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ASSISTIVE ROBOTIC ARM

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by

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ABSTRACT

ASSISTIVE ROBOTIC ARMS

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The University of Texas at Arlington, 2019

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An estimated 58,000 individuals in the United States alone require assistance with eating and drinking. Current robotic technologies on the commercial market that attach to electric wheelchairs, and are capable of performing motions associated with eating and drinking, cost around $30,000. This exorbitant cost renders many persons with a disability reliant on other people for their basic care. In partial fulfillment of MAE 4188, our senior design group has designed and built a wheelchair attachable, assistive robotic arm capable of reaching a distance of two feet to retrieve a two-pound object. The target cost for the prototype is $1500. In completion of this project, we will bring an affordable mobility solution to those who need it most.

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CHAPTER 1

MOTIVATION

1.1 Mobility Limitations in the United States

An estimated 40 per 1000 persons 18 to 44 and 188 per 1000 persons over 85 in the United States suffer from a mobility limitation [1]. Mobility limitations impede the ability to partake in activities of daily living (ADL) [1]. In the United State alone, an estimated 58,000 people are not able eat and drink by themselves [2]. These people must rely on caregivers or family members for basic care, which can result in malnutrition. Additionally, mobility limitations also impair social opportunities, which leads to anxiety, social isolation, and depression [1]. These combined conditions reduce quality of life.

1.2 Financial Burden on Persons with a Disability

People with mobility limitations that inhibit them from performing ADL often rely on costly medical treatment, home healthcare, and assistive devices. Live in caregivers typically cost $24,000 per year [3]. The average cost of electric wheelchairs is $12,000 [4]. Existing robotic arms to help persons with a disability eat and drink start at $26,000 [5]. These financial burdens are rarely funded by insurance companies. Since persons with mobility limitations face difficulty finding employment, they must often do without these amenities and their independence.

CHAPTER 2

COMMERCIALLY AVAILABLE ARMS

Three main robotic arms exist on the commercial market to help aid in eating and drinking for persons with a disability: Meal Buddy, Jaco2, and Mico2.

2.1 Meal Buddy

The Meal Buddy is a table top robotic arm create by Richardson Products Inc. Its chief function is to provide assistance in eating and drinking. The Meal Buddy is shown in Figure 2.1 [6].

Figure 2.1: Meal Buddy

The Meal Buddy is capable of scooping food from three bowls using either the button or sip and puff input devises. The sip and puff option requires an additional $272.70 add-on.

It is not capable of retrieving a class of water or anything not in one of the three bowls. The Meal Buddy starts at $3,535 [6].

2.2 Jaco2 Robotic Arm

The Jaco2 robotic arm is a high-end wheelchair attachable robotic arm that is currently available on the commercial market. The Jaco2 robotic arm is shown in Figure 2.2 [7].

Figure 2.2: Jaco2 Robotic Arm

The Jaco2 arm features 6 degrees of freedom, one at each motor location. The total weight of the arm is 4.4 kg. It can lift 2.6 kg, or 5.7 lb. This makes it suitable to pick up virtually any item associated with eating and drinking. The Jaco2 arm can reach 90 cm, or just under 3 feet. Thus, it can comfortably reach across a table. The arm is made out of carbon fiber, which is a lightweight, strong, and expensive. The Jaco2 arm starts at $30,000 and requires a $4,950 end effector. The Jaco2 robotic arm contains all the functionality abilities to provide independence, but is out of reach financially for most persons with a disability [5].

2.3 Mico2 Robotic Arm

The Mico2 robotic arm is another commercially available are that meets virtually all the functionality requirements associated with eating and drinking, and is shown in Figure 2.3 [8].

Figure 2.3: Mico2 Robotic Arm [8]

The Mico2 arm has 6 degrees of freedom, one at each motor location, and weighs 4.6 kg. It can lift 2.1 kg, or 4.6 lb. This makes it capable of retrieving virtually all items associated with eating and drinking. The Mico2 arm can reach 70 cm, or about 2.3 feet. This makes it capable of reaching most items on a table. The Mico2 arm is made out of reinforced plastic, which is cheaper than carbon fiber while still maintaining structural integrity. The shorter reach of the Mico2 than the Jaco2 arm allow for it to use smaller motors since torque requirements are less. The shorter reach and cheaper material make the Mico2 arm considerably cheaper than the Jaco2 arm, $20,900. The Mico2 arm requires the same $4,950 end effector. The Mico2 arm is financially unavailable to most persons with a disability [8].

CHAPTER 3

PREVIOUS RESEARCH

3.1 Wheelchair Mounted Assistive Robot by Bath Institute

In 1999, A research group at Bath Institute in the United Kingdom created a wheelchair mounted assistive robot, shown in Figure 3.1 [9]. Some of their main design objectives were that the arm would: be mounted to a wheelchair, be capable of reaching floor to head height, and assist the user primarily in ADL.

Figure 3.1: Bath Institute Arm

The robotic arm manipulator created by the Bath Institute researchers features a linear actuator to vertically translate the gripper. Motor torque is transmitted to the joints via pulleys. The arm is mounted to the back of the chair such that it is out of the way of the operator. The arm is not modular, and is permanently appended to the chair. No information about cost, weight, or reach was included in the research paper. It is unclear if Bath Institute continued research on robotic arm manipulator [9].

3.2 A Low-cost Compliant 7-DOF Manipulator

A research team at Stanford University created a low-cost robotic manipulator with 7 degrees of freedom, shown in Figure 3.2 [10].

