

# Optimal Design: Assistive Robotic Arm

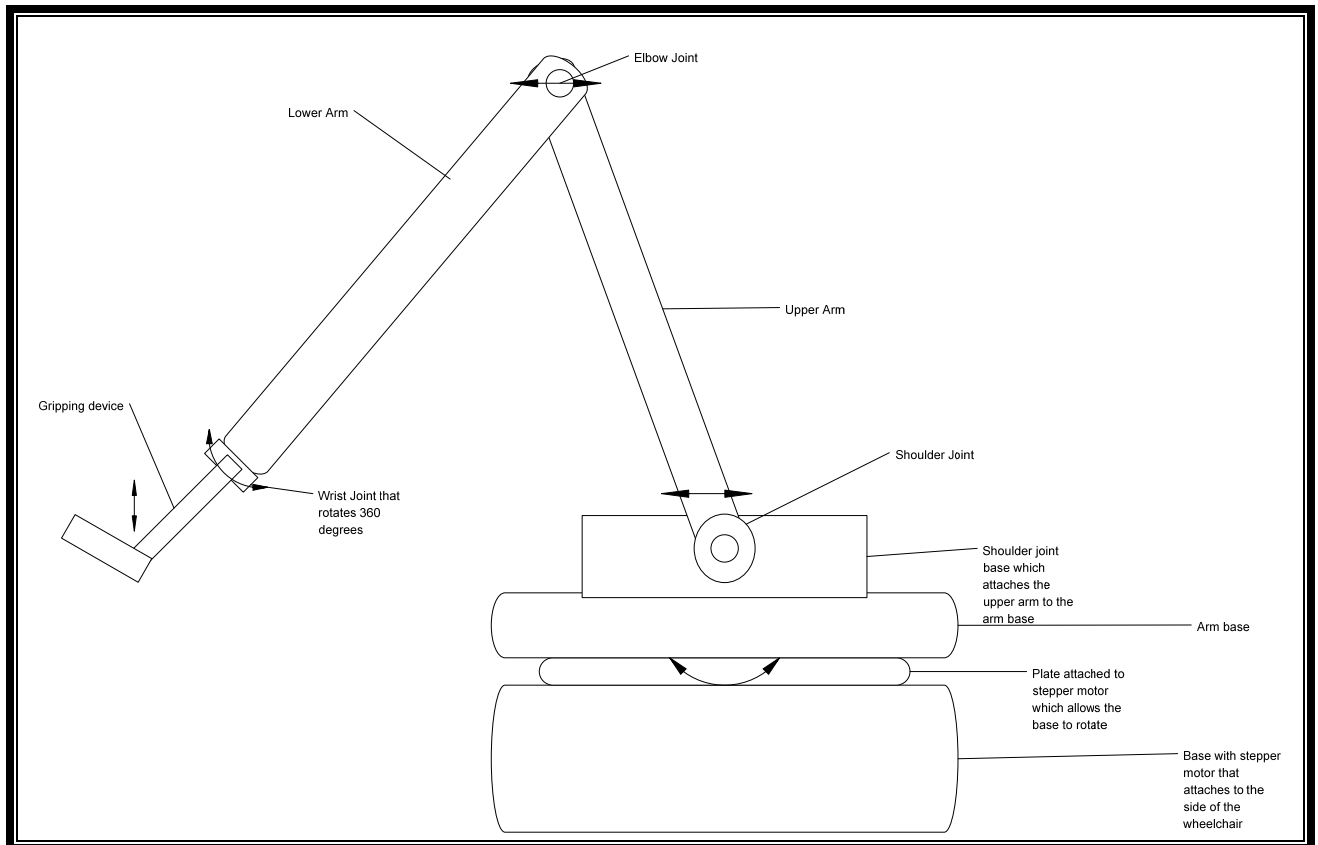
Group #9:  
Danielle McGeary  
Megan Madariaga  
Asma Ali

Client Contact:  
Merriam Kurland  
Speech Pathologist  
Hampton Elementary School  
263 Main Street  
Hampton, CT 06247  
(860)-455-9490

# 1 - Introduction

The following design, contained in this report, will aid a client with quadriplegic athetoid cerebral palsy function more independently in an integrated classroom setting. Due to the nature of the client's disability, the client is physically incapable of any fine motor control. The client is confined to a wheel and forced to communicate nonverbally since he is incapable of oral articulation. The design being implemented is an assistive robotic arm with will that will attach to the client's wheelchair. Since oral communication is not an option, the client communicates via electronic devices. If the client is engaged in a conversation, he will use the DynaVox, a supplementary augmentative communication device that speaks what the client inputs from the keypad. The client is also unable to eat independently and obtain objects for himself. He is not capable of opening his laptop and cannot begin any work until his personal aid is available to assist him. The client is very dependent upon his aid, especially for eating. Everyday for lunch, the client is forced to eat alone with his personal aid. The client's personal aid hand cuts all of the client's food and then physically feeds him. This client does not like this and finds it frustrating. Having to be fed by the aid also eliminates a social aspect from the client's school day that is essential to the learning process.

Academically, the client is at high school level. He mentally astute and is capable of expressing himself, on his DynaVox unit, in a more mature and descriptive manor than his classmates, who have full verbal capabilities, can. Communication though an augmentative device requires a strong aptitude for spelling and vocabulary. The client proves that he possesses this knowledge and is capable of being independent if given the proper resources.



**Figure 1:** Complete Robotic Arm device

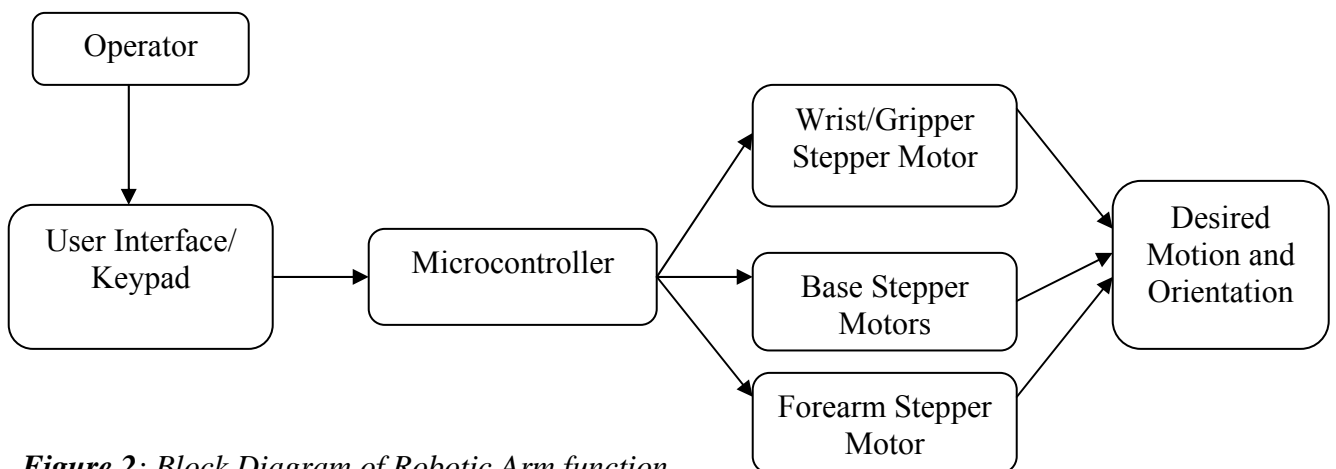
The assistive robotic arm, as seen in Figure 1, will allow the client to eat independently. The design that is being implemented for of this child will allow for all six degrees that human arm is capable of. The device will also allow the client to obtain objects that he was never capable of obtaining before on his own. This device will provide the client with a sense of independence that he has been a stranger to for so long.

Presented in this design are the following subunits: a base, upper arm, lower arm, wrist, gripping device, microcontroller, motors, batteries, and circuitry. The base will house one motor, a microprocessor, and the circuit board. The base will also have the capability of rotating a full 360 degrees. The base will consist of a rotating plate, similar to that of a microwave that will allow the entire device to rotate. This will allow the client to have the capability to reach anything around his wheel chair. The base will also be securely mounted to the client's chair. This will allow stability for the device and will also prevent any injury to the client or wheelchair.

The upper arm will then attach to the base. This is the portion of the arm that will rotate 360 degrees with the base. The upper arms connection to the base will also function as a hinge joint and extend 90 degrees. Next, the upper arm portion of the device will connect to the elbow joint that will attach to the lower arm. The elbow joint connecting these two components will have the capability of moving -90 to 155 degrees vertically. This is a safety feature for the client. Since the device will be used for eating with a fork, the 155 degree limit will prevent the device from over rotating and puncturing the clients soft pallet with the fork attachment.

When both of the vertical joints are extended to 120 and 90 degrees simultaneously, a maximum extension of 25 inches can be added to the client's reach. This extension is well surpasses that a normal arm. Since the arm will be positioned on the client's wheel chair in front of the client, the client will actually have an even larger radius of extension. Finally, the lower arm will be connected to the grippers by a wrist joint.. The gripping device itself will be controlled by two gears. One of the gears will be rotate via a motor. The gears will also be padded rubber so that they will not be slippery. The rubber will also protect any object from becoming scratched. The grippers will also be created to hold utensils such as a spoon and fork. These utensils will be made out of a durable rubber so that they will not injure the client if the arm were to malfunction. Also, the grippers will be constructed in a way that only the specific utensils created in this design will be able to be attached. This will be another safety mechanism to prevent any extraneous object from becoming attached to the grippers. If time permits, more specialized tools will be created to suit the various needs of the client and to make the device more versatile.

The entire device will be powered by the microprocessor located in the base of the device. The microprocessor will be controlled by on external keypad that will be operated by the client. This keypad will consist of ten keys while being durable and simple to use. Each key will also have a high spring constant to compensate for the aggressive manor in which the client types due to his lack of fine motor control. Finally, the entire device will be constructed out of PVC piping. This piping is extremely durable, light weight, and cheep. The general outline of how the device will function is contained in Figure 1. The clients will orient the device to his desired position by operating the keypad. The keypad will then transmit the entered motion via a signal to the microcontroller. The microcontroller will then convert this signal into current that will be passed to any of the 6 motors. The motors will the function and orient the arm based on the signals transmitted from the microcontroller.



**Figure 2:** Block Diagram of Robotic Arm function

For this design, some changes have been implemented. The first change is that the pillow bocks from the last design will be replaced with oil sintered bronze bearings. This

change was made since the oil sintered bronze bearing weigh much less then the pillow blocks do. This will make the entire arm much lighter and so alleviate much stress from the motors. Spacers were also added to the elbow joint. The addition made the elbow joint more efficient. This change causes the gears to remain in place better and also prevents them from sliding. The diameter of the pipe was also increased to 1.5 inches and the thickness of the pipe was decreased to .145 inches. This size change will provide more strength to the device. The over-all diameter of a pipe contributes more to its strength then does its thickness. Thicker piping will only add excess weight to the device without providing any additional strength. It was also decided that gears of a 1 inch diameter will be the most optimal for this design. Gears of this size will be able to turn at a rate that is most favorable for this design. Also, calculations, in the subunits part of this paper, were calculated with estimated weights. These weights were determined from the weights of the individual parts the being planned to be used in our design. This will give a realistic view of what the design is capable of.

After meeting with the assessment committee last week, further changes were also implemented to our design. From the meeting, the group was informed the client is unable to drink independently. Due to his lack of motor control his aid must hold his cheek together when he drinks. He is also incapable of drinking from a straw for the same reasons. This newfound information eliminates the cup option from the utensil section of our design. The group also learned that the client's new wheel chair weights over 250 pounds and the client weighs 55 pounds. This information solidified that the wheelchair will not tip when the robotic arm's center of gravity is located furthest from the center of the chair.

## 1.2 Subunits

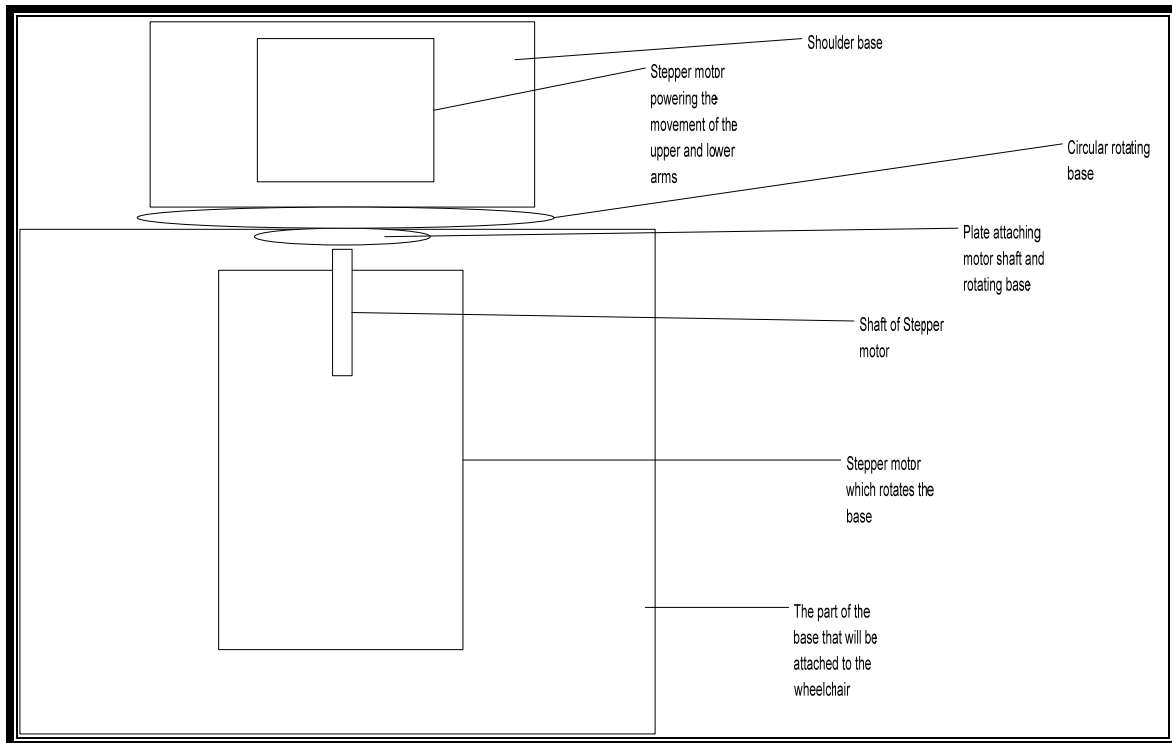
The complete robotic arm will provide form and function that the client will need to use this assistive mobility device. The side view of this device, as shown in Fig. 2 depicts the simple design which contains movements at each of the three joints to cater to the client's particular needs. The description of the robotic arm will start at the bottom and work upward.



