

Doug's Kitchen Robot, ECE 480, Senior Capstone Design

Department of Electrical & Computer Engineering
Michigan State University

Spring 2011

Design Team

Thomas Manner
Ka Kei Yeung
Daniel Phan
Ali Alsatarwah

Sponsored by:

RCPD Representative: Professor Stephen Blosser

Executive Summary:

The goal of our project is to construct a wall mounted robotic arm to help a quadriplegic person be more independent. The arm is designed to help him cook and lift heavy object such as a pot of boiling water. This arm will move in X-Y-Z directions, and will have a gripper that rotates. It will be operated using a wireless joystick controller, with knobs that are designed specifically for people with limited muscular movements.

Pre-Proposal

February 03, 2011

ECE 480 Team 3

Facilitator: Professor Lixin Dong

- i. Table of Contents
 - 1. Introduction
 - 1.1 Customer Needs/Requirements
 - 2. Background
 - 3. Design Specifications
 - 1. Safety

2. Function
3. Quality/Reliability
4. Energy Consumption
5. Aesthetic/Size
6. Human Interaction
4. FAST Diagram
5. Comparison of Conceptual Designs
6. Proposed Design Solution
7. Risk Analysis
 1. Power
 2. Speed
 3. Gripper
 4. Torque
 5. Testing
8. Project Management Plan
9. Budget
10. References

1. Introduction

For Doug, who is a young quadriplegic man, independence is of the utmost importance. One desire that Doug has is to be able to cook independently without help from anyone. Although the house that is being built for Doug will have accommodations for his quadriplegia, he would need assistance for cooking. Doug cannot generate enough muscle power to lift and move heavy pots of water, food, and other items in his kitchen.

The goal of our design project is to build a wall mounted robotic arm to assist Doug in lifting and moving items within the confines of his countertop, stove, and sink. The robotic arm should be interfaced with a three joystick wireless controller that is designed for easy operation.

1.1 Customer Needs/Requirements

The idea of the design project is to build a robotic arm to assist a quadriplegic person named Doug in cooking his own food. In order to assess the customer needs and requirements, an interview with Doug and the sponsor is necessary. In the interview with the sponsor, the basic requirements of the robotic arm will need to be established. Examples of the following are listed below:

- The lifting strength of the robotic arm
- Whether the movements of the robotic arm will be Cartesian or Joint
- How many degrees of freedom will the robotic arm have
- What microcontroller and software should be used

In the interview with Doug, who is to receive the end product, questions should be more on a functionality basis. Examples would include the following:

- What kind of joystick will make the robotic arm easier to operate?
- Would a wireless controller make it easier to operate?
- What other functions besides lifting heavy pots would be needed to assist him in cooking?

The constraints for this design project are mainly monetary and time issues. The motors, amplifiers, microcontroller, and other mechanical parts will push our budget to its limits. As for the time issue, the amount of features of the robotic arm will have to be limited to ensure completion of the robot arm. The criteria for determining the feasibility of the project design is whether the robotic arm can accomplish its basic functions in the most efficient way. Since the mechanical parts are most expensive, the design of the actual robotic arm will need to be efficient.

The criteria for ranking the feasible designs would include the following:

- Is the design an efficient in its movements?
- Will the robotic arm be simple to operate?
- Can the robotic arm accomplish all the basic functions specified by the customer?
- Are there too many unnecessary features that cannot be realistically accomplished within the semester?

One conceptual design for a Cartesian Robotic Arm is shown in figure 2.

