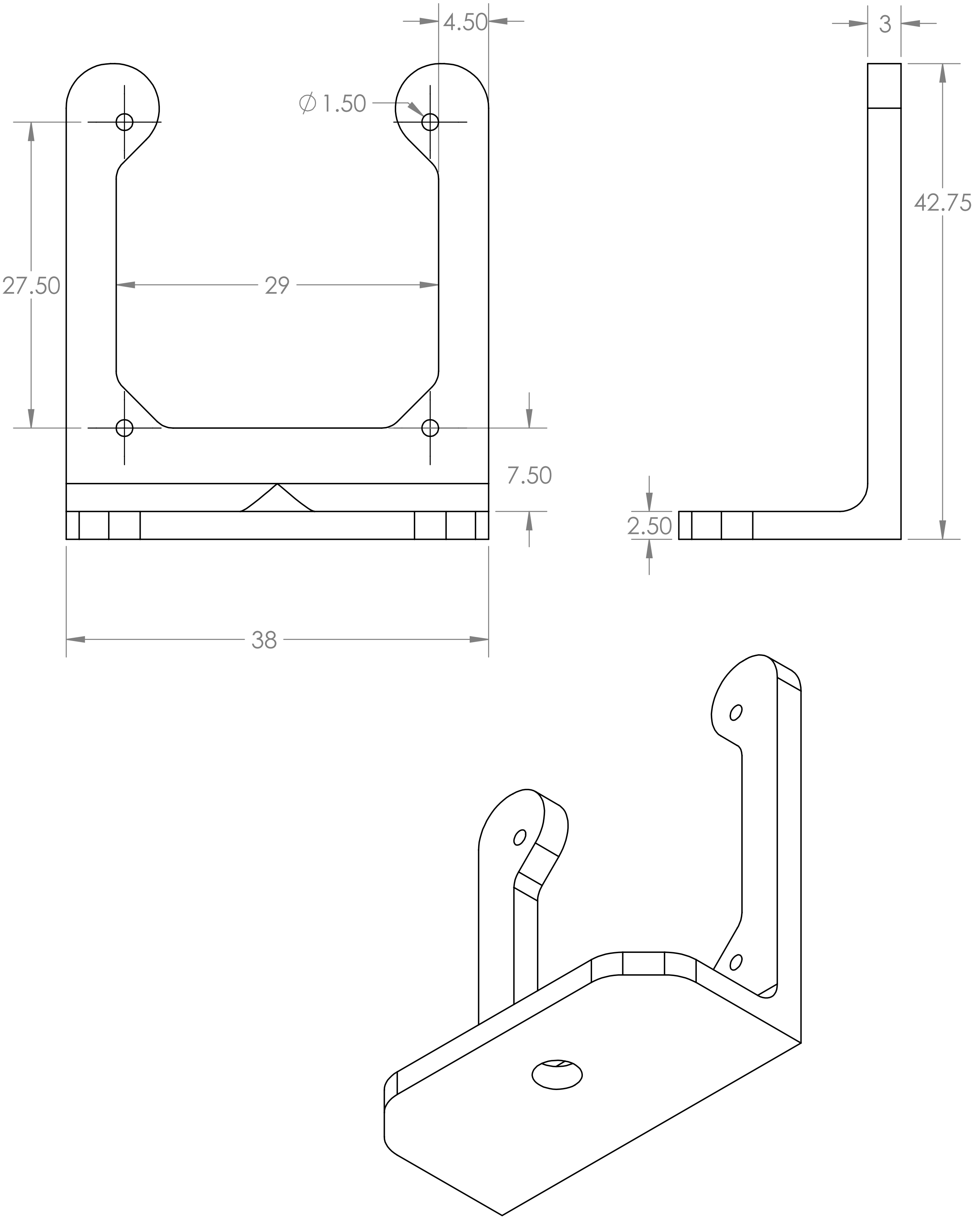
SIZE	DWG. NO.		REV.
A	Large gear 10p		
SCALE:1:1	WEIGHT:	SHEET 1 OF 1	