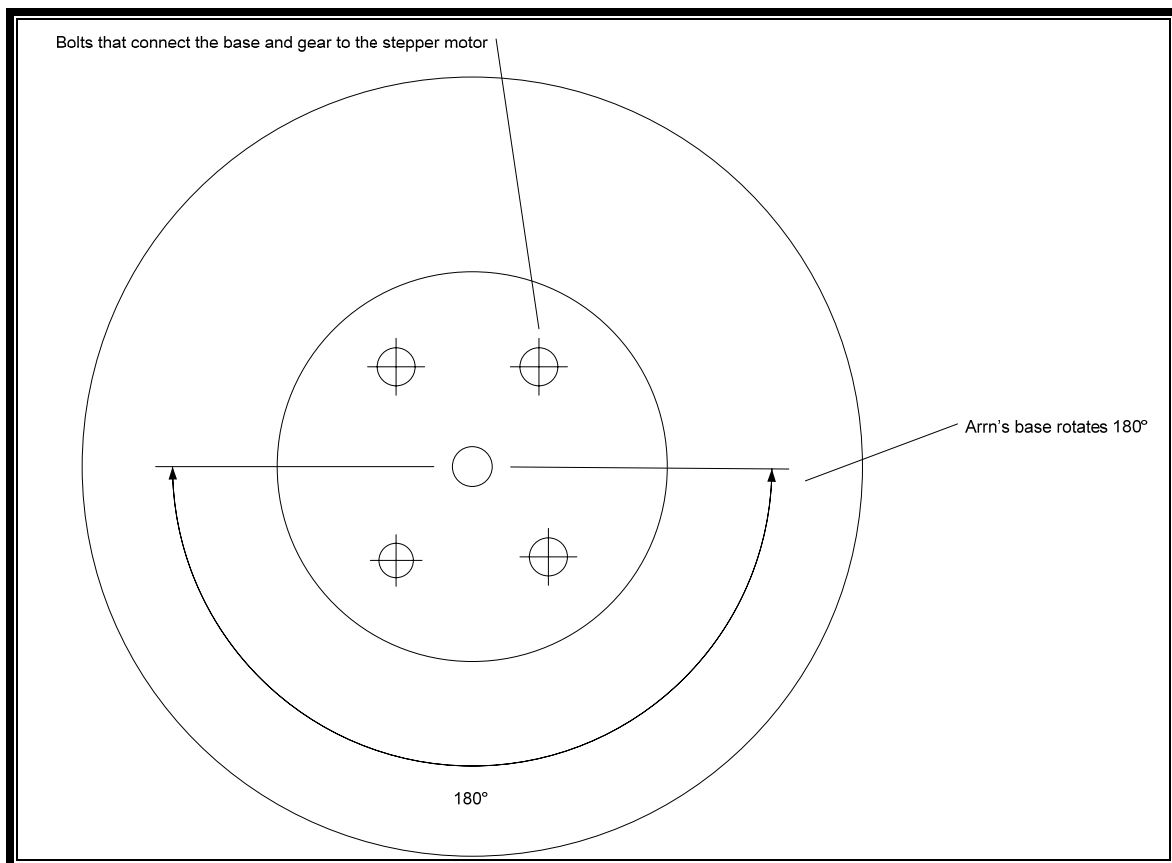
*Figure 3: Model of complete robotic arm*

### 1.2.1 The Base

The base will be made out of Lexan panels, which are PVC panels. The base of the device will be circular and house a stepper motor as seen in Fig. 4. This device will be able to attach to the side of the client's wheelchair. Also connected to the base will be a bearing device that will add support and allow the circular arm base to rotate freely. The arm base will be circular and attached to a stepper motor. A gear will be attached to the stepper motor; and will also be bolted to the arm base which will allow the base to rotate 360 degrees. To ensure the safety of the client a mechanical constraint will be placed on the base to allow it to only rotate 180 degrees. This way there will be no chance that the robotic arm will hit the client. This can be seen in Fig. 5. The base of the robotic arm will be constructed in the University of Connecticut machine shop.



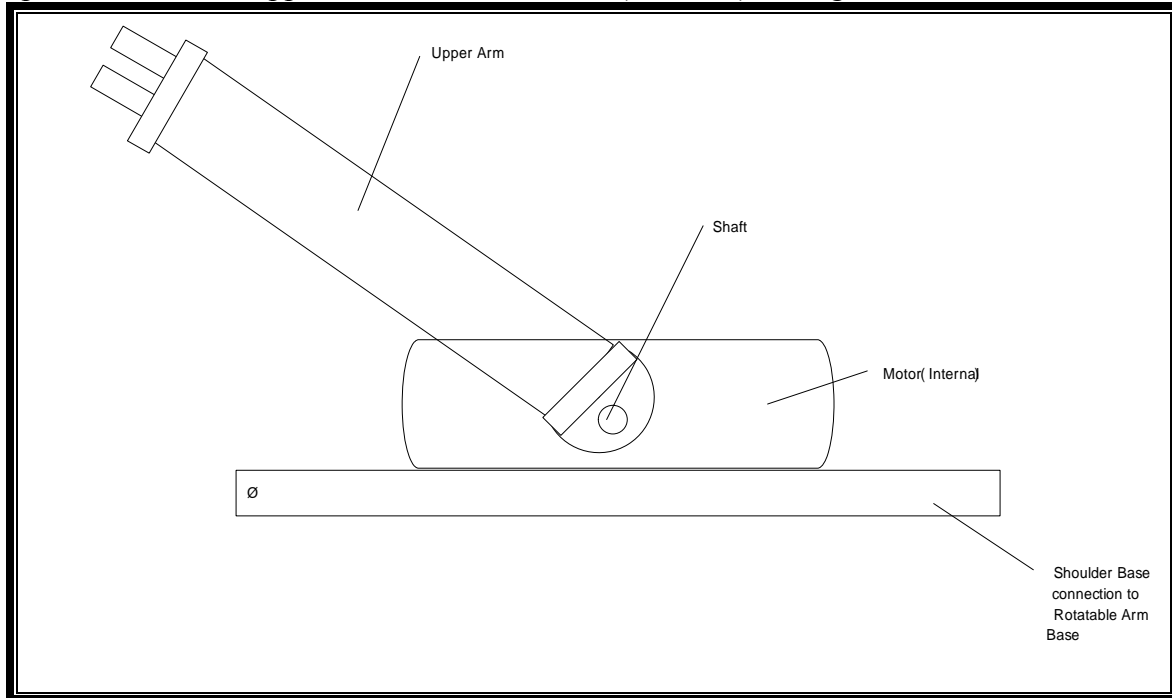
**Figure 4:** Side view of the base



**Figure 5:** Top view of the arm base

### 1.2.2 The Upper Arm

The Upper Arm will be connected to the base and attached by oil sintered bronze bearings to the shaft in the base as seen in Fig 6. The arm will have a rotation of 180 degrees, as it will be attached to the free rotating base. It will also be capable of moving up and down. The upper arm will be 13 inches (33.02cm) in length.



**Figure 6:** Side view of upper arm base connection

The material used for the upper and lower arm will be PVC piping seen in Fig. 7. The piping used would be from schedule 80 and have a 1.5 inch (3.81cm) diameter. The inner diameter will be 1.21 in (3.07 cm) and the outer diameter will be 1.315 in (3.34 cm), making the pipe thickness .145 inches (.3683 cm). It would be clear piping with smooth finish that will be good for visual monitoring of the wires inside the device. With the PVC piping it will eliminate the safety hazard of the wires associated with this device.



**Figure 7:** Clear PVC piping

Polyvinyl chloride is produced by the polymerization of the monomer vinyl chloride. It is very similar to polyethylene. Its configuration is unique since on every other carbon on the chain, the hydrogen atom is replaced with a chloride atom. PVC is



widely used in plastics since it is inexpensive and easily accessible. Also, it is useful due to its strong resistance for fire and water. This material is fire resistant due to the chlorine substitution in its empirical configuration. When compound is burned, chlorine atoms are released and inhibit combustion. Some important physical properties are included in Table 1.

Physical Properties of Polyvinyl Chloride	
Density	1380 kg/m <sup>3</sup>
Young's modulus (t)	2900-3400 Mpa
Tensile Strength	50-80 Mpa
Elongation at break	20-40%
Notch Test	2-5 kJ/m <sup>2</sup>
Glass Temperature	87°C
Melting point	212°C
Vicat B'	85°C
Heat transfer coefficient	16W/m·k
Linear expansion	8E5/k
Specific Heat	.9kJ/kg·k

**Table 1:** *Physical properties of Polyvinyl Chloride*

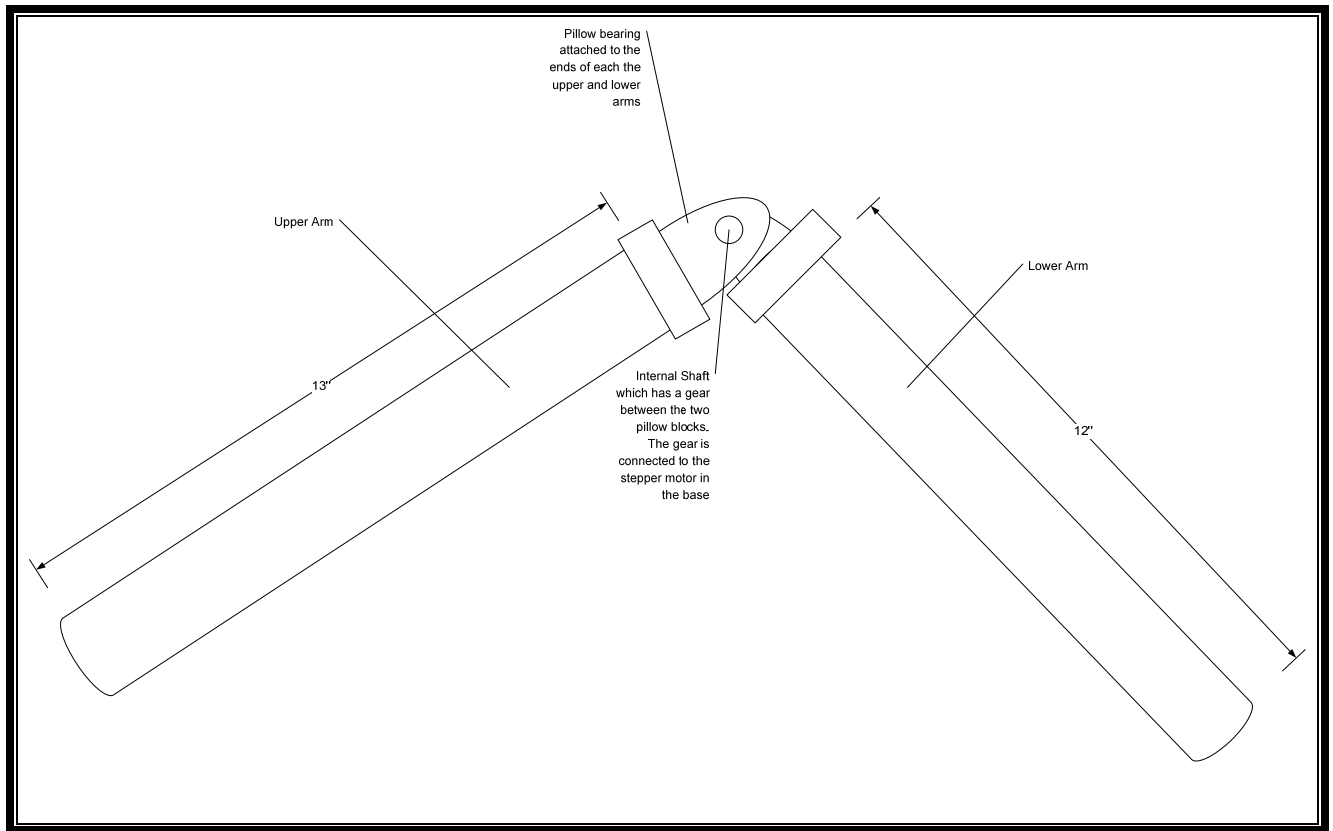
### 1.2.3 The Elbow Joint

The elbow joint will connect the top segment of the upper arm and the proximal section of the lower arm as seen in Fig. 7. This joint will function as a hinge joint. It will have three force components and two couples on the y and z axis. The upper and lower arms will be controlled by a stepper motor. This stepper motor will have a torque of 100 lb·in. A torque of this quantity is necessary for the device since the moment about the shoulder was calculated to be 89.38 lb·in. This calculation can be seen in equation 1.