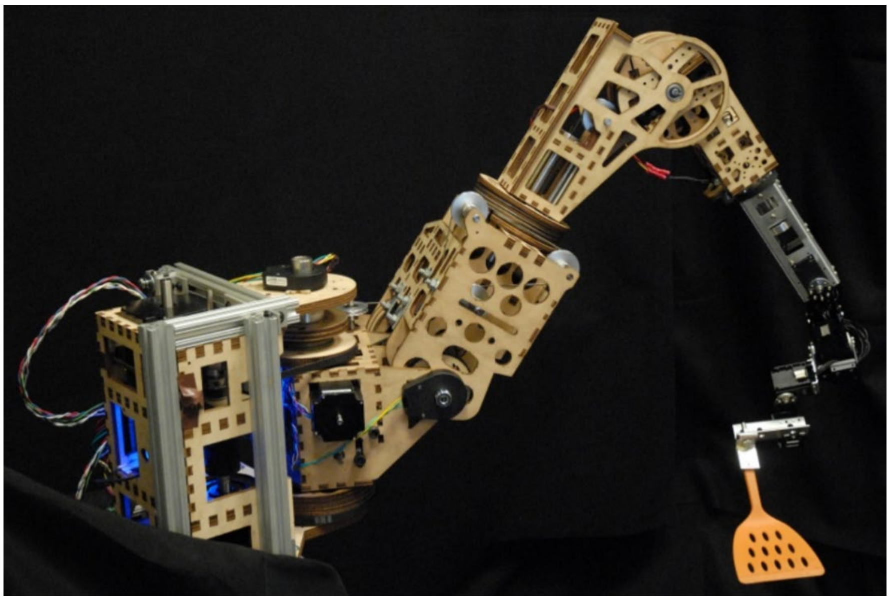


Figure 3.2: Stanford 7-DOF Manipulator [10]

The main structure of the prototype was plywood, laser cut to the correct shape and dimensions. The wood makes the prototype easily assembled, structurally strong, and fast production. Drawbacks to using wood are its stability in extreme temperature conditions and in humid conditions. The manipulator created by Stanford has very little backlash, moves at 1.5 m/s, and has a 2 kg payload. Power from stepper motors are transmitted to joints via belts. The arm is not modular due to the belts. The arm was controlled using a standard closed-loop PID controller. The entire assembly of the arm takes around 15 hours. It was capable of performing several ADL such as flipping pancakes and moving chess pieces. The total cost of the prototype was $4,135. This included $700 for stepper motors,

$1,335 for servo motors, $750 for electronics, $960 for hardware, and $390 for encoders [10].

3.3 Wheelchair-Mounted Robotic Arm by USF

A mechanical engineering design group at the University of South Florida build a wheelchair-mounted robotic arm, shown in Figure 3.3 [11].

Figure 3.3: USF Robotic Arm [11]

Their design featured a DC servo drive, actuators at each joint, 7 degrees of freedom, and reconfigurable link lengths. The objectives for the prototype were: to make the total system mass under 14 kg, to make it capable of lifting a 4 kg payload, and making the design reconfigurable such that it can be used in different applications. Carbon fiber was considered for the prototype, but, due to cost, it was ultimately made from 6061 Aluminum. The final arm mass was 12.5 kg, the maximum reachable height above the floor was 1.37 m, and the final payload was 6 kg including a gripper. The only cost information for the prototype produced by the University of South Florida was that the target cost was kept at the mid-range of commercially available arms [11].

CHAPTER 4

RESEARCH DONE BY ARMS

Our senior design group, Assistive Robotic Machines (ARMS), aims to provide affordable independence to those who need it most. Our objectives were to design and manufacture a cost effective, modular, assistive robotic arm appended to an electric wheelchair that is capable of reaching 2 feet to retrieve a 2-pound object. These functional criteria allow for most objects associated with eating and drinking to be retrieved. The cost goal for the prototype was $1,500, which is over a magnitude cheaper than any commercially available assistive device with the same functionality.

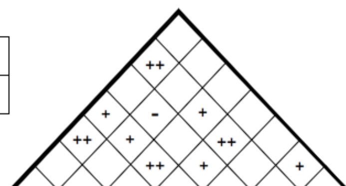
4.1 Conceptual Design

Before developing a prototype, conceptual designs were produced. Those conceptual designs are used in a down selection process to yield the best solution to our design objectives. To produce conceptual designs, ARMS applied common practices of product development processes. Some such practices include the construction of a House of Quality, physical decomposition, functional decomposition, and morphological charts. The product of which are concept sketches that represent possible solutions to the design objectives.

4.1.1 House of Quality

A House of Quality is an objective, graphical method of applying engineering characteristics to customer requirements and ranking them such that emphasis can be placed on the features of the design most important to the customer. The left columns list the customer requirements and provide them a weight factor and relative weight based on the best judgement of the engineer after conversations with the customer. As seen in Figure 4.1, the customer requirement categories were: versatility, ease of use, ergonomics, cost, weight, payload, and non-intrusive. These customer requirements are assigned an quantitative engineering requirement that can be explicitly designed for. For example, the customer requirement of “Low Cost” correlates directly to the engineering requirement of “Material & Manufacturing Cost.” At the intersection of a customer requirement and an engineering requirement, a relationship rank is applied. These, along with the importance weight factors, can be used to create a rank order of the most important design features. This rank order is shown in a row at the bottom of the House of Quality.