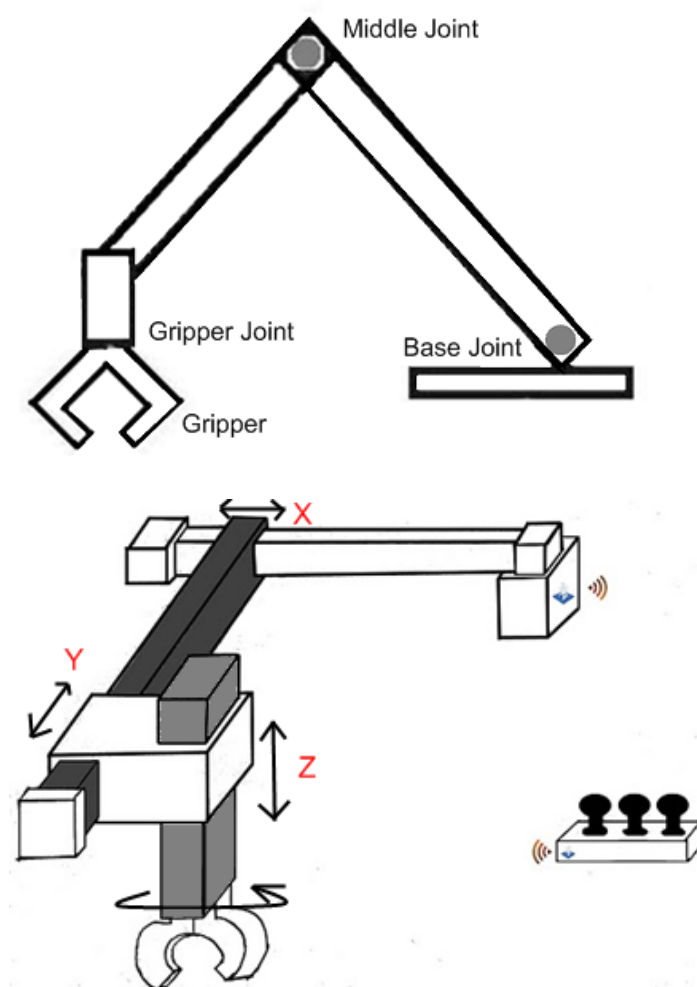


Figure 1: Concept I – Triple Joint Robotic Arm

Figure 2: Concept II – Wall-Mounted Cartesian Robotic Arm

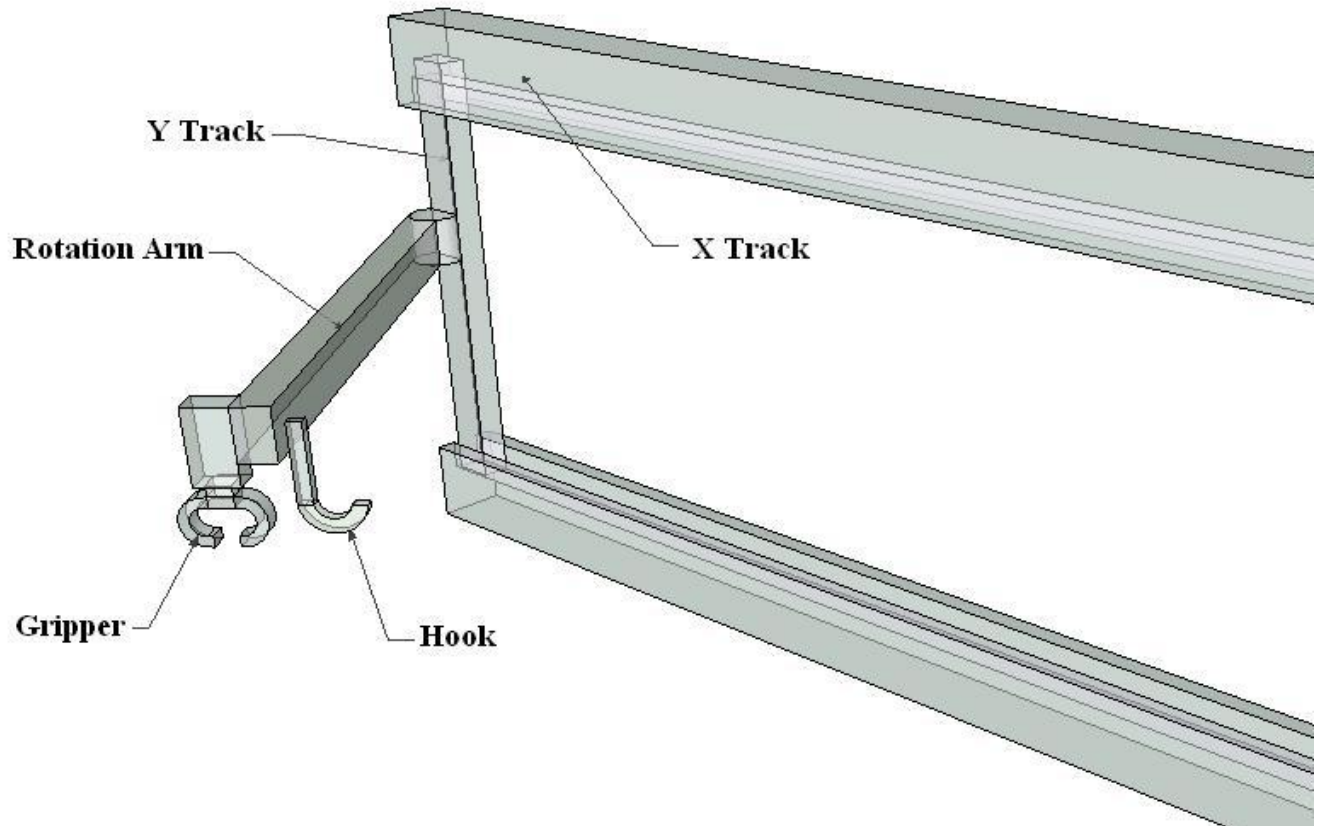


Figure 3: Concept III – Wall Mounted Cartesian Robotic Arm (2 Axes) with Rotating Arm