$$\sum M_s = 0 = .5''(W_{\text{joint lbs}}) + 7.5''(W_{\text{upper arm lbs}}) + 14.5''(W_{\text{joint lbs}}) + 15.5''(W_{\text{joint lbs}}) + 22''(W_{\text{lower arm lbs}}) + 29''(W_{\text{motor}}) + 35.5''(W_{\text{grippers}}) + 40.5''(W_{\text{load}}) - M_s \quad (\text{eq. 1})$$

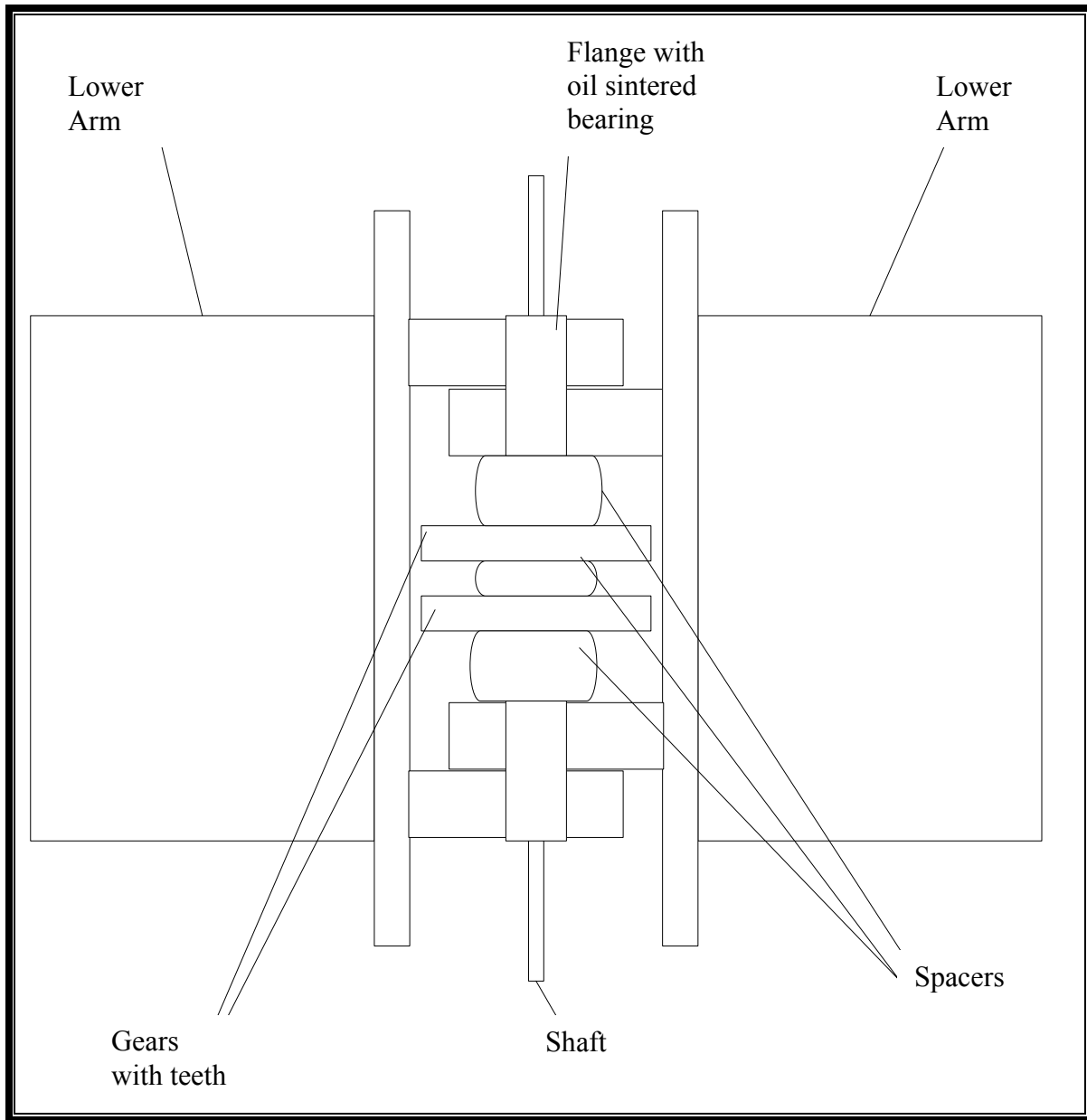
Part	Weight (lbs)
Stepper at Shoulder	8.7
Upper Arm	0.44017
Lower Arm	0.4087
Stepper at Wrist	0.0267
Gripper	0.5
Load	1
Joint	0.01022

**Table 2:** *Robotic Arm part Weights*

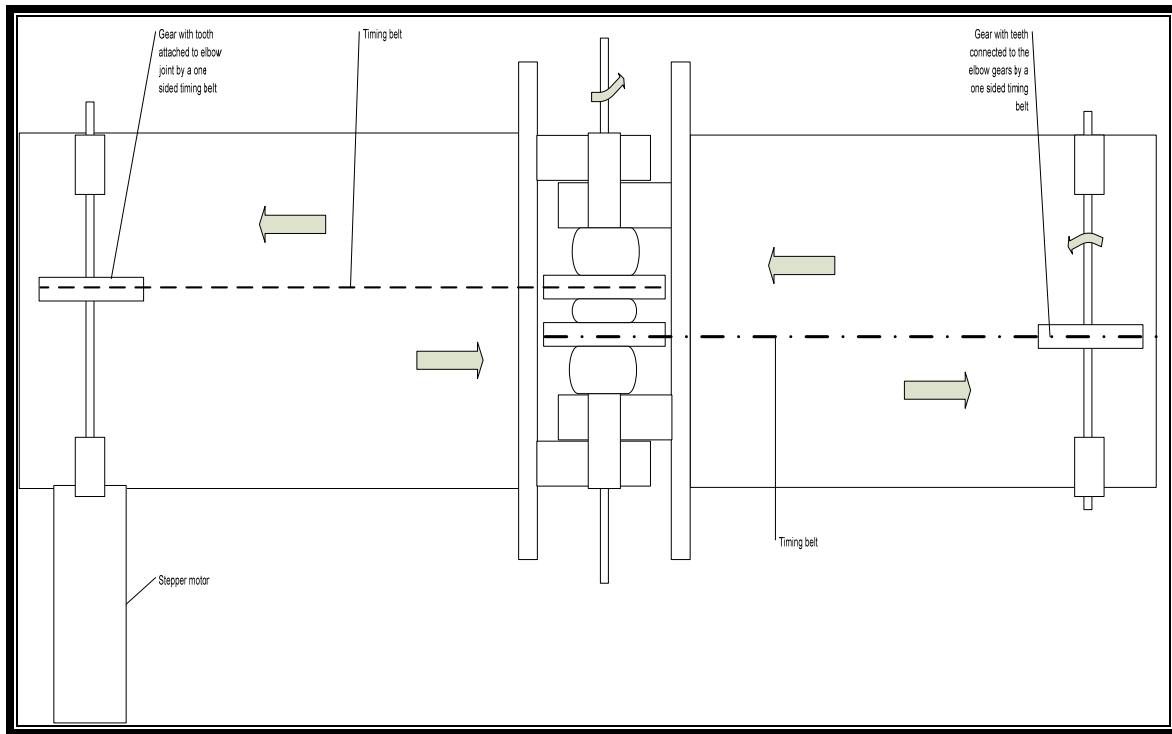


**Figure 8:** Side view of Elbow joint

The elbow joint will consist of the two oil sintered bearings (one on each the lower - upper arm connection), a shaft that will function as a connector for these two components, and two Delrin gears and spacers. These components will provide movement as seen in Fig. 8. This Delrin gear will have teeth. Connected to this gear will be two, one sided timing belts with indentations that intertwine with the teeth on the gears. One of the timing belts will be located inside of the upper arm. The positioning of this timing belt will connect to the gear attached to the stepper motor inside the base. The other timing belt will run through the lower arm and be attached to the shaft in the wrist. This configuration will cause the lower and upper arms will move together while the wrist is continuously sustained parallel to the ground. This is seen in Fig. 9 below. This joint will be controlled by a stepper motor that will receive input from the keys on the keypad.