Project:	House of Quality
Team:	ARMS



			Engineering Characteristics							Customer Competitive Assessment (1-5)		
		Direction of Improvement	▼	▲	▼	▼	▼	▲	▲			
		Units	$	unit	in	lbs	min	oz-in	in/s			
Relative Weight %	**Importance Weight Factor (1-5)**	**Customer Requirements**	Material & Manufacturing Cost	Module Components	Arm Size & Dimensions	Overall Weight	Setup & Disassembly Time	**Arm Strength/Motor Power**	Arm Movement Speed	Kinova: JACO Robotic arm	Assistive Innovations: iARM	*ABB: Single-arm YuMi
20%	5	Versatility/Modular		9			3			2	2	2
12%	3	Simple/Ease Of Use	1	3	3	3	3			4	3	4
8%	2	Ergonomics	3	3	1		1			3	3	3
16%	4	Low Cost	9	1	3	3		9	3	1	2	1
16%	4	Low Weight	9		3	9	3	9	3	5	3	2
20%	5	2 lbs Minimum Payload	1		1			9		2	4	2
8%	2	Non-obtrusive			3					4	3	3
		Raw Score (374)	86	64	46	57	38	117	24			
		Relative Weight %	19.9%	14.8%	10.6%	13.2%	8.8%	27.1%	5.6%			
		Rank Order	2	3	5	4	6	1	7			
		Competitive Assessment	1	3	3	3	2	4	3			
		Target Values	1500	5	2-2.5	<25	10	550	2.5			

Correlation Matrix Legend	
Strong Positive	++
Positive	+
None	
Negative	-
Strong Negative	- -

Direction of Improvement	
Maximize	▲
Target	◻
Minimize	▼

Relationships	**Weight**
Strong	9
Medium	3
Weak	1

Competitor Rankings	
Excellent	5
Ok	3
Poor	1

Figure 4.1: House of Quality

As established in the House of Quality, the most important engineering requirement are the robotic arm's strength and motor power. The Resulting ranking of the House of Quality are shown in Table 4.1.

Table 4.1: HOQ Results

Engineering Characteristics	Rank Order
Arm Strength/Motor Power	1
Material & Manufacturing Cost	2
Module Components	3
Overall Weight	4
Arm Size & Dimensions	5
Setup & Disassemble Time	6
Arm Movement Speed	7

Table 4.1.1.1 enumerates the areas of design that emphasis was placed on, in order. Thus, an objective method was used to obtain the ranking of design requirements.

4.1.2 Physical and Functional Decompositions

In conjunction with the House of Quality, additional methods of product decomposition are physical and functional decompositions. A physical decomposition utilizes a top-down approach to graphically show the components typically found in robotic arms. The physical decomposition is shown in Figure 4.2.

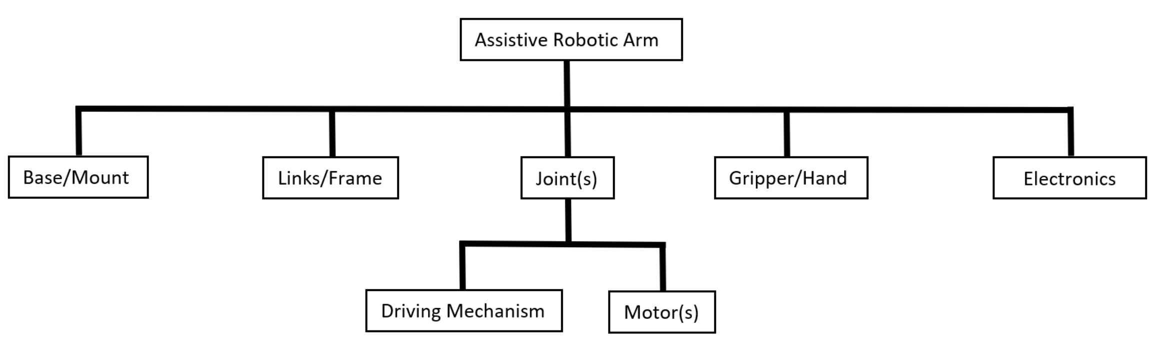


Figure 4.2: Physical Decomposition

The physical decomposition allowed for the ARMS team to visualize what components will make up the overall design. From the physical decomposition, a functional decomposition was created to identify the functions and subfunctions making up the overall behavior. Overall, the arm must take in human input and electrical energy to retrieve an object from a table. This is represented by the initial input and final output arrows in Figure 4.3. A functional decomposition takes key functions that must happen within a product in order to change the input to the desired output. These functions are placed in boxes and connected with arrows representing energy transfer, a material interface, or a signal.

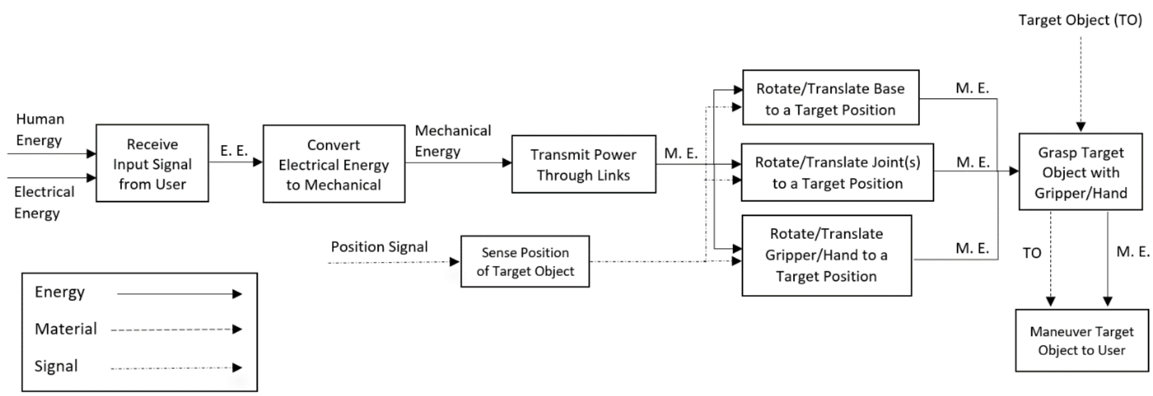


Figure 4.3: Functional Decomposition

The boxes and arrows in the Functional Decomposition allowed the arms team to graphically see which components needed to be designed and what they needed to do.