2. BACKGROUND

The goal of this project is to construct a manual robotic arm that is capable to lift and move heavy kitchenware. The design aims to help a quadriplegic person, Doug be more independent. It specifically aims to fulfill his desire to cook regularly but does not have the muscular versatility or power to perform these tasks.

There are many robotic arms in the market designed for quadriplegics and people with other physical disabilities. However, most of these commercial products, especially the automatic modules, are capable of lifting only light objects such as bowls and cups. These available designs mostly focus on precision and versatility rather than the ability to handle heavy payloads. In addition, a pilot study conducted by the University of Central Florida found that most users preferred manual controls and considered the automated designs “too easy”¹.

In order to satisfy the specific goals of this project, this design could simplify to Cartesian robotic arm, which means it would move linearly in the X, Y and Z directions. By installing a sturdy gripper to

the bottom of the Z arm, it is sufficient to move heavy objects across a kitchen counter, as long as the parts used are manufactured to handle these payloads. The arm will be operated manually with a controller console consisting of a combination of joysticks, with knobs that are customized for quadriplegics.

3. Design Specifications:

Important specifications in designing the Doug's Kitchen robot need to be achieved are: Safety, function quality/ reliability, Aesthetics/size, Energy consumption, and human operation of the robot.

3.1 Safety

The safety concern about robotic arm is mainly on the risk of electrical shock and the unexpected movement or the failure of the robotic arm. An electrical shock could result from uses of high voltage and high current, as well as water conductances. To solve this issue, fuses are being considered in many parts of our circuit as they are convenient, inexpensive and easy to replace. A fuse works will terminate its short circuit connection and thus create an open circuit to block the flow of current. Dealing with water or any conductive liquid is one of the sources of electrical shock or a device malfunction. The team is aiming to utilise waterproof component especially with the gripper and the arm in the z direction, which might have contact with water and vapor. In addition, enclosure and isolation of the components using nonconductive materials greatly minimize the probability of any potential danger. These design precautions will protect the system itself and most importantly, the end user.

The other concern regarding safety is the potential force of the arm movement or the likelihood of mechanical failure. Sensors would be used to reject illegal inputs or unexpected movement. Automatic termination will be implemented should such cases arise. The structure and the material used in the design will take into account the minimization of the any potential risk to the user.

3.2 Function

The robotic arm will be based on Cartesian robotic designs and thus moves in the X, Y and Z directions. A gripper will be installed on the bottom of the Z arm, which is designed to rotate clockwise and counter clockwise. The robotic arm would be able to achieve the requested function such as lifting and moving pots of water, food and other items that require the level muscular power that a quadriplegia's person cannot generate.

3.3 Quality/ Reliability

In order to achieve a reliable system, the team would attempt to avoid the use of complex system or structure to reduce the chance of malfunctioning and reduce the debugging process. Simplicity in the design also encourages simpler procedure in identifying and fixing bugs and other issues. This promotes the possibility of modification and expansion in the long term. In addition, the robotic arm would be constructed from cheap and readily available component such as (car windows motors, sliding actuators

and grippers and power supplies (car parties)) to achieve a robust device. The control device would be wireless with a Bluetooth transmission so the user has the freedom and ability control the device from a distance, and would not have to deal dealing with clumsy cables or interface.

3.4 Energy Consumption

The use of DC motors for the robotic arm requires a significant amount of current and thus power supply. However, to minimize energy consumption, it is essential to reduce the number for the motors in the design and to purchase models whose specifications are closest to what are necessary. In addition, power supply and circuit manipulation will be attempted to avoid unnecessary energy consumption.

3.5 Aesthetics/Size

The size of the device would be sufficiently small so it would not interfere with other house furniture or obstruct (or be obstructed by) other kitchen appliances. On the other hand, the team would attempt to create an aesthetically pleasing device so it is suitable for a comfortable home environment.

3.6 Human Interaction

Similar to the design ideals outlined in 3.3, the interaction between the end user and the robotic arm would be as simple as it is technically permissible. This ideal extends to the possibility that the device should be easily useable by people other than quadriplegics. The wireless control interface consists of three joysticks and reset bottom. One design option includes joystick1= left-right (x-direction) , joystick2= in-out (y-direction), joystick3=up-down and cw-ccw rotation.