**Figure 9:** *Elbow joint connection Top View*

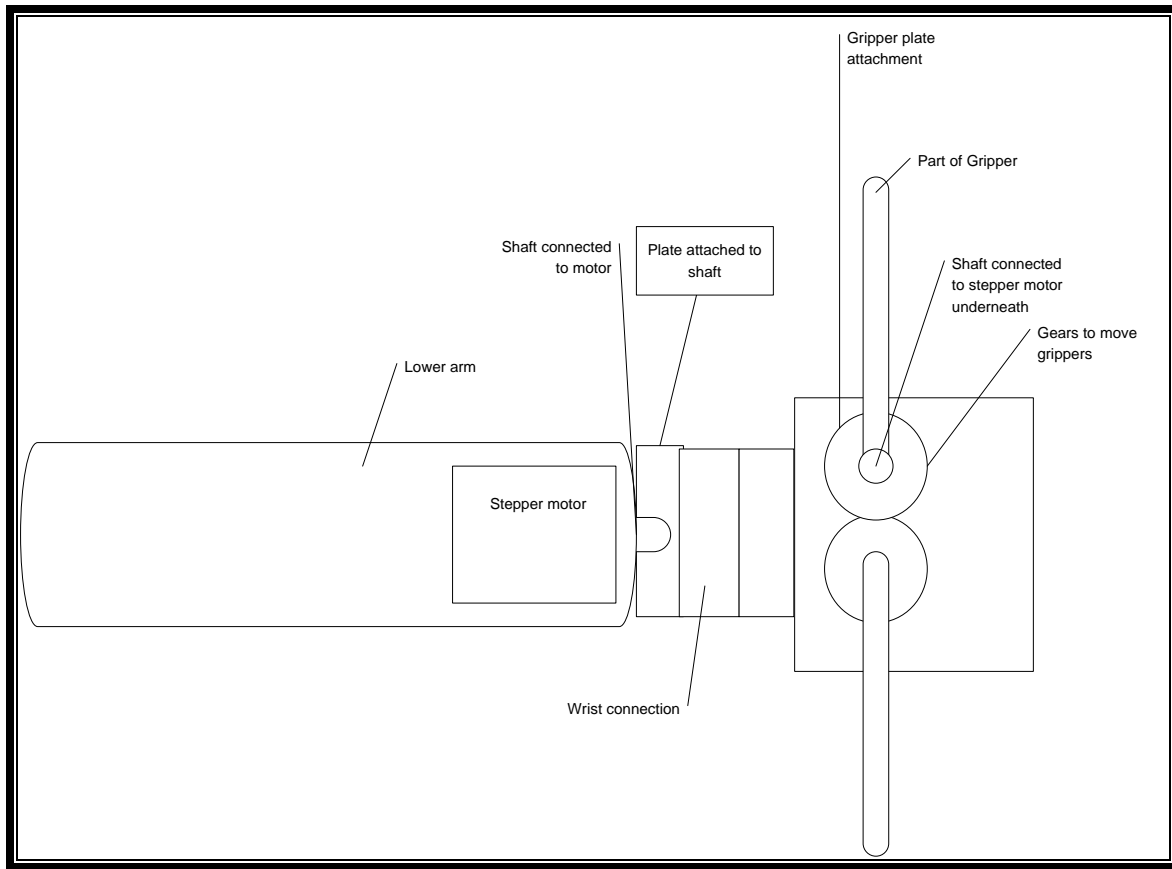


**Figure 10:** Gear system responsible for the movement of the upper and lower arms

#### 1.2.4. The Lower arm and Wrist

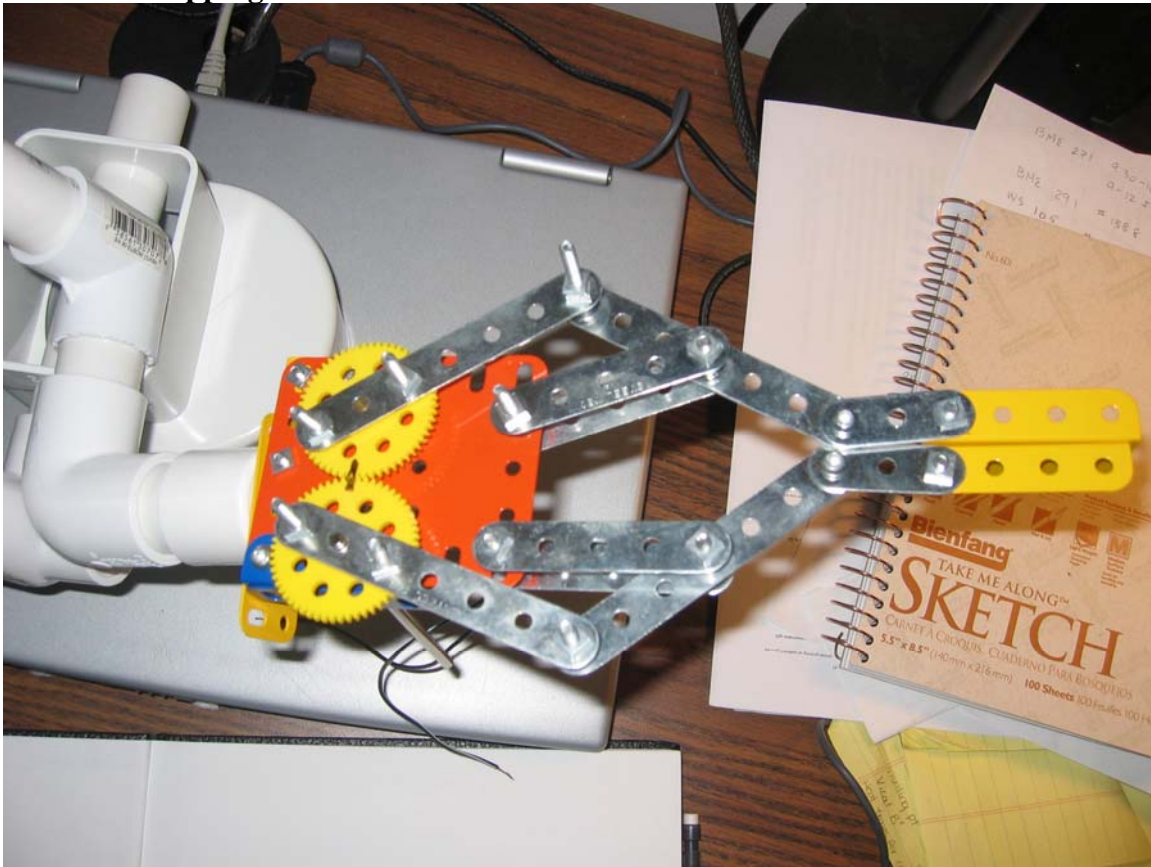
The lower arm will be 12 inches in length (30.48 cm). It will be constructed from clear PVC piping with a thickness of .38 inches (.97cm). The lower arm will be constructed in the University of Connecticut's machine shop. The lower arm will move in tangent with the upper arm. Both the lower arm and wrist will be powered by a stepper motor stored in the base of the robotic arm.

Connected to the shaft inside the wrist will be the two oil sintered bronze bearings in the lower arm and a gear. This gear will be bolted down to the wrist plate. This attachment allows the wrist to rotate 90 degrees toward the client in the x plane. This stepper motor will be attached so that the body of the motor will be on top of the wrist. This will make it possible for the wrist to move toward the client without contacting his tray. A bearing device will be included to give the wrist smooth rotation. Connected to the wrist plate is the gripping plate. This is the place of attachment for the grippers. This attachment can be seen in Fig. 11.



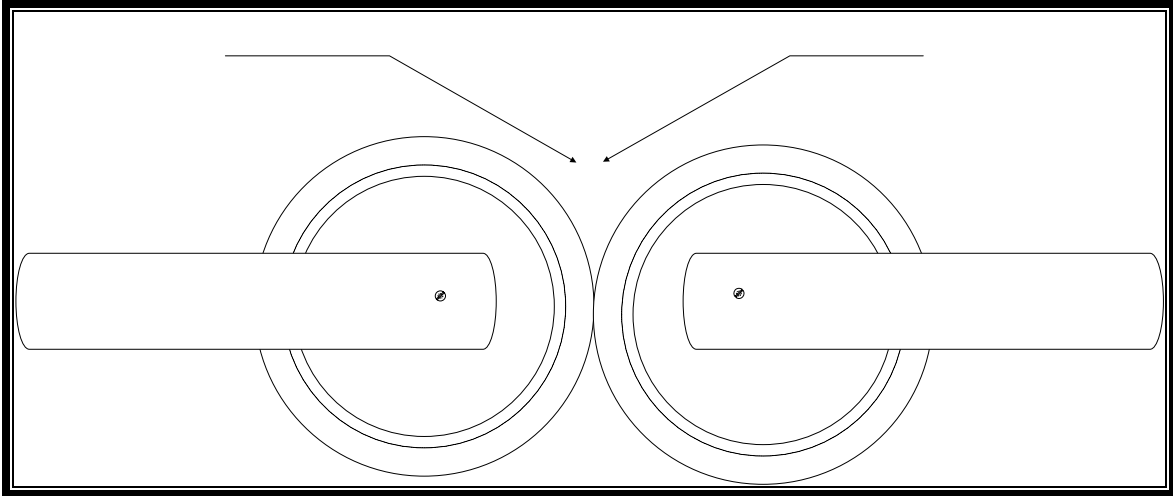
**Figure 11:** *The Wrist Joint*

### 1.2.5 The Gripping Device

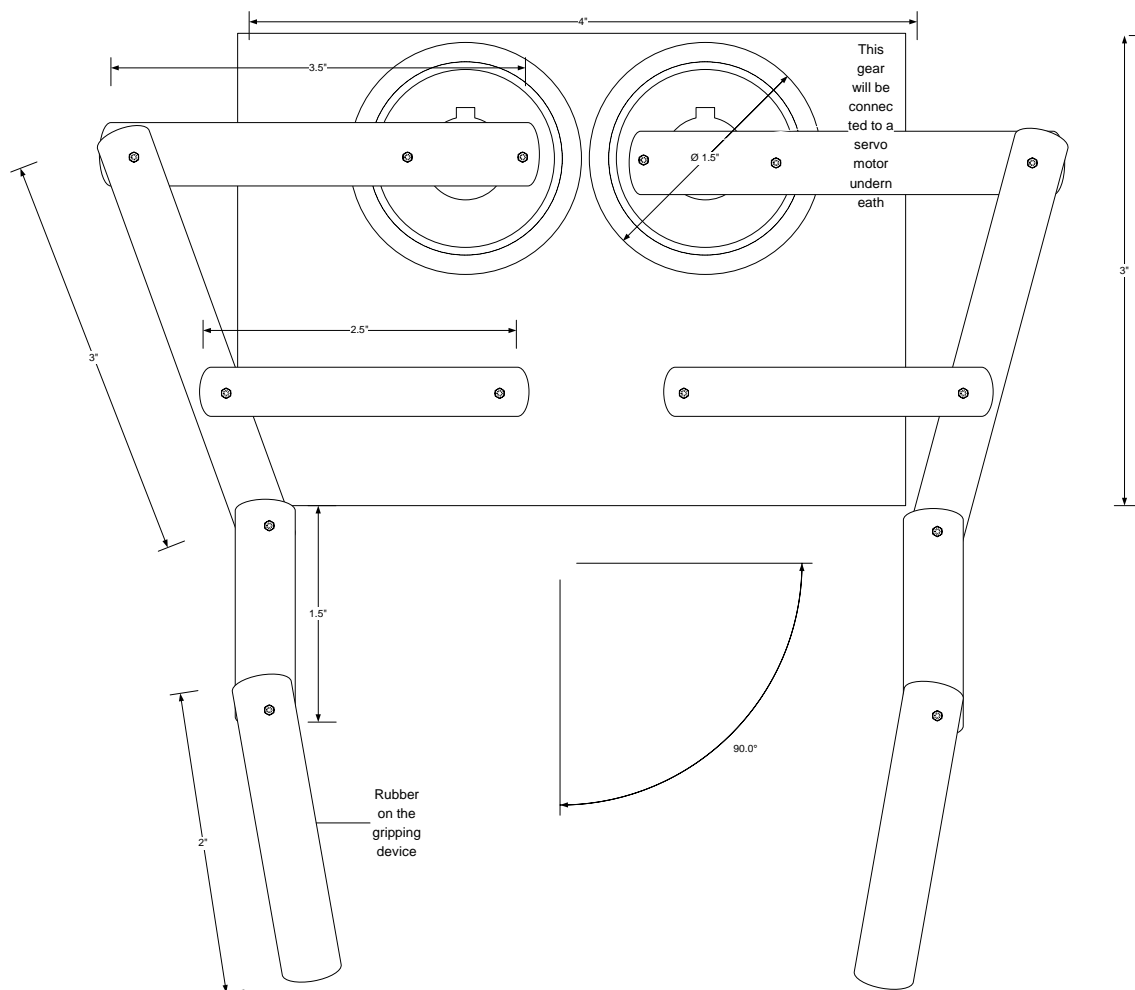


**Figure 12:** Model of gripping device

The gripping device will be constructed on a steel plate with a width of 4 inches (10.16 cm) and length of 3 inches (7.62 cm). Attached to this plate are two gears. One of the gears will be attached to a stepper motor. Due to the configuration of the gears and their attachment to the motor, both will move in unison to the other. The fluid motion will open and close the grippers as seen in Fig. 12. The grippers will consist of a steel plates connected together for support as seen in Fig. 13. A plate 3.5 inches long (8.89 cm) will be attached horizontally in two places to each of the gears. This will be attached to another plate with a nut, bolt and spacer. This intermediate plate will be 3 inches long (7.62 cm) and attached to the gripping device plate on the top and bottom with spacers to keep the grippers level. Also the intermediate plate is attached to a 1.5 inch (3.81 cm) connector to the actual grippers. These grippers will be made out of steel and have a rubber covering which will cause less damage on anything that it would come in contact with. The grippers will have indentations in the rubber to fit with the utensils used for eating. An organic solvent base will be used to bond the steel and the rubber together. The grippers will be 2 inches long (5.08 cm) and have width of 1.97 inches (5 cm).



**Figure 12:** Rotation of the gears to open the grippers



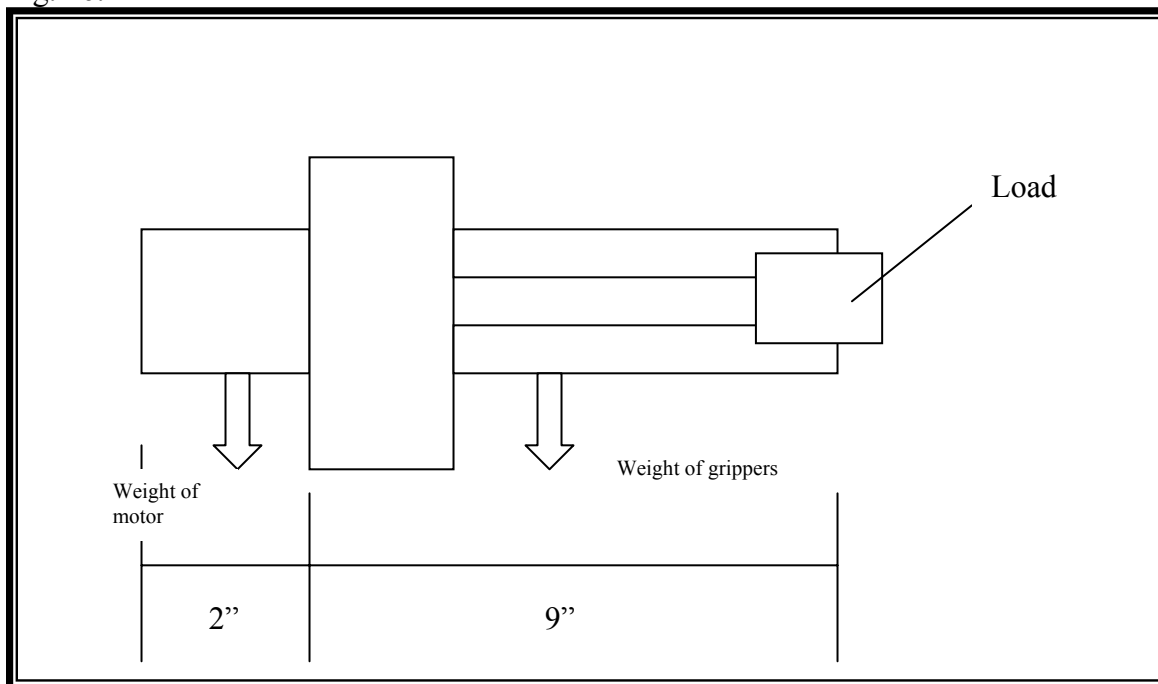
**Figure 13:** The Grippers

### 1.2.6 Utensils

The main goal of this device is to give the client more independence, especially when eating. To make sure that this device is safe for the client, the utensil will be comprised of a hard rubber material that resembles a spatula. The spatula's handle will contain grooves that will fit together with grooves in the rubber coating of the grippers. The idea resembles the "lock and key" concept. The design also creates a secure fit when the grippers are closed around the utensil, making it impossible for the fork to fall out. This design also functions as a safety precaution so no one will be able to put dangerous foreign objects into the grippers when the client is eating. Also an eating platter will be provided for the client. The platter will contain a plate with high sides, which will give the client the ability to scrape his food onto the utensil.