4.1.3 Morphological Chart

From the functional decomposition, a morphological chart was created. A morphological chart takes each block of the functional decomposition and provides a structural solution. The morphological chart is shown in Table 4.2.

Table 4.2: Initial Morphological Chart

Input Signal	EE to ME	Power Transmission	Rotate Components	Translate Components	Sense Target Position	Grasp Target
Joystick	Linear Actuator	Pulley	Articulated	Telescoping	Optical Sensor	3-Finger
Brainwaves	Rotary Motor	Hub	Cylindrical	None	Acoustic/ Sound Sensor	Hand
Voice Command		Gear	Polar		User Input Position	Claw
Ocular		Bushing	SCARA		Haptic	Suction Cup
Touch Screen			Cartesian		None	Tentacle

Table 4.2 is used to down select components for the prototype. The primary purpose of our research was not the input device, target sensing mechanism, or end effector design. Therefore, a joystick and basic claw were selected due to their simplicity and low cost. Additionally, user sensing of object position was selected to reduce cost of implementing close loop controls. For reasons outlined in section 4.1.4, an articulated skeletal structure was chosen.

4.1.4 Skeletal Structure

The five main robotic arm structures are shown in Figure 4.4.

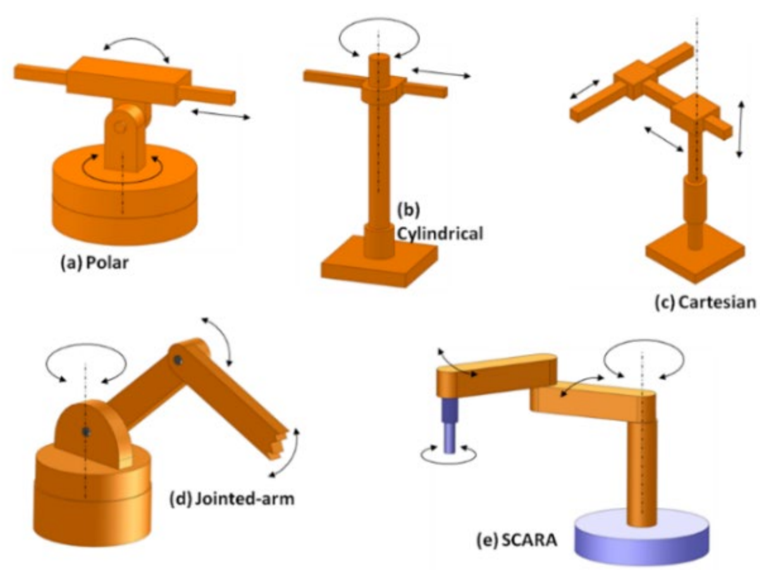


Figure 4.4: Robotic Arm Skeletons [12]

As shown in Figure 4.4, the polar, cylindrical, and cartesian designs have a translating bar atop the structure. This feature would pose a risk of injuring the user if mounted to an electric wheelchair. This would also require that a linear actuator be mounted to the non-translating component. This would disallow the separation of the final two links, impinging upon the modularity goals of the project. The SCARA (Selective Compliance Assembly Robot Arm) design is typically fixed in one direction. This characteristic makes them very accurate when working in one plane, such as on an assembly line. However, this feature renders it useless for our application, since the arm must retrieve a water bottle from a table and return it to the user. The articulated design has the best dexterity in the workspace, is the design established by industry precedent, and functions most like an actual human arm. Therefore, the articulated design was the best for our application.

Each joint of the articulated design has revolute joint connections. The revolute joint at the base allows for complete revolutionary motion. These features allow for a high dexterity in the workspace. Adding a link to the articulated design increases the degrees of freedom by one, whereas removing a link decreases the degrees of freedom by one. Therefore, the mobility and degrees of freedom can be easily modified with the articulated design.

From Table 4.2, once the articulated design, joystick input device, gripper end effector, and user target sensing were selected, the remaining ambiguity remained in the joint design. Therefore, an additional morphological chart was created for the joint design.

4.1.5 Morphological Chart for Joints

The remaining ambiguity in the joints can be broken down into the joint elements shown in Table 4.3: power transmission, component support, fastening, and motor.

Table 4.3: Morphological Chart for Joints

Transmit Power	Support Components	Fasten Components	Position and Type of Motor
Infinite ROM	Cylindrical Links	Button Clips	Parallel Dual Shaft
< 360° ROM	Square Links	Welded at joints	Parallel Singe Shaft
	Beam Links	Threaded	Perpendicular Single Shaft
	Frame/Tubes	Clamped	Perpendicular Dual Shaft

Button clips are already used in the medical community. Therefore, a caregiver would also already be familiar with their use. Button clips would also maintain modularity while keeping the cost low. Therefore, to fasten links together, button clips were chosen. Cylindrical links can be easily created from stock material, have the fewest areas of stress concentrations, and do not have any sharp edges. Therefore, the team chose cylindrical joints. The remaining element selection cannot be made by mere observance from the table, since it is difficult to visualize which elements would produce the most cost effective and best functioning prototype. Therefore, conceptual sketches for the remaining possible choices from Table 4.3 were created to better visualize which solutions will produce the best functioning prototype.

4.1.6 Conceptual Sketches of Joints

The remaining selections of joint elements from Table 4.3 are power transmission and motor type. Four conceptual sketches with various selections from these columns are shown in Figures 4.5-4.8.