SIZE A	DWG. NO. Rotational Guide		REV.
SCALE:1	WEIGHT:	SHEET 1 OF 1	

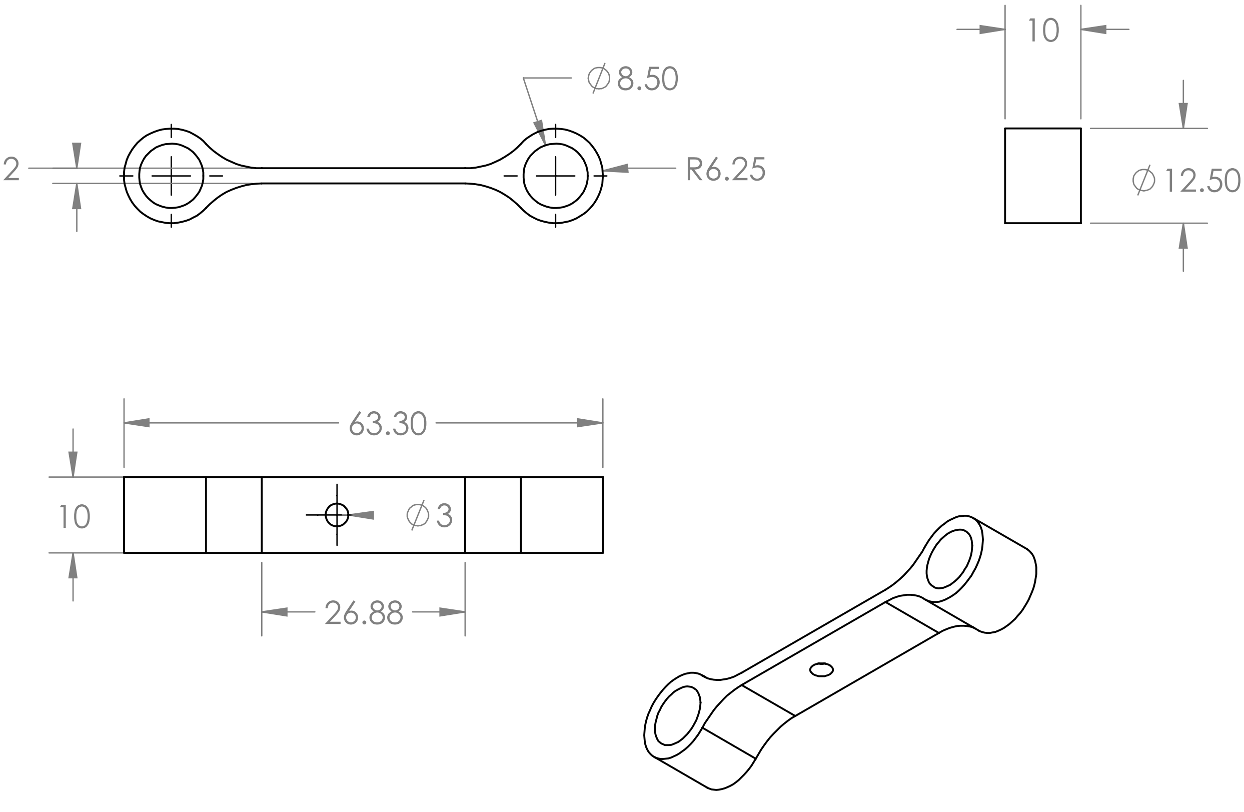


SIZE A
DWG. NO. Claw and camera mount.
REV.
SCALE:1:1
WEIGHT:
SHEET 1 OF 1



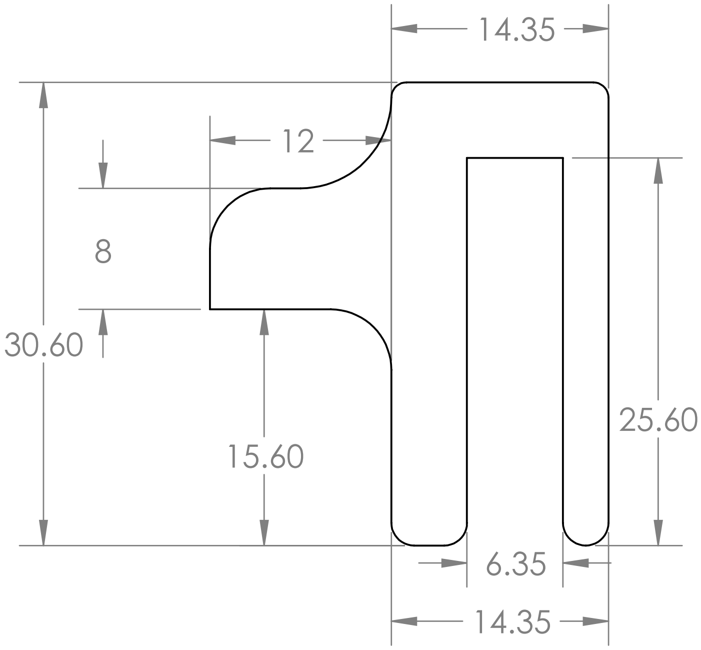