### 1.2.7 Equations:

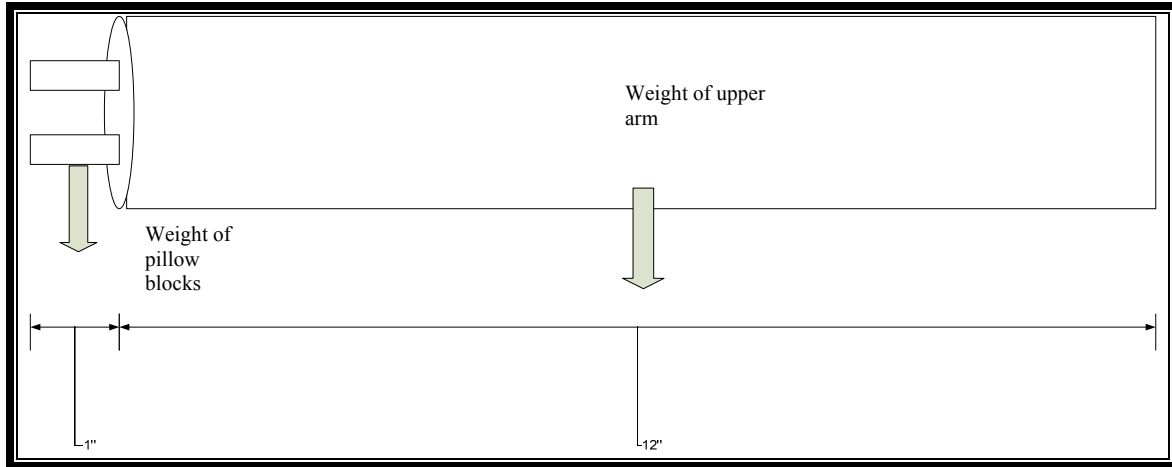
The following diagrams and equations were used to calculate the moment at each of the joints, and these were combined together in equation 1 in the elbow joint subunit. Finding the moments at each of the joint was important to know. This information lead to the determination of the amount torque required the stepper motor to move the base of the arm. This calculation was done in the worst case scenario with the arm completely outstretched in the horizontal position. In Fig. 14 the moment was taken about the wrist and was 39.52 lbs·in, calculated from equation 2. In Fig. 15 the moment was calculated about the elbow and was 42.651 lbs·in, calculated from equation 3. Finally the moment about the shoulder was calculated to be 89.39 lbs·in from equation 4. This can be seen in Fig. 16.



**Figure 14:** Moment diagram for the wrist

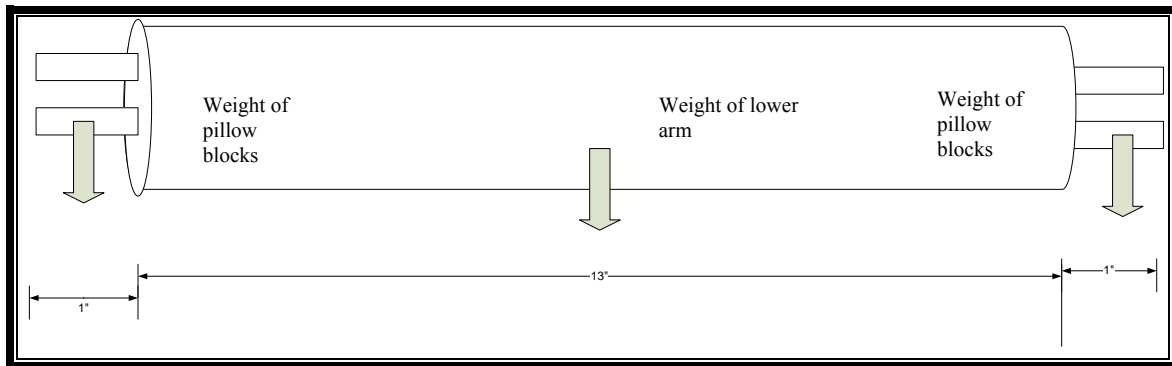
$$\sum M_w = 0 = 1''(W_{\text{motor}} \text{ lbs}) + 6.5''(W_{\text{grippers}} \text{ lbs}) + 11''(\text{Load lbs}) - M_w \quad (\text{eq. 2})$$





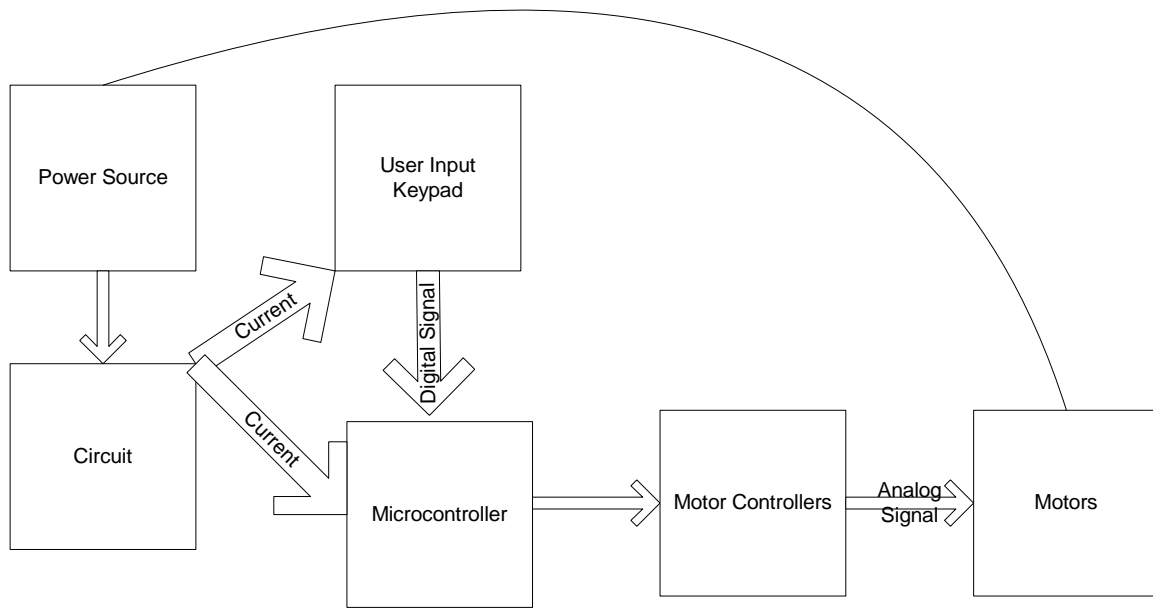
**Figure 15: Moment Diagram for the lower arm**

$$\sum M_E = .5''(W_{\text{pillow block}} \text{ lbs}) + 7''(W_{\text{lower arm}} \text{ lbs}) + M_w - M_E \quad (\text{eq. 3})$$



**Figure 16: Moment diagram for the upper arm**

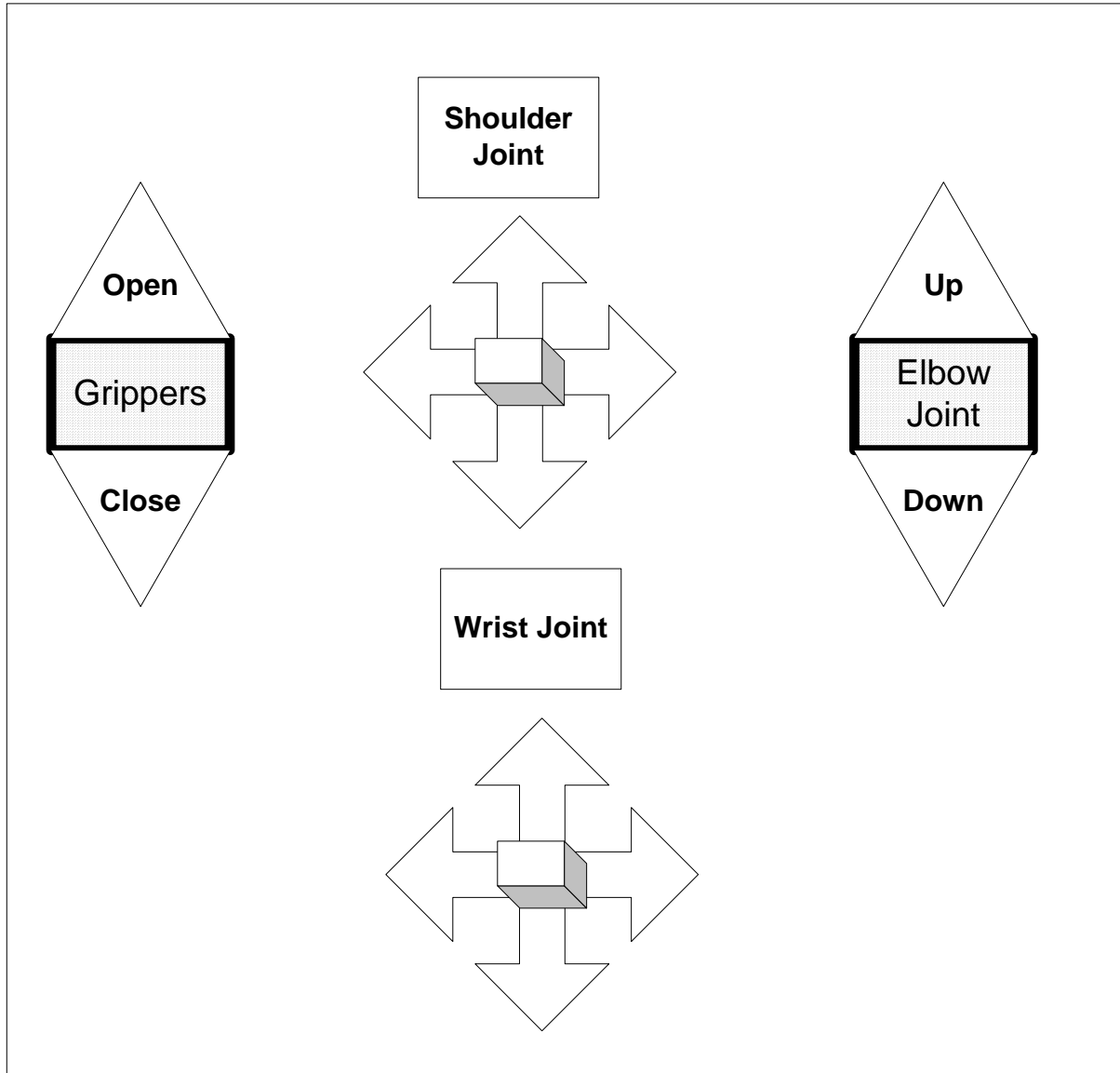
$$\sum M_S = .5''(W_{\text{pillow blocks}} \text{ lbs}) + 7.5''(W_{\text{upper arm}} \text{ lbs}) + 14.5''(W_{\text{pillow blocks}} \text{ lbs}) + M_E - M_S \quad (\text{eq.4})$$



**Figure 17:** Block diagram of processes

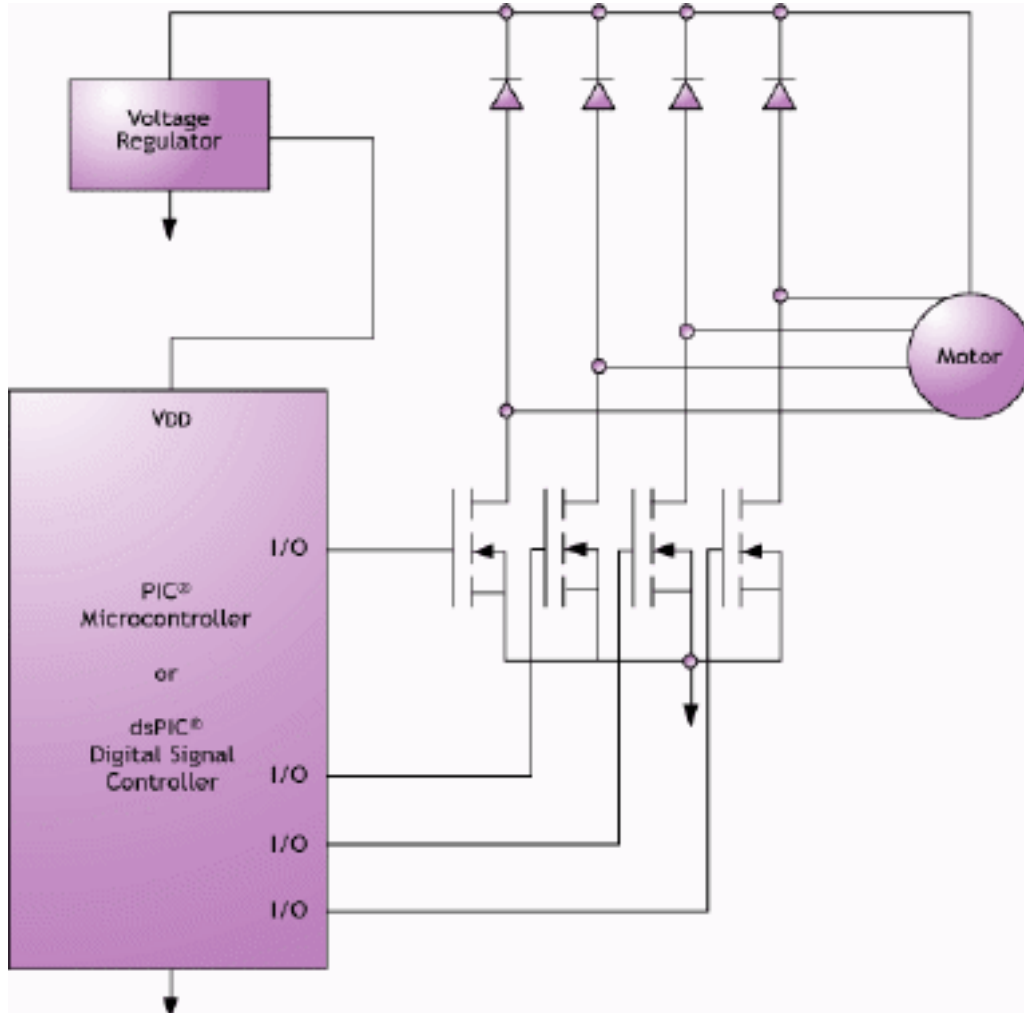
This is a basic mechanical robotic arm with three different joints running by the stepper motors. It is a small motor that is wired to the receiver. If given instructions to do so by the transistor, each motor will move a certain amount. Also, there is a user interface which is controlled by the ten separate input keys. User will be able to control the movements of each joint by pressing the forward or backward keys. Since the client has gross motor controls, he is still able to use a keyboard without any problems. Even though, the motors will be driven by the analog signals, a microcontroller is used to convert the digital signal input from the keypad and then it transmits the signal to the stepper motors located in each joint. Figure 17, above, explains a general overview. The power source is connected to both circuit and the motors. Circuit is then responsible for generating the current and then transmitting to the input keypad and microcontroller. User input keypad generates a digital signal and then sends out to the microcontroller. Microcontroller produces output signals to control motor controllers. The stepper motors interpret these signals in order to provide movements and the desired positioning of each joint.