The concept sketches featured in Figures 4.5 and 4.6 are a saddle joint, which have less than 360° of rotation. This feature reduces workspace area, making it more difficult for the arm to perform some maneuvers. This feature allows the arm to fold back on itself, giving rise to a potential pinch point for the user or surrounding people. Figure 4.5 features a direct shaft motor, whereas Feature 4.6 features a 90° shaft orientation. As shown in the figures, each arrangement requires a dual shaft motor, which is more expensive than a direct shaft orientation.

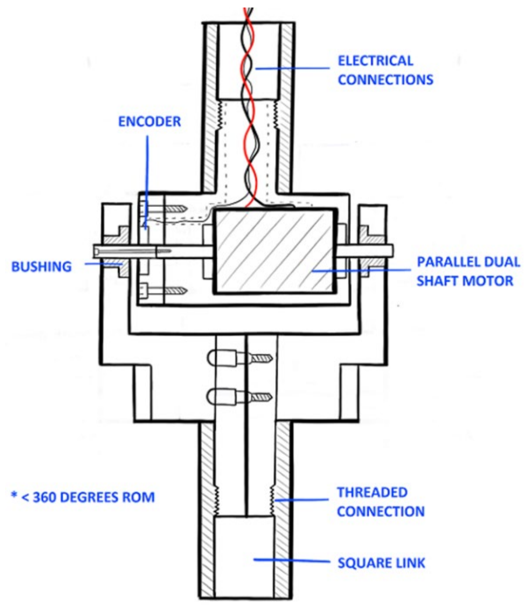


Figure 4.5: Parallel Dual Shaft Concept

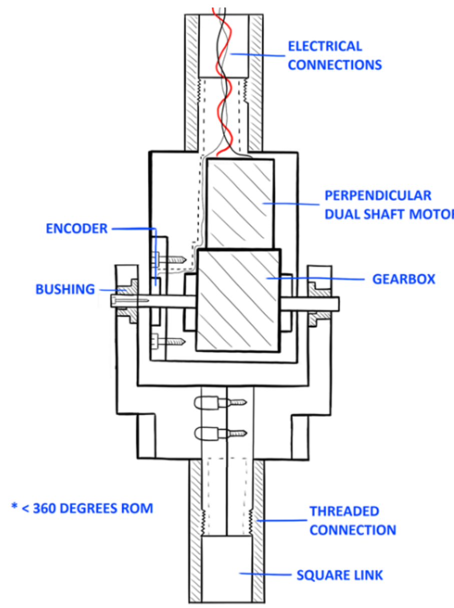


Figure 4.6: Perpendicular Dual Shaft Concept

The concept sketches for completely revolute motion are shown in Figures 4.7 and 4.8. Revolute joint motion allows for the best dexterity and largest workspace. It also prevents pinch points. Figure 4.7 shows a direct shaft orientation, whereas Figure 4.8 shows a 90° shaft orientation. The team priced direct and 90° shaft motors and found direct shaft motors to be much more cost effective. Therefore, the design shown in Figure 4.7 was chosen.

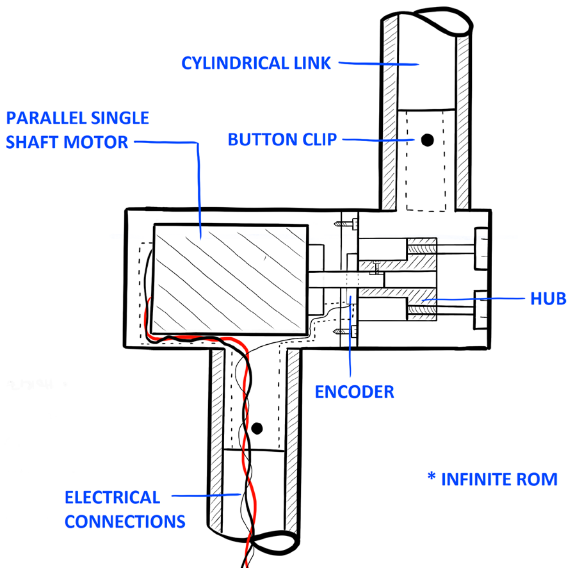


Figure 4.7: Direct Shaft Concept Sketch

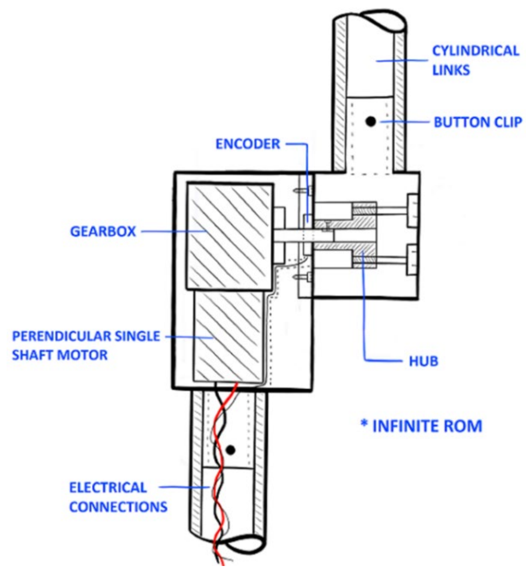


Figure 4.8: Perpendicular Shaft Concept

A physical decomposition, resulting in a functional decomposition, resulting in morphological charts, resulting in concept sketches allowed the ARMS team to objectively select a prototype design that best met the customer requirements established in the House of Quality.

4.2 Mechanical Design

4.2.1 Final Design

SolidWorks is the modeling software used to render all 3D models of the arm elements along with engineering drawings for manufacturing the prototype. The SolidWork models were combined into assemblies to yield a full prototype model. This model was used to perform structural analysis in ANSYS along with visualize the entire structure. Parametric modeling also allows for feature sizes on the 3D model to be easily adjusted. Figure 4.9 shows a prototype rendering from SolidWorks of the assembled components.