SIZE A DWG. NO. Camera Mount REV.

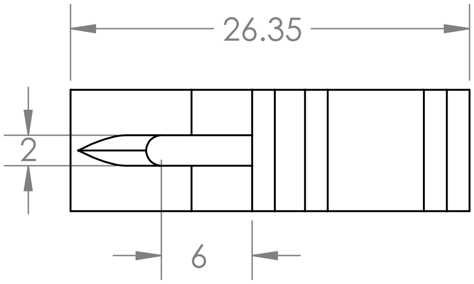
SCALE:2:1 WEIGHT: SHEET 1 OF 1

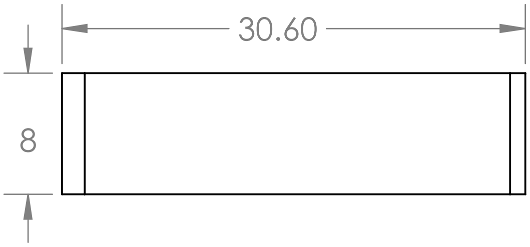


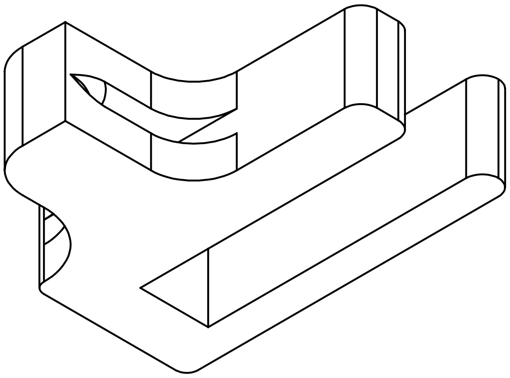
SIZE **A** DWG. NO. 2in Linear Rod Spacer REV.