## The Keypad:



**Figure 18:** User Keypad

The user will be able to control the arm using a keypad. This keypad is designed to function like a joystick with all the controls built into keys. Each set of four keys is designed to mimic the controls of a joystick. As mentioned in the beginning of the report the arm will consist of three joints; shoulder, elbow and the wrist where all the attachments and grippers can be installed based on various functional needs. Since the shoulder and wrist joints consist of a 360° rotation, there are four keys governing the movements; up and down, left and right. There are two keys for grippers; open and close. Similarly the keys for elbow joint will be functioning in terms of up and down as well.

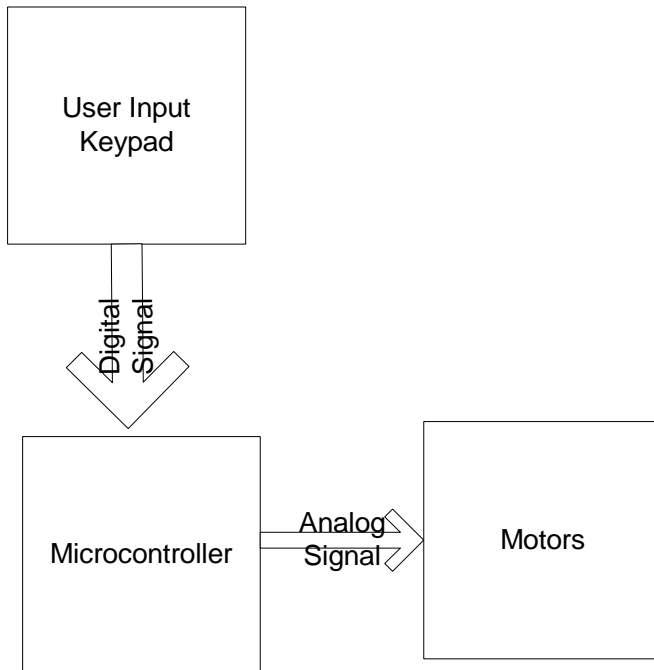


**Figure 19:** This block diagram shows a typical circuit used to drive a stepper motor without a motor controller chip <sup>1</sup>

The block diagram above indicates typical requirements for the stepper motor control using a PIC microcontroller. For a stepper motor, inputs are usually pulses and the control is basically input/output for a full or half step. Comparators are used for over-current detection. Limit switches are used for homing and safety when designing for the feedback. Multiple switches (MOSFETs) are implemented in design to act as a driver. \*

<sup>1</sup><http://www.microchip.com>

## Microcontroller



**Figure 20:** *An overview of Microcontroller*

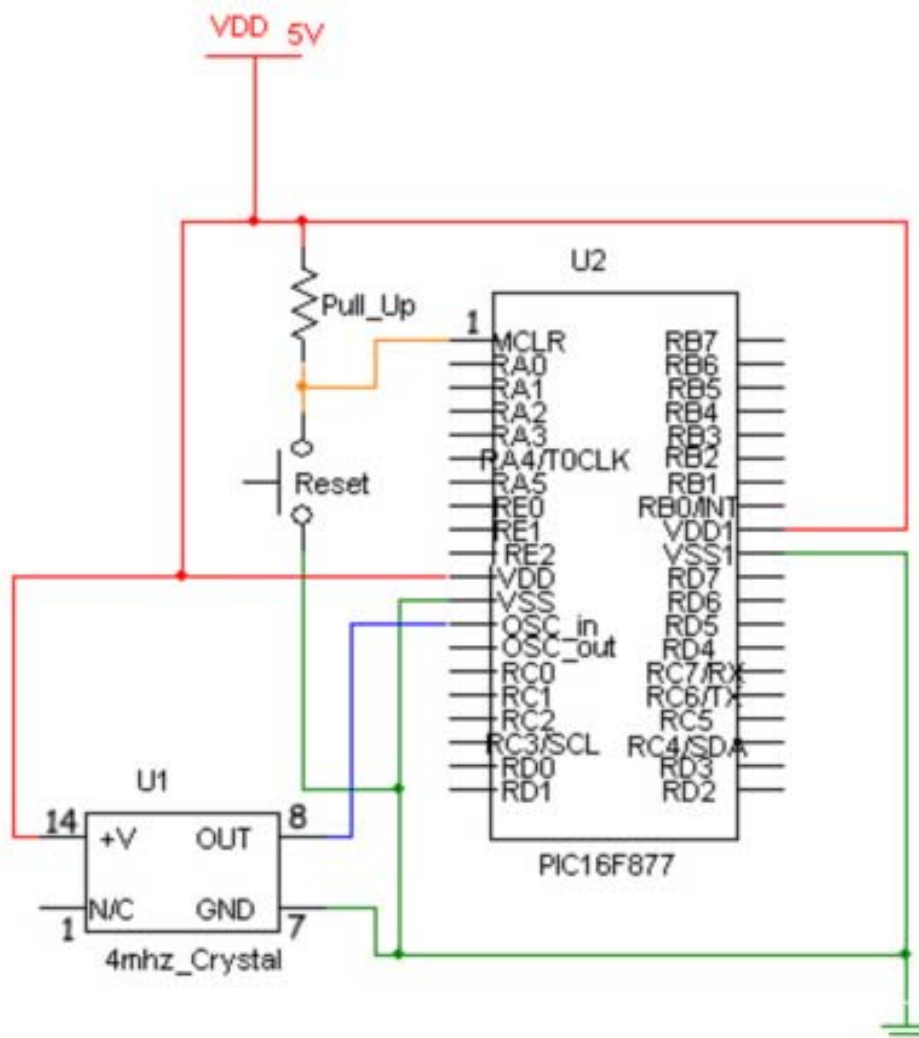
Figure 20 above explains the process of the microcontroller. The user input from the keypad is transmitted to microcontroller for processing. It is responsible for converting digital signal from keypad to analog signals that will be utilized by the stepper motors. Also, at this point, all other error checks are conducted to see if all joints are functional and not moving. It is important to have this check since problems can arise if any other parts of arm are in motion before analog signals are received. Once all the checks are approved, the microcontroller will send out a series of signals which will allow the stepper motor to position the rotational joints in the desired orientation.

For the robotic arm, PIC16F877 microcontroller chips will be implemented in the design. This is a powerful (200 nanosecond instruction execution) device. PIC16F877 features 256 bytes of EEPROM data memory, self programming, an ICD, 8 channels of 10-bit Analog-to-Digital (A/D) converter, 2 additional timers, 2 capture/compare/PWM functions, the synchronous serial port can be configured as either 3-wire Serial Peripheral Interface (SPI™) or the 2-wire Inter-Integrated Circuit (I²C™) bus and a Universal Asynchronous Receiver Transmitter (USART).<sup>2</sup>

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<sup>2</sup>

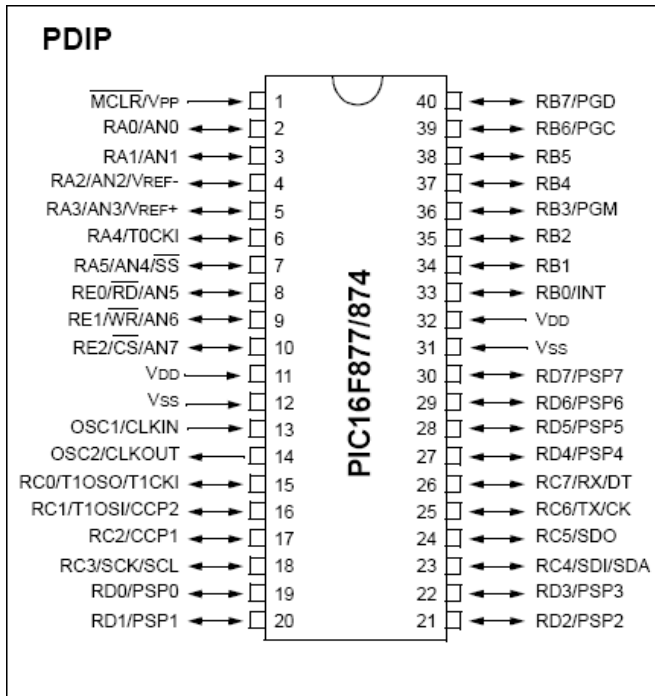
[http://www.microchip.com/stellent/idcplg?IdcService=SS\\_GET\\_PAGE&nodeId=1335&dDocName=en010241](http://www.microchip.com/stellent/idcplg?IdcService=SS_GET_PAGE&nodeId=1335&dDocName=en010241)



**Figure 21:** Implementation of a general PIC chip without an augmented board <sup>3</sup>

Clock speed will determine the frequency of the signals going into the microcontroller. A faster clock speed will result in faster movements of the joints since an increased speed will allow the microprocessor to control the movements at an enhanced pace. Figure 21 above shows implementation of a microcontroller by itself without an augmented board.

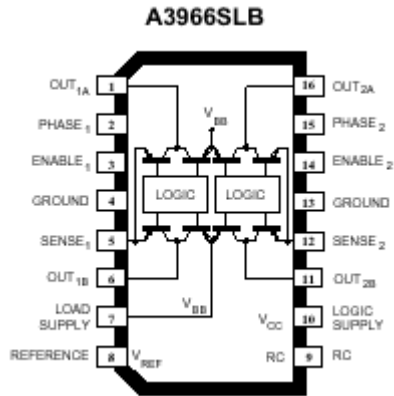
<sup>3</sup> <http://oak.cats.ohiou.edu/~db283101/pichowto.html>



**Figure 22:** Pin Connections for PIC16F877 Microcontroller

Figure 22 above depicts a pin connection for PIC16F877. In general, each PIC chip can control two independent stepper motor controller chips. However, in the design for the robotic arm, only one PIC per motor controller chip will be used. There will be five of these PIC chips implemented in the design. Each PIC chip will be responsible for driving the motor controller A3966 chip. Each A3966 chip is a dual-H bridge chip. These motor controller chips are also known as slave chips. There will be a 16-bit oscillator implemented in the design to control the period of oscillation.