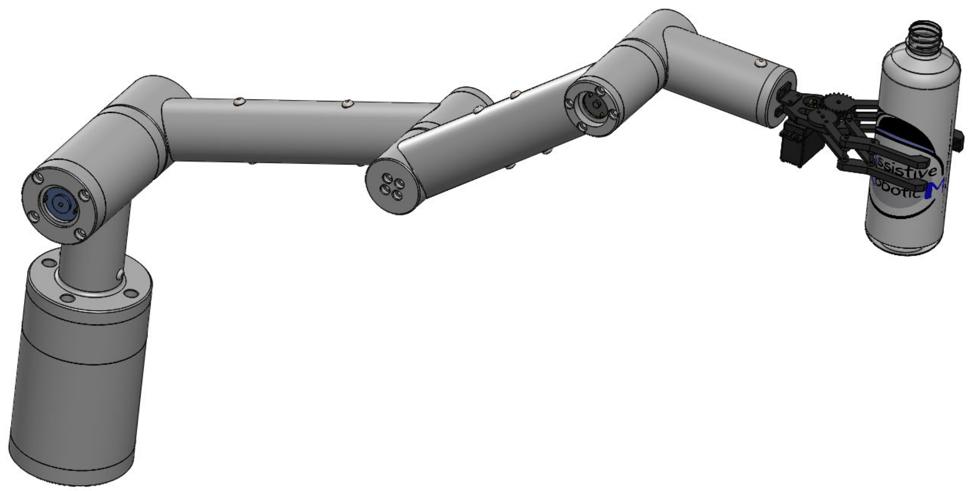


Figure 4.9: Prototype Solid Model Rendering

The diameters of the links were initially based on commercial-off-the-shelf (COTS) PVC dimensions. However, after various discussions with our client, the structural integrity of PVC under hot temperature and high stress conditions was brought into question. Therefore, the dimensions were changed to COTS aluminum tubing. An ANSYS analysis showed aluminum to have safety factors over 10 under any foreseeable operating loads the arm would endure. Keeping the links the same diametral dimension allows for the links to be easily manufactured and replaced along with allowing for the joints to be identical.

The joints selected allowed for complete, revolute motion. When put to use, it is impractical, and in some cases dangerous, to have a complete, hemispherical motion allowance in the workspace. For example, the arm should not be capable of reaching behind the user, since it could potentially knock something off a shelf and onto the user's head. Encoders allow for the rotational motion and speed information to be sent back to a computer to moderate the position of the arms. Encoders allow for digital constraints to be placed on the arm to inhibit particular motions. In addition to position constraints, encoders allow for speed constraints to be placed on the arm. The arm is intended to move slowly for the safety of the operator. Therefore, encoders were sourced and their 3D models were downloaded from the internet and included in the digital assembly.

Some of the engineering drawings for the more vital components of the prototype are shown in the Appendix.

4.2.2 Material Selection

Steel and aluminum were considered for the construction of both the joint assemblies and the links of the arm. Steel has a higher strength, stiffness, and density than aluminum. Using steel would increase the weight of the arm considerably, increasing the required torque from the motors. The higher power motors required would increase the cost arm. These disadvantages led to the selection of 6061 aluminum as the primary material for the arm.

While 6061 aluminum currently gives the best combination of cost and strength, the use of composite materials offers the possibility of drastically improving stiffness and weight. The high cost of composite materials kept them from being considered for the prototype material.

4.2.3 Motor Selection

In order to select motors, the approximate required torques at each motor location needed to be found. The arm is intended to move slowly for safety of the operator. Therefore, maximum static loading was used to obtain preliminary torque requirement values. In order to do this, a simplified version of an articulated arm was sketched, as shown in Figure 4.10.

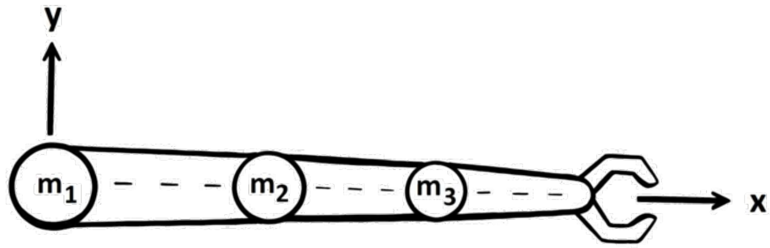


Figure 4.10: Articulated Arm Sketch

For this model, the links were assumed to be hollow, circular tubes. The motor weights were assumed to act through points. The link weights were modeled as corresponding forces acting through the link's center of mass. The combined weight of the final link and end effector was approximated as a single force acting through the mid length.

Using these approximations, an appropriate equation could be written for each motor location summing the moments to determine required torque output under maximum static loading. An example calculation for motor 1 is shown below.

$$T = \sum Wd = \rho V_1 \frac{L_1}{2} + W_{m2} L_1 + \rho V_2 \left(\frac{L_2}{2} + L_1\right) + W_{m3}(L_1 + L_2) + W_{ef}\left(L_1 + L_2 + \frac{L_3}{2}\right)$$

Where the variables are defined below:

$$T = required\ torque$$

$$W = weight$$

$$\rho = material\ density$$

$$T = required\ torque$$

$$V = link\ volume$$

$$L = link\ length$$

Material density, motor weight, link volume, and link length cannot be independently determined and require an iterative selection process. Therefore, a code was written that allows for various parameters of the arm to be adjusted such as: inner and outer link diameter, material density, link length, motor weight, and end effector weight. The code outputs the approximate torque requirement at each motor location. The code can be found in Appendix A. A sample output is shown in Figure 4.11.

```
maximum static torque
motor 1  141 [lbf in]  16 [N m]  2249 [oz in]
motor 2   78 [lbf in]   9 [N m]  1250 [oz in]
motor 3   28 [lbf in]   3 [N m]   448 [oz in]
```

Figure 4.11: Sample Output

The output suggested torques from the code appear in several different units to make motor selection easier, since motor supplier websites do not use consistent units.