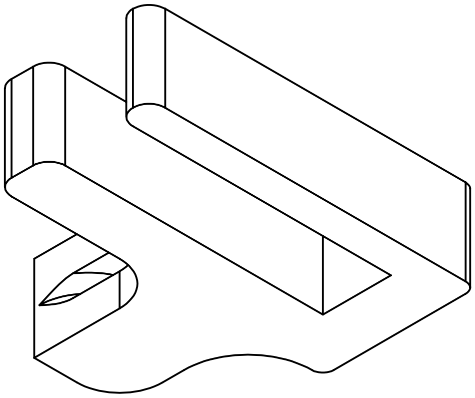
SCALE:1:1 WEIGHT: SHEET 1 OF 1



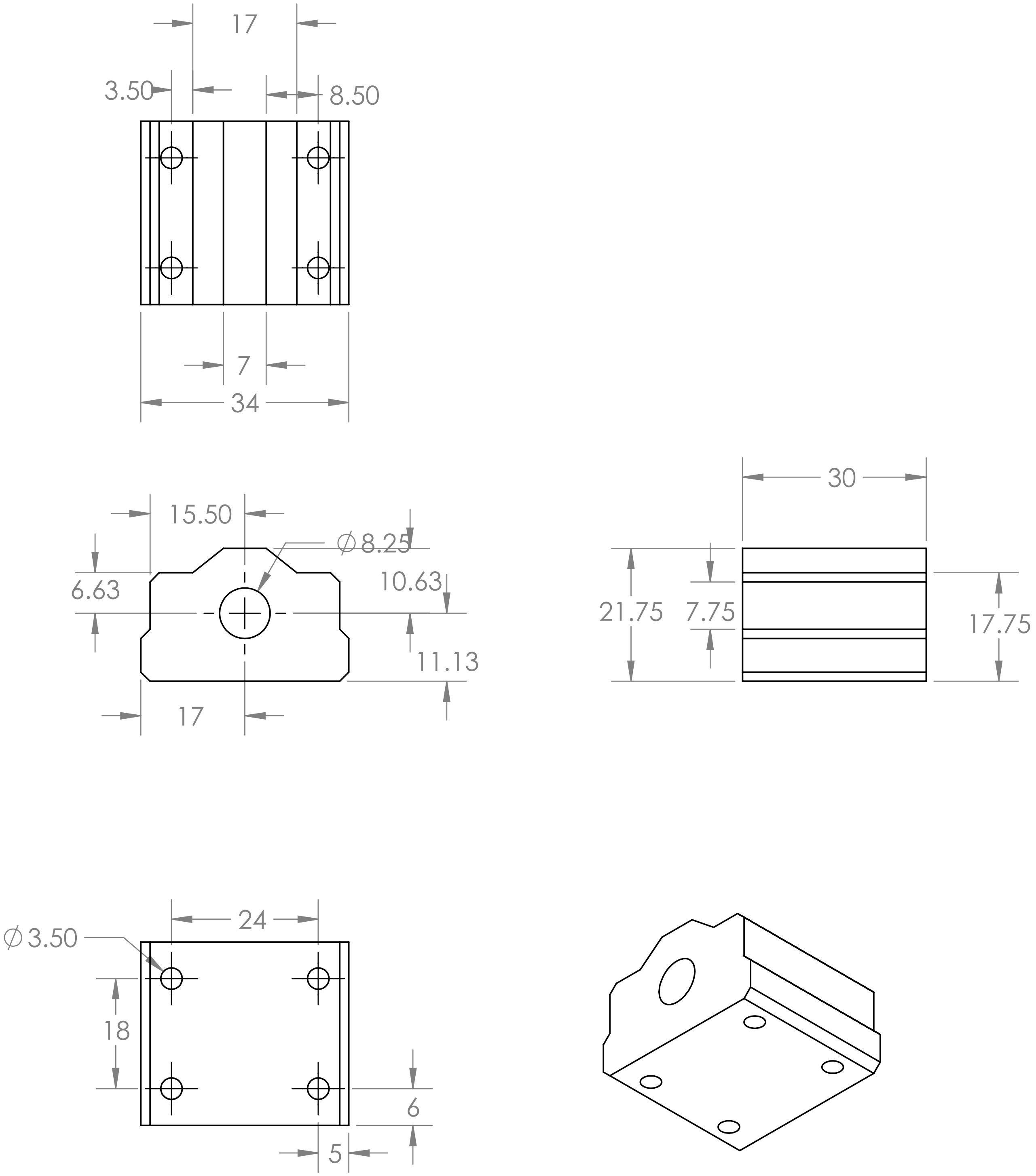




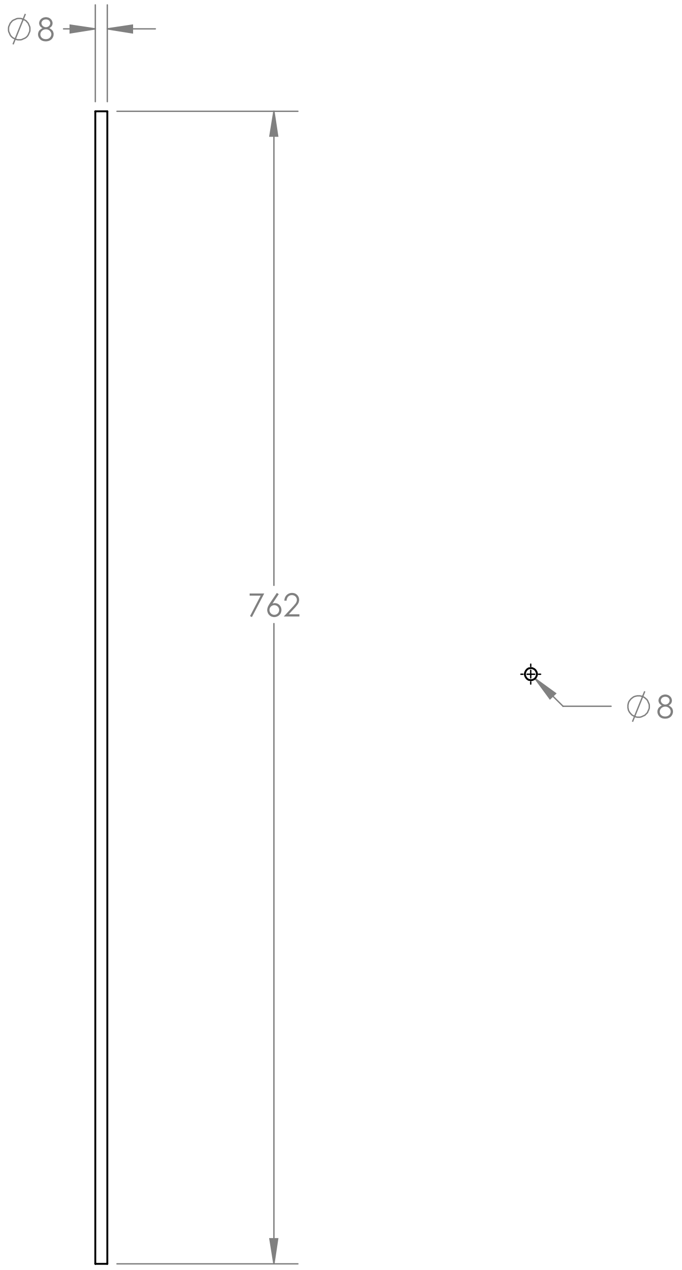




SIZE A	DWG. NO. Wire Guide	REV.
SCALE:2:1	WEIGHT:	SHEET 1 OF 1



SIZE A	DWG. NO. Linear Bearing		REV.
SCALE:1:1	WEIGHT:	SHEET 1 OF 1	



SIZE **A**	DWG. NO. Linear Shaft		REV.
SCALE:1:5	WEIGHT:	SHEET 1 OF 1	

APPENDIX E
SPECIAL THANKS

Team C.L.A.W.
California State University, Sacramento

April 30, 2016

Dear Dr. Fethi Belkhouche,

Thank you for lending us a wheelchair for our project. This helped reduce our costs on the project. We also value and appreciate the feedback and support you have given us throughout the semester that motivated us to finish and possibly pursue it after graduation.

Thank you,

Kevin Hartmann

Cindy Chao

Jesse Graham

David Stark