Motor Controller Integrated Chip Allegro 3966:



**Figure 23:** Pin out connections for A3966 Dual Full-Bridge PWM Motor Driver <sup>4</sup>

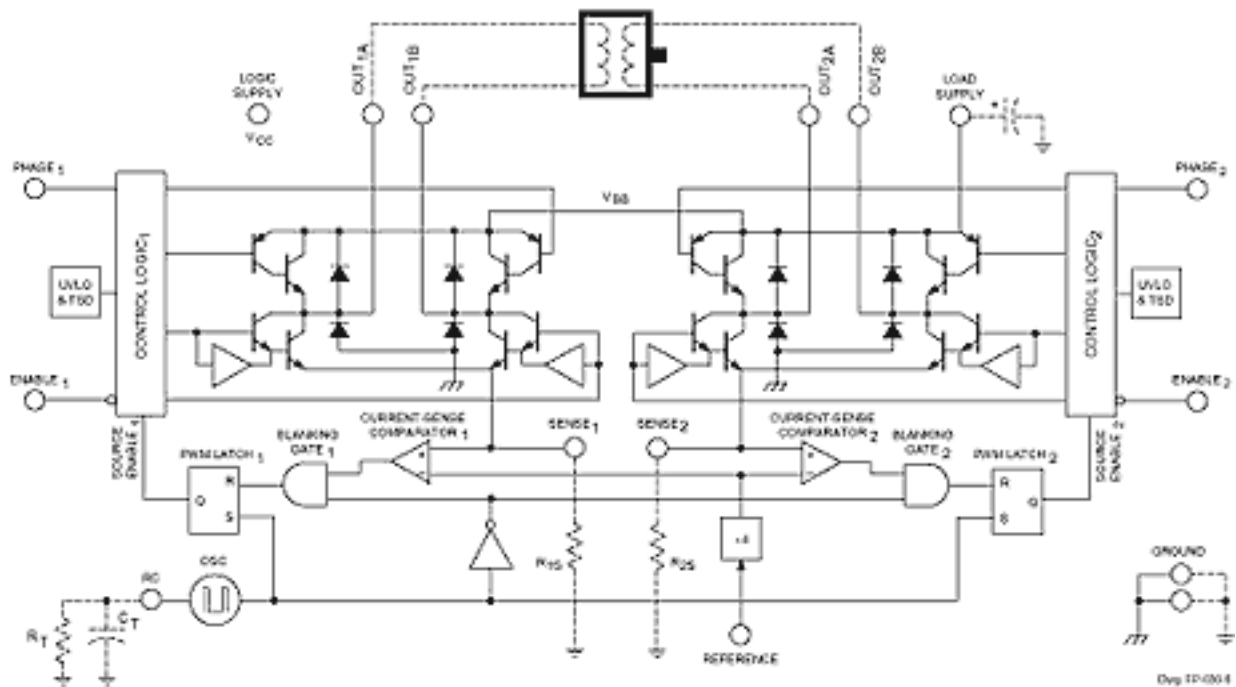
## Features <sup>5</sup>

- $\pm 650$  mA Continuous Output Current
- 30 V Output Voltage Rating
- Internal Fixed-Frequency PWM Current Control
- Satlington<sup>®</sup> Sink Drivers
- Internal Ground-Clamp & Flyback Diodes
- Internal Thermal-Shutdown Circuitry
- Crossover-Current Protection and UVLO Protection

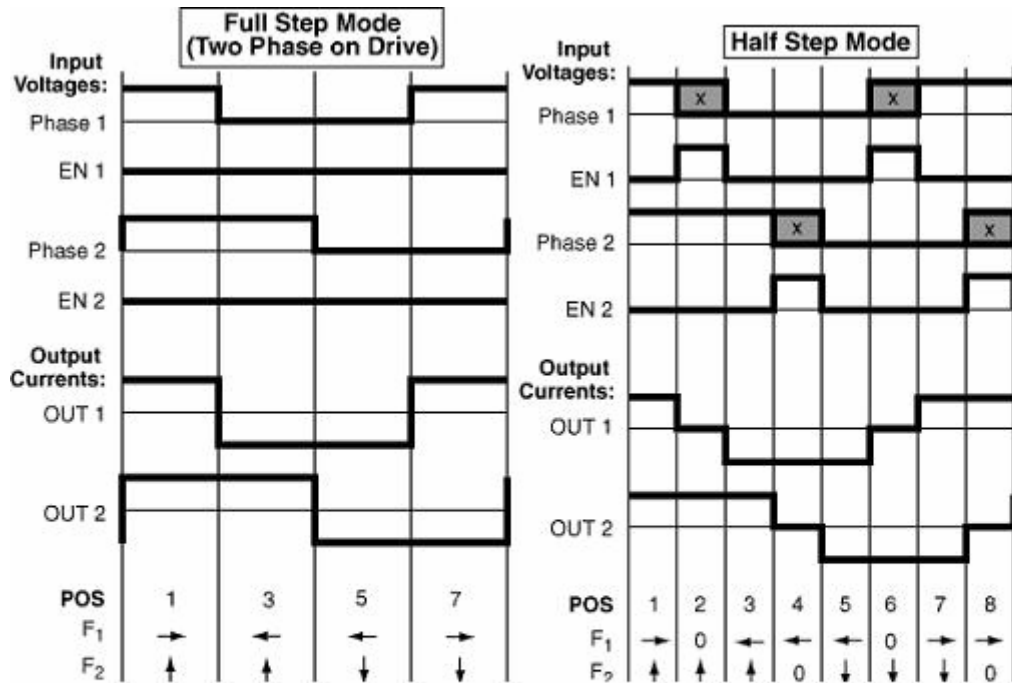
<sup>4</sup> <http://www.allegromicro.com/sf/3966/>

<sup>5</sup> <http://www.allegromicro.com/sf/3966/>



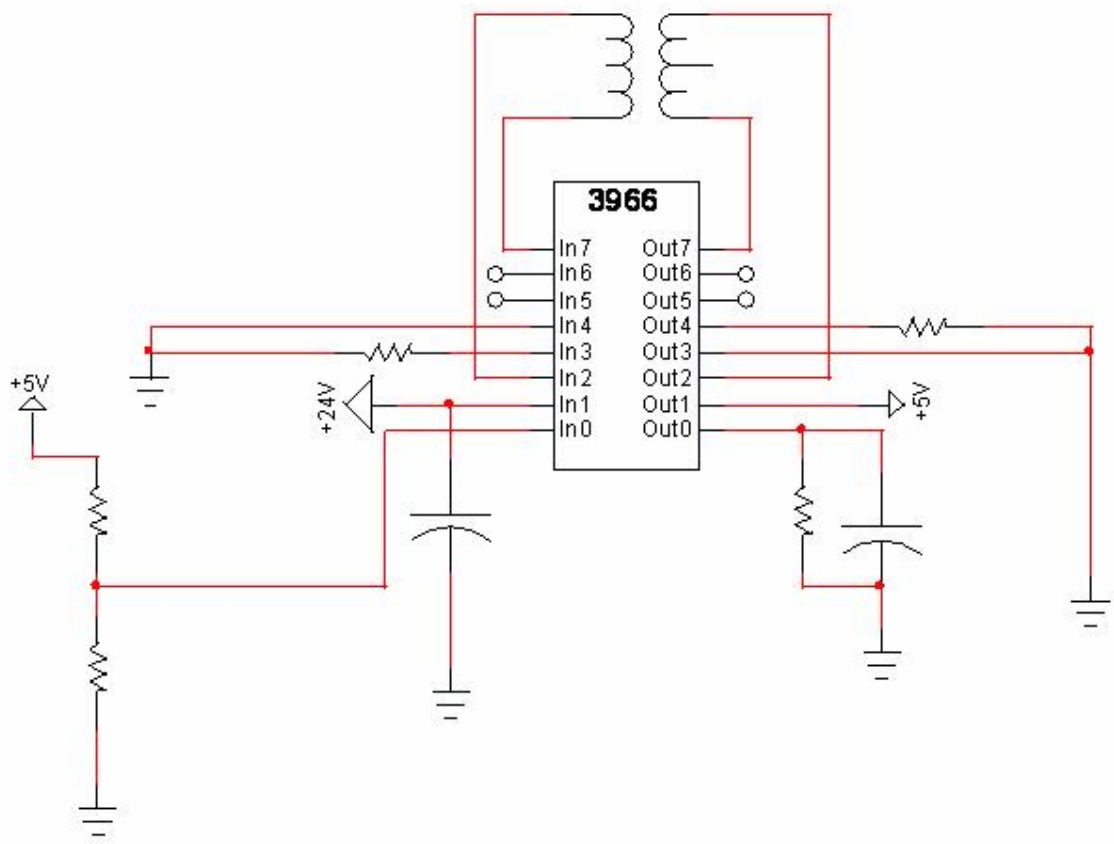


**Figure 24:** Functional block diagram of Allegro 3966 chip <sup>5</sup>



**Figure 25:** Timing diagrams for A3966 chip<sup>6</sup>

The waves depicted above in Figure 25 are also known as out of phase square waves and they are sent into the connector.



**Figure 26:** A3966 implementation

For each bridge, a PHASE input controls the load-current polarity by selecting the appropriate source and sink driver pair. For each bridge an ENABLE input, when held high, disables the output drivers. Special power-up sequencing is not required. Internal circuit protection includes a thermal shutdown with hysteresis, ground-clamp and fly back diodes, and crossover-current protection.<sup>7</sup>

<sup>7</sup> <http://www.allegromicro.com/sf/3966/>



upper electromagnet is deactivated and the right electromagnet is activated. That causes the rotor to move 90 degrees in the clockwise direction. This is followed by the deactivation of the right electromagnet and the activation of the lower electromagnet to move the rotor another 90 degrees. The same process is followed to inactivate the lower and activate the left electromagnet to move the rotor 90 degrees further. Finally the cycle is completed as the left electromagnet is deactivated and the upper electromagnet is activated. It is important to note that this example of 90 degrees resolution is not practical. An average resolution is 5 degrees per step so to rotate a complete 360 degrees, it would take 72 pulses (steps). Another term associated with the rotation of device is “half-stepping”. This is when instead of switching to the next electromagnet in the rotation, with a half step it turns on both electromagnets. This causes an equal attraction in between doubling the resolution. That would mean that if you had the 5 degree stepper motor half stepping it would take 144 steps to complete 360 degrees, instead of the already specified 72 steps.

Stepper motors have some unique characteristics that make them effective. First the stepper motors produce high torque at low speeds. The motor also possesses the ability to hold its torque. This means each motor has the ability to firmly hold its position when not turning. It is good for things that stop and start a lot. Other advantages are the low cost, no feedback required in the open loop, rugged for any environment and there is no tuning involved.

#### **1.2.14 Batteries**

In this design, deep cycle batteries will be used to power the arm. Compared to other sources of power, deep cycle batteries will be the most beneficial since they allow for an 80% power discharge. This specific type of battery as has a significantly thicker positive lead plate. This factor is crucial to the elongation of battery life since a thicker plate is a key factor in the prevention Positive Grid Corrosion. This factor is one of the most common reasons that lead to a battery’s failure. In any battery the positive plate slowly degrades over time. When the positive plate is completely consumed it falls to the bottom of the battery creating a sediment. Due to the durability of deep cycle batteries, they are often used in forklifts and golf carts. The plate thickness of a deep cycle battery even supercedes that of an automotive battery. Unlike the automobile battery, these batteries are quite powerful and do not need to depend upon a medium, such as an alternator, to keep a machine functioning. Another reason that an automobile battery would not be suitable for this application is because it provides a large amount of current over a short period of time.

Most deep cycle batteries contain Lead-Antimony plates rather than the traditional Lead-Calcium plate. The unique alloy also increases plate life and strength. The Lead-Antimony plate additionally allows for a plate to discharge at a rate of about 1-2% per month where other batteries discharge at a rate of 2% per week. Since the robotic arm will be utilized quite frequently within his academic setting, the type of battery that can produce the longest life span would be the most economical and beneficial to the client.



**Figure 28:** *Deep Cycle Batteries*

### **1.2.15 Testing of Subunits**

Many parts of this design will have to be tested for stability and functionality. A major durability concern would be for that of the keypad. It is essential that the keypad be able to withstand vigorous and aggressive movement since it is essential for proper functioning of the arm. In order to test this, each individual key on the keypad will be aggressively punched 150 times and then tested for proper functioning. Ultimately, the keypad should be able to withstand approximately 1 million punches. If the client were to use one particular button fifty times a school day every day, the keypad would have a life span of 55 years.

It is also important to observe how the device functions in space after vigorous consistent motion. In order to test this each motion, along with its opposition motion, will be conducted 100 times. This will show if any particular motion in space will degrade or malfunction over time. Tipping is also another major concern for the device. Since the arm will be attached to the side of the client's wheel chair, the device will be positioned in the area where its center of gravity is furthest from the chair. This position will be located when the arm is fully extended perpendicular to the side of the wheelchair's arm. This test will be conducted when the client is not in the wheel chair. If the chair does not tip when the client is absent from his seat, the chair will never tip with the client sitting in it.

## **2 - Realistic Constraints**

This design incorporated many engineering standards, along with health and safety concerns, to produce a device that best benefits the client. The PVC piping and plastic materials that were chosen for this device will provide the client with the same reliability that would be expected of any product currently on the market. The materials chosen are very adaptable to various deviations in weather and temperature. This abides by engineering standard 60605-3-4. Engineering standard 60812 was also followed since a safety mechanism was implemented in case of a device failure. By calculating all of the mathematical expressions that correspond to the various orientations and motions of the

device, another standard, 61703, was followed. Ultimately, the completed device will be durable and provide much functionality for the client. This would be desirable of any product currently on the market today.

### **Economic**

A major economic constraint for the project is the budget. The budget allotted for all design projects sponsored by the National Science Foundation is 750 dollars. This is a concern since many assistive mobility products on the market can cost an upwards of one thousand dollars. The budget places a limit on the versatility and sophistication of the completed device.

### **Environmental**

Environmental constraints include variations in weather and temperature. The device must be able to withstand moisture in the form of precipitation or humidity. Also, the device should be able to function flawlessly in extreme temperatures. The device should not breakdown when relocating to an area of opposite climate. Since the client is in an elementary school environment, there is a strong possibility of accidents with food and beverages. The device should not malfunction and should show no signs of corrosion if this were to happen. Finally, the client will also be using this device for his sixth grade gardening project. The corrosive nature of soil should not deteriorate the device by becoming interlocked within any joints.

### **Sustainability**

The device should be composed out of a durable and corrosive resistant material such as PVC piping and plastic. PVC piping is a good material of choice since its unique molecular structure allows it to be durable. This material is both extremely robust and is ideal for mechanical applications involving stress and strain. PVC piping is relatively cheap and easy to obtain. The device should also be weather proofed at any joints as a precautionary act.