After determining the required torque output of the arm, the type of motor needed to be selected. There are four major types of DC motors: brushed, brushless, servo, and stepper, all of which would meet the specified torque requirements. Therefore, cost was the main consideration in motor selection. The benefit of servomotors is their closed loop control. However, this same control can be achieved by adding an encoder to a brushed motor for a lesser cost. Stepper motors are more expensive due to required motor controllers, have a lower efficiency and are louder than brushed motors. Brushless motors, although smaller, are more expensive than brushed motors. Therefore, brushed DC motors were selected.

4.3 Prototype

4.3.1 Assembled Arm

The final prototype created by ARMS is shown in Figure 4.12. The pieces for all the joints were 3D printed out of ABS plastic with a 33% infill. 3D printing was inexpensive, allowed for parts to be created quickly, and was strong enough to handle the loads experienced by the arm. The intended final design has machined aluminum components. The links are machined from stock aluminum tubing and fitted together with button clips. The motors and encoders are wired to H-bridges and a MyRIO controller, which control the motion of the arm.

Figure 4.12: Fully Assembled Arm

The prototype weighs a little over 20 pounds, making it light enough for a caregiver to handle. The total cost of the prototype was about $500, about three times cheaper than the budgeted cost. Therefore, for the final design, more expensive motors could be used to refine the motion of the arm. The arm is capable of reaching a little over 2 feet to retrieve a 2-pound object. Therefore, the design requirements were met.

4.4 Future Goals

This project formed the foundation for future graduate research, including research into various input devices and end effectors.

4.4.1 Various Input Devices

By changing the input device, the prototype created by ARMS can easily be modified to suit those with various forms of disabilities. Current input devices available to control robotic manipulators include sip and puff, joystick controllers, and remote controls. The sip and puff input device essentially functions as a straw that the user can either blow or suck on. This makes it a useful device for people who have little or no use of their hands. However, by only providing two input options, this input device is tedious when put to use. Joystick and remote controllers often provide good use and dexterity in the hands of the user. Persons with a disability who require a robotic arm manipulator attacked to their wheelchairs often do not have good dexterity in their hands.

Input devices that are in the early stages of research, but may provide a more inclusive solution to controlling robotic manipulators include brain waves and voice control. Severe disabilities may render a person unable to speak. There is some research in using brain waves to direct a manipulator to a specific object. If this becomes feasible, the operator may only need to wear a baseball cap to control the manipulator. Voice control would be a useful input device for persons with a disability that have no control of their arms. This would allow for them to say something such as, “apple” and the manipulator would retrieve the apple. This type of input device requires an object detection system that is capable of object recognition, and providing the 3-coordinate location of it.

4.4.2 Various End Effectors

The type of end effector appended to a robotic manipulator determines the type of tasks it is able to perform. Common types of end effectors currently on robotic arms used for ADL are simple grippers and tableware. Two and three finger grippers provide the maneuverability necessary for grasping most objects. Tableware, as previously shown on the Meal Buddy, is used at the end of robotic manipulators for the specific purpose of holding food. Future research lies in haptic manipulation. In haptic devices, sensors are placed on the surfaces of the gripper intended to interact with the grasped object. These provide insight to the contour of and forced placed on the grasped object. This allows for the end effector to conform better to the object, and for an appropriate grip strength to be used

CHAPTER 5

CONCLUSIONS

ARMS has designed and manufactured an assistive robotic arm that will reach two feet and pick up a two pound object. The articulated design makes use of commercial off-the-shelf tube links attached with button clips, making the arm modular. Although a commercial production cost analysis was not performed, the prototype cost was kept under $500. This was a third of our cost goal. Therefore, all design objectives were met.

58,000 individuals in the United States have mobility impairments that prevent them from being able to eat and drink by themselves [1]. This project proved that there is a cost-effective solution to provide them independence. The next step of this project is in reach even more people, which lies in the work of graduate research.

Advances on this project done in graduate research would include changing the end effector and input command to accommodate for various levels of disabilities. This may include, but is not limited to haptic feedback, closed loop controls, and vocal input commands. Since the main arm design was kept modular, adding various end effectors and input devices is functionally easy and financially efficient. Different input devices allow for the arm to be tailored to suit the needs of individual disabilities while changing the end effectors allows the arm to perform specific functions to suit the needs of the user.

By designing and assembling the first iteration of the robotic arm, ARMS provides affordable independence to those who need it most and lays the groundwork for many more applications of assistive care. This project proved that engineering is a tool that can be used to provide independence to people in all walks of life.