4. FAST Diagram

5. Comparison of Conceptual Designs

5.1 Decision Matrix

DESIGN CRITERION	Importance	Concept I Triple Joint Arm	Wall Mounted Cartesian Arm	
			Concept II (3 Axes)	Concept III (2 Axes 1 Rotation)
Aesthetic	2	4	3	2
Coding Complexity	2	2	5	4
Durability	4	2	3	4
Flexibility and Orientation	3	5	4	4
Payload	4	2	5	5
Power Consumption	4	3	2	4
Retractability	4	4	2	5
Safety	5	2	4	5
Size	4	5	2	3
Sturdiness	5	2	5	4
User Friendliness	4	4	5	4
Upgradability	2	2	5	4
	Total:	131	159	177

Table 1: Design Criterion Feasibility Rankings

5.2 Concept Descriptions

Concept I (figure 1) is a robotic arm with 3 joints and a gripper that will be situated on Doug's wheelchair and would be removable. The base joint is capable of a half-circle rotation on the horizontal plane and a half-circle rotation on the vertical plane. The middle joint is capable of approximately a half-circle rotation (with limitations due to arm thickness). The gripper joint is capable of a full-circle rotation.

Concept II (figure 2) is a Cartesian robotic arm that will be wall mounted in the kitchen. There will be three actuators (X, Y and Z directions) as illustrated in figure 2. The gripper is attached to the bottom of Z arm and is capable of one full-circle rotation. This arm will be wirelessly controlled with a controller console with three joysticks. The controller console is mobile and could be placed on Doug's wheelchair.

Concept III (figure 3) is a Cartesian Robotic arm that will be wall mounted in the kitchen. This prototype will have two axes (X and Z). These axes will both be situated against the wall. In order to retrieve items, the arm will rotate about the Z axis for a maximum of 180 degrees. A gripper is attached to one side of the bottom of the arm end and hooks are attached to the other side (see figure 3). The gripper is capable of full-circle rotation and is designed to handle lighter payload. The hooks will be able to handle heavier payload. Controller design is similar to Concept II.

5.3 Force and Geometry

Calculations of forces in the articulated robot arm are complex, as the force required to lift is dependent on the current angle of the arm segments. With the Cartesian(xyz) arm the force equations become much simpler. All lifting will require a force that is only dependent on the weight, because the gripper and the motor doing the lifting will always be directly above the object. By using a linear actuator or a track actuator for the x and y directions, the force needed to drive the payload becomes quite small. This force could be further reduced by placing wheels or bearings to reduce friction between the cart and the track. For this criterion, Concept I would be more complex than Concept II and Concept III .

5.4 Force and Power Consumption

A realistic weight of water plus pot plus the z component of the arm is roughly 30 lbs, which requires a force of around 138 N. Seven watts of power will be necessary to lift that load and transport it at two inches per second. In order to ensure that the motor capable of performing this task easily, a minimum 15 watts of power delivered to the shaft would be ideal. Concept I would require motors that could exert this force on each joint. Concept II would exert this force on the motors driving both the Z Arm and partially on the X and Y axes. Concept III centralize this force on the Z arm while the rotation motor and X actuator could utilize bearings or wheels to reduce friction.

5.5 Gripper Selection

There are two types of grippers that would work in this application, a two finger and a three finger. Both grippers consist of a solid bottom half and a mobile top half. In the three finger design, two of the digits are immovable and lie in the same plane while the third moves perpendicularly into the gap between them. The three finger variant offers more stability because it has three points of contact, and is less likely to fail because the third digit may overlap the other two so that the weight is not being supported by the contact point.

5.6 Controller Interface

The controller interface has several options associated with it. The first one discussed was whether the controller should be wireless or wired. A wireless controller adds a small cost to the project but greatly increases the possibilities, allowing the user to move freely and operate the robot at the same time. A wired controller would limit the range of operation considerably and would pose a potential safety risk because of the cable(s) over the counter. To negate that risk the controller could be mounted to a surface but this would also greatly limit operable area. Two platforms have been suggested for the controller to be built around, LEGO® Mindstorms™ and the Arduino development platform. Both platforms are very powerful tools with many options for customization and easy to use interfaces. The LEGO platform has 4 input ports and 3 output ports. Each of these outputs is expandable to address 7 additional devices using the I²C serial addressing protocol. This functionality is available but requires custom made hardware to interpret the signal. It is also compatible with Bluetooth for wireless transmission of data between the brick and a computer or multiple bricks. The Arduino platform has many variations, the one that suits

this project the best is the Arduino Fio. The Fio has eight analog input pins and 14 digital output pins, six of which have pulse width modulation built in². This particular board also has a preconfigured socket for an XBee wireless chip to allow wireless communication between the chip and a computer or with another Arduino board which is simple to implement. The robot will have at minimum four motors in it, therefore output extension will need to be done to the LEGO NXT brick if this platform is chosen, while the Arduino solution has six pulse width modulation outputs and another eight strictly digital outputs. In addition, the LEGO system costs \$150 for each brick, whereas the Arduino Fio is \$25 and an additional \$23 for the XBee radio.