### **Manufacturability**

If this device were to be manufactured for a company, the device would have to be made custom to fit the needs of each individual client. This particular device will be manufactured for a child who only has control of his right hand. This specificity poses a manufacturing discrepancy since some clients may only have control limited to their left hand. Eventually, the device would be much more effective if it had the capability to be reoriented for usage with either hand. This way two separate devices would not have to be created depending upon which side is dominant to a patient. Also, other clients may have severe impairments that limit them to the usage of only a solitary finger. The device would have to be adaptable for any of these circumstances in order to be truly effective and sold on the market.

### **Health and Safety Concerns**

The device must not only be safe for the client to use, but should not pose a potential injury to any of the client's surrounding peers. The device should not be capable of producing any form of an electrical shock or impulse under any circumstance. The

device should also have a safety release mechanism in case it were to become attached to any part of the client's body. The current running through the motor should be kept within a narrow limit so that the device will not over heat or become extremely hot. Also, since the client will be feeding himself independently with the device, it is important to consider the potential injury fork moving a high velocity could cause to the patient's throat or soft palate. It is essential that the elbow joint of the device can move no further than 155 degrees towards the client's face. Since the entire arm will be placed in front of the client, the client will be forced to lean forward to obtain his food from the fork. The client does have enough head control to perform this motion.

Since the client only had gross motor control, he is required to meet with an occupational and physical therapist frequently. Once this design is partially created, it is important that the keypad be integrated into the client's occupational therapy routine. Also, since the client has a very limited range of motion it is essential to constantly communicate with the therapists so that the device that is being created for the client is as convenient and simple for him to use as possible.

### **Social**

Socially, the client never wants to deviate from the norm. With an assistive device it is hard to make a disability inconspicuous. Also, even with this assistive device, the client will never be capable of accomplishing complete independence. In some cases, individuals may be derogatory to those with impairments. This could cause frustration to any client and may cause the device to not appear as appealing.

### **Political**

It is also important that all FDA and OSHA regulations be followed in the creation of this device. FDA and OSHA regulations usually concern the safety of all clients. It is not uncommon for the government to step in if they feel that a device is doing more harm than it is good. Also, patent infringement is always a lingering concern. It is crucial that the device being created does not mimic any other device too closely.

## **3 - Safety Issues**

### **Electrical**

Safety issues regarding electricity were a primary concern when implementing this design. Given the nature of the device, many electric components are necessary in order for it to function properly. The circuit board, which consists of electrical wiring that will generate a current, is housed within the base unit. This was designed for the protection of the client. Water is an excellent conductor of electricity and should not come in contact with any of the internal circuitry in the electrical board. This could pose a potential danger and shock to the client. All wires will be contained within the PVC piping. It is pivotal that no bare wire be exposed. Bare wire has the potential to create a short within the circuit. The short could either cause the arm to either shut down or malfunction in a dangerous way. Bare wire also poses the risk a potential electrical shock to the client or any of his peers. It was also determined that the maximum velocity that any of the motors should operate at is 6 cm/sec. For any joint to exceed this speed, the



current being generated throughout the device would have to surpass the limit that is considered safe.

### **Mechanical**

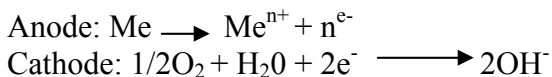
A safety release mechanism will be implemented into this design in the case of a mechanical malfunction. While the microprocessor should be telling the arm exactly how to position itself, there is always a risk of the arm becoming clamped around an unwanted object. There is also the risk of the arm gripping an object too tightly. It is essential to determine this ultimate force so that objects, such as those composed of glass, do not shatter and cause harm to the client or any of his surrounding peers. This force is also important so that objects will not be gripped too loosely and later be dropped while in transportation. The breaking of any object is always a potential risk of harm. It is also important to have a safety release mechanism since the client has only gross motor skills. Since the client has limited mobility, it is a strong possibility the client could accidentally press a button that he did not intend to. This possibility could lead to a major safety hazard. If the client were to trigger a button unintentionally, the client could mount onto another person or even the client, himself. While the grippers are not strong enough to crush major bones within the body, they could still present quite an injury. It is important that a safety mechanism be implemented into the design.

Another safety concern is that of the client when he is eating with a fork. Instead of a fork, a rubber spatula will be used. This is to prevent injury to the client or his peers. If the device were to malfunction and enter the client's mouth at a fast rate, the client could risk puncturing his soft palate or trachea. Sustaining an injury such as this could be very critical. Also, another concern is the client's teeth. The constant banging of metal on the client's front teeth could potentially cause them to chip or discolor.

Finally, it is essential to verify that the arm does not cause the wheel chair to tip when its center of gravity is located furthest from the center of the chair. If the chair were to tip, the client could become injured. The chair should not tip without the client present either. It is also important to place the device at a location where it will not interfere with any of the inner workings or mechanisms or the wheel chair.

### **Chemical Hazards – Corrosion**

Another potential safety hazard that corresponds to the nature of this device is corrosion. Since there are many nooks, crannies, and connections within this device, there is a risk of crevice corrosion. Crevice corrosion occurs when moisture and debris collect within a crevice and become stagnant. When moisture and debris remains trapped in a fissure, the surrounding surface begins to dry out and oxidize. When this happens an anodic attack of the metal takes place near the mouth of the crevice and a cathodic reduction of oxygen takes place on the surface surrounding the metal. The reaction is as follows:



This is very important to this device since the risk of crevice corrosion is especially heeded in passive metals such as stainless steel, which the grippers will be constructed out of.

Everything else will be constructed out of plastics and PVC piping to avoid this type of corrosion all together. Crevice corrosion can also be catalyzed when a metal is contacting a nonmetal. This was taken into account in the planning of this design. In the PVC piping, there will be many joint connections, it is important to make sure that no debris becomes lodged within the connections. In order to prevent this from happening, all joints will contain oil sintered, bronze bearings. This is also important if the client will be using this device around soil. Soil is a very corrosive material that can cause deposit corrosion. Deposit corrosion is very similar to crevice corrosion. Deposit corrosion happens when moisture forms and becomes trapped under a deposit. In this situation, the area directly under the deposit acts as the anode and the area surrounding the deposit functions as the cathode. Corrosion protection is very important to the proper functioning of this device. If significant corrosion were to occur, the device could severely malfunction.

Another chemical hazard is from the deep cycle batteries. Since batteries all contain acid, it is important to make sure that they do not leak. It is also important to be sure that these batteries are discharging to their full 80% capability so that the battery life will be maximized.

#### **4 – Impact of Engineering Solutions**

This device has the potential to bring independence to those who are confined to a wheel chair and lack the basic mobility that many take for granted. Many who are confined to this state, lack the basic ability to eat, open doors, cabinets, or refrigerators, and obtain objects independently. This device, specifically for this client, will aid him within his classroom setting so that his academic prowess will not diminish over time.

This product will socially benefit the client greatly. Since the client has only gross motor skills, it is very hard for him to communicate. Since he is a determined individual, he succeeds fairly well although he finds his means of communication difficult. The assistive robotic arm will provide this child with a simple way of operating his two main communication devices; the “Dyna Vox” unit and his laptop. For the client, providing him with a new communication device would be expensive. Also communication devices and computer keypads on the market that are geared for persons with disabilities still require fine motor control. Unfortunately the level of control that many of these communicative devices require far exceeds what the client is capable of. The device being implemented in this will allow the client to operate these two communicative devices with more ease. This will place the client on a new level socially.

Being able to eat independently will also embellish the client’s life style socially. He will be able to join his peers during lunch hour instead of eating alone with his personal aid. If the client’s personal assistant cuts his food before lunch, this device will allow him to eat independently with a rubber spatula resembling a fork. Also, since the grippers are made to be interchangeable, they can be customized for any task that the client would desire as long as the diameter of the inserted tool is the same as the insert socket on the grippers.

Many devices on the market that could be purchased for the client are extremely expensive and do not provide enough features to suit the client’s needs. This can become quite frustrating to the client since he only wants to fit in amongst his peers. This device

will be effective since it is being created to cater specifically to his individual needs. Many products on the market today are not durable enough to withstand the force at which the client types. This device will compensate for this by providing an extremely large keypad with a high spring constant. This feature would be beneficial to any patient with limited motor control.

Globally, a custom made device similar to the one described in this design could revolutionize the field of medicine. While many devices on the market today are very beneficial to aid a patient's needs, they are often created in a very generic style in hopes to a broad array of individuals. Since there are so many debilitating diseases and medical conditions, it is almost impossible for a patient to reap the full benefits of any device. The device may either contain too many features or may not contain enough. This is very important since an individual may be paying for features that could potentially never be utilized.

Since an ongoing dispute in the medical realm is insurance and high costs, this device was created to be relatively inexpensive. Many patients cannot afford the outrageous prices of the devices that exist on the market. Ironically, patients are often not concerned with having the most high-tech or savvy device on the market. They are often just concerned with being able to complete a daily routine and feasible manner. This device is capable of making that happen for many.

For this client, and for any other student, this device will make an academic setting more welcoming. Students and young children will not feel as secluded for their peers and surroundings. In the client's specific case, being able to eat lunch with his peers will give him the opportunity to make new friends and expand upon preexisting relationships. For a child to always be segregated from his setting eventually becomes a mental burden with age. No child wants to deviate from the norm. While it is unrealistic that any supplementary device could completely compensate for such an impairment, this device has the potential to embellish the client's quality of life.

This device will also allow for the client to not fall as far behind academically. To some students, this constant struggle may cause a child to give up and work to their full potential. In the case of the client, he is often required to come in early and stay late after school to compensate for all the extra time he requires. The client puts in an additional three hours a day compared to the other children. If a device such as this one could be implemented into school system globally, many students who are mentally sharp and exceptionally bright would not require special education classes to take away time from the normal school day. The client is not attending special education classes because he struggles in school; he is the most intelligent child in the classroom.

Economically, these devices could also lower costs and school budgets. If children with solely physical disabilities were capable of functioning independently in regards to completing class and homework, additional help sessions before and after school could be cut back. These children would be relieved and excited to leave school with their peers. From an additional economic standpoint, mentally astute individuals, with the aid of an assistive device, may be able to obtain entry-level jobs. This would create a new found sense of independence in each of these individuals.

## **5 - Life long Learning**

This project consists of life long learning in that we are always trying to increase knowledge with each of our alternative designs. In a sense we are learning the technical things such as what batteries to use, how to create a circuit and how much torque it will require to move the robotic arm. Also, we are learning how to work under pressure and finish by a certain deadline. Finally, the most important aspect of these alternative designs is to realize that when designing something, nothing is ever foolproof. All of the projects have many unforeseen obstacles to overcome before becoming functional. Another lesson learned from the creation of these designs is how beneficial the collaborations of ones thoughts can be with another. When creating a device such as this, there are often an infinite number of directions to proceed with a design. Since everyone is unique, these directions are often all interpreted in a numerous amount of ways. It is this differentiation in interpretation that often leads to success. We have been able to witness first hand just how ideas and improvements can spawn from an idea of a peer. We have also learned just how important it is to be challenged by our mentors. These challenges often come in the form of constructive criticism that enlighten our minds and embellishes our ideas.

Paralleling with these thoughts, it is often import to seek out and utilize the resources that we are surrounded by. With this idea, it is important to seek out help of others who are more knowledgeable then ourselves. In order to survive in the field of engineering it is essential to be open minded and value the ideas given by others. This will allow for a much more eclectic design and ultimately lead to a greater success. Since our world with filled with such a plethora of information, it is impossible for one person to posses all the knowledge needed to create a design independently. In the field of engineering teamwork and communication is essential.

Some of the most valuable resources are the challenges that we face on a daily basis. The testing and failure of a device should not be viewed as a disappointment but as learning experience. Failure does not define unintelligence, defeat does. It is important to possess a drive and ambition that continuously leads one towards the improvement of ones work and knowledge. These essential qualities also lead to respect, which is essential to survive in such a demanding field.

Through these designs, it is important to realize that a functioning and optimal device cannot be devised in one design. Engineering is a cumulative process that involves much planning. Even when a design appears to be at its peak, there is always a way to improve it. These improvements may be as simple as lowing the raw cost or as complicated as implementing a new technology. Whatever the case may be, the lesson to be learned from all this is that it is important to challenge yourself and your fellow team members. The work force is a competitive industry and it is important to be sure that a design is beyond what is deemed satisfactory. Those who contribute the more time will reap greater benefits in the end. Those who refuse to find ways to continually alter and improve their ideas will slowly fade along with their device.

The group has also learned how essential visual aids can be to the progress of a design. When implementing a design as complex as a robotic arm, it is often hard to

visualize mentally just how a device such as this will function and work. Even when one thinks they have a firm visualization established in their mind, it can never compare to a tangible model. Once a model was constructed, the group was able to see precisely how the grippers would function. The design was also altered based upon the different types of positions and configurations that were perceived. The model enlightened the group and brought about an entire new perspective to the project. While creating a model seems like more work initially, one cannot even imagine the time and frustration it can save in the end. Building a model was one of the most beneficial decisions for this project. The model brought about a sense of clarity and really aided to our past two designs. From this experience, it seems illogical to even attempt to construct a device without a physical representation.

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