APPENDIX A

MATLAB CODE FOR STATIC LOADING

```
%to define variables
p=0.1; %density [lb/in^3]
ro1=2.05/2; %outer radius link 1 [in]
ri1=1.83/2; %inner radius link 1 [in]
ro2=2.05/2; %outer radius link 2 [in]
ri2=1.83/2; %inner radius link 2 [in]
W3=3; %weight of the third link including the griper [lbf]
mw1=1; %motor 1 weight [lbf]
mw2=1; %motor 2 weight [lbf]
mw3=1; %motor 3 weight [lbf]
W4=2; %weight of thing you are picking up [lbf]
L1=8; %link 1 length [in]
L2=8; %link 2 length [in]
L3=8; %link 3 length [in]

V1=pi()*L1*(ro1^2-ri1^2);
V2=pi()*L2*(ro2^2-ri2^2);

W1=p*V1; %weight of link 1 in lbf
W2=p*V2; %weight of link 2 in lbf

T1=W1*(L1/2)+mw2*L1+W2*(L1+(L2/2))+mw3*(L1+L2)+W3*(L1+L2+(L
3/2))+W4*(L1+L2+L3); %torque on motor 1 [lbf in]
T2=W2*(L2/2)+mw3*L2+W3*(L2+(L3/2))+W4*(L2+L3); %torque on
motor 2 [lbf in]
T3=W3*(L3/2)+W4*L3; %torque on motor 3 [lbf in]

T1O=T1*16; %torque on motor 1 [oz in]
T2O=T2*16; %torque on motor 2 [oz in]
T3O=T3*16; %torque on motor 3 [oz in]

T1N=T1/8.85746; %torque of motor 1 [Nm]
T2N=T2/8.85746;  %torque of motor 2 [Nm]
T3N=T3/8.85746; %torque of motor 3 [Nm]

fprintf('maximum static torque \n')
fprintf('motor 1  %0.0f [lbf in]  %0.0f [N m]  %0.0f [oz
in] \n', T1, T1N, T1O)
fprintf('motor 2   %0.0f [lbf in]   %0.0f [N m]  %0.0f [oz
in] \n', T2, T2N, T2O)
fprintf('motor 3   %0.0f [lbf in]   %0.0f [N m]   %0.0f [oz
in] \n', T3, T3N, T3O)
```

REFERENCES

[1] Simpson, R., C., LoPresti, E., F., Cooper, R., A., "*How many people would benefit from a smart wheelchair?*" Journal of Rehabilitation Research and Development, Department of Veterans Affairs, Volume 45, Number 1, 2008, pp. 53-72, Available: https://pdfs.semanticscholar.org/7220/13048b32ba47e9220c469dbd95745fa6fb6d.pdf?_ga=2.75449300.796265460.1536597207-196560500.1536597207

[2] "*Feeding Assistance a Case Study*," Available: http://www.ewh.ieee.org/soc/es/Aug1996/030/cd/feeding/report/s1.htm [Accessed: 15-Nov-2018]

[3] T. Worth, "*How Much Should You Pay a Live-in Caregiver? Live-In Caregiver Costs*," Caring.com, 10-Feb-2017, Available: https://www.caring.com/articles/live-in-caregiver-cost. [Accessed: 01-Dec-2018].

[4] "*Medicaid Electric Wheelchair - Medicare Wheelchairs*," Karman Healthcare, [Online], Available: https://www.karmanhealthcare.com/medicaid-electric-wheelchair/

[5] Cobotsguide, "*cobotsguide*," CobotsGuide, 01-Mar-2018, Available: https://cobotsguide.com/2016/06/kinova/

[6] "*Meal Buddy,*" (n.d.), Performance Health, Available: https://www.performancehealth.com/meal-buddy-systems

[7] "*Jaco Robotic Arm*." Partners In Medicine, 20 June 2018, Retrieved September 20, 2018, Available: partnersinmed.com/jaco-robotic-arm/

[8] "*MiCO^2 Robotic Arm*," MiCO^2 Robotic Arm | ROBOTS IN SEARCH Australia, 29-Oct-2015. [Online]. Available: https://www.robotsinsearch.com.au/products/mico2-robotic-arm. [Accessed: 01-Dec-2018].

[9] Hillman, M., Hagan, S., Jepson., J., Orpwood, "*A Wheelchair Mounted Assistive Robot,*" Bath Institute of Medical Engineering Ltd, Available: https://pdfs.semanticscholar.org/7818/5fbfbda14dc90c560f9c01e9f257a1322e16.pdf?_ga=2.110528707.796265460.1536597207-196560500.1536597207

[10] Quigley, M., Asbeck, A., Y., A., "*A Low-cost Compliant 7-DOF Robotic Manipulator,*" Available: http://www.robotics.stanford.edu/~ang/papers/icra11-LowCostCompliantManipulator.pdf

[11] Edwards, K., Alqasemi, R., Dubey, R., "Wheelchair-Mounted Robotic Arms: Design and Development," Department of Mechanical Engineering, University of South Florida, Available: https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=1639157

[12] "*Lecture 5 : Industrial robotics-1*," Module 7 : CNC Programming and Industrial Robotics, Available: https://nptel.ac.in/courses/112103174/module7/lec5/3.html. [Accessed: 01-Dec-2018].

BIOGRAPHICAL INFORMATION

Amelia Jackson is currently a senior in mechanical engineering at the University of Texas at Arlington. During her time at UTA, she participated in many student organizations. She served in cochair, chair, and senior senator positions in student senate. She taught four UNIV 1131 classes as a Peer Academic Leader in which she mentored and advised over 80 freshman students, gave around 75 50-minute presentations, and held weekly office hours. Amelia was also involved in Society of Women Engineers, Engineering Student Council and intramural sports.

Amelia received various honors and recognitions while at UTA. She received the President's Charter, Lockheed Martin Merit, Charles R. Knerr, and Valedictorian Waiver Scholarships. She was on the Deans list every semester Spring 2017 to Spring 2019. Amelia was honored Maverick of the Month in November 2017, and she was recognized as the Honors College's most active member in Fall 2016. She was also presented with the Outstanding Mechanical Engineering Senior Award in Spring 2019.

Amelia has accepted a job offer at Lockheed Martin Aeronautics as a Systems Engineering Associate, which will begin after she graduates. She plans to work while taking graduate courses to obtain a Systems Engineering Masters.