6. Proposed Design Solution

The final design of the robotic arm must meet several different criteria when finished. The robotic arm must be able to complete the basic functions set by the sponsor, while maintaining the safety aspects defined earlier in the proposal. For those reasons, Concept III (figure 3) was chosen as the final design for this project. The advantages of this design are that three out of four motors will be mounted near the wall, minimizing the amount of torque applied to the overall system. The movements of the robotic arm will be programmed to be Cartesian for ease of operation.

The concerns regarding the payload the gripper must carry were resolved by adding hooks to the end of the arm. The hooks would carry the heavier loads, while the gripper is used for lighter load applications. The pots and heavier kitchenware will have to be modified to be carried by the hooks. Since the gripper is being used for lighter load applications, a two fingered gripper was chosen for the final design. The advantages of the two finger gripper are the ease of operation, lower cost and accuracy.

The robotic arm will be controlled wirelessly. The mobile controller console will have three joysticks. Although designing a wireless controller is more expensive, the elimination of a potential risk due to cables on the countertops proved essential in satisfying one of our main design criterions – safety. The Arduino Fio with Xbee Radio was chosen as the platform to accomplish the wireless controller. By choosing the Arduino Fio with Xbee Radio instead of Lego NXT, there was no additional circuitry needed to be customized to extend the number of inputs and outputs. Since these Arduino products are open source and hobbyist commercial items, should a circuit fail, it will be easy to replace these parts with basic engineering and computing expertise.

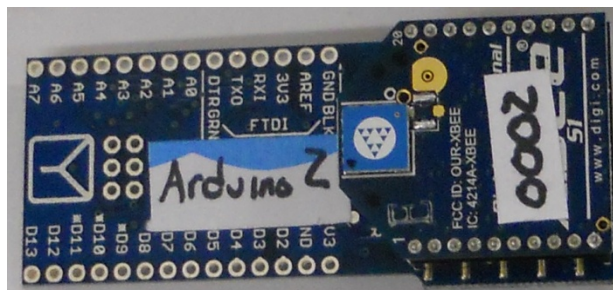


Figure 4: Arduino Xbee board

7. Risk Analysis

7.1 Power

The amount of power required to run the robotic arm is a concern. Since the current driving the motors is relatively high, the need for safe wiring and encasement is critical. The encasement would have to be waterproof and the leads of the wires shrink wrapped to prevent shorts.

7.2 Speed

Another concern is a safe operating speed for the robot. The robot will need to carry a pot of hot water at a safe speed, so that it will not spill on and burn the operator. The robotic arm would need to be variable speed, but kept within a certain safe speed range. Preferably the operator would need to let the water cool before draining.

7.3 Gripper

There were concerns regarding the gripper during the development of the conceptual design. The type of gripper needed depends on what the specific function it is designed to perform. A three finger gripper would be safer in lifting a heavy pot. It is also necessary to waterproof the gripper as well its motors. Since the gripper will be at close proximity to the food it handles, it will most likely come in contact with water or vapor. Precautions will need to be taken to keep the motor from getting wet and thus prevents shorting circuits and other malfunctioning.

7.4 Torque

The amount of torque applied to the robotic arm concerned our design team. The weight of the arm itself would put a lot of torque on the certain parts of the robotic arm. The Cartesian robot design would help to control the amount of torque applied to the robot, whereas the joint robot would have problems.

7.5 Testing

One of the challenges of the project is the great cost of materials required to build the robotic arm. The budget limitation might lead to insufficient funds to support prototyping of the design. Testing and debugging performed on the joystick controllers with smaller motors could indicate if the controller is bug free. Once the controller is proven to work, the signal can be amplified and applied to the larger motors of the robot arm. This means testing and debugging is essential at every stage of development of the robotic

arm to ensure its proper functionality.

8. Project Management Plan

8.1 Personnel

Name	Technical Role	Non-Technical Role
Thomas Manner	Interface and Coding	Management
Ali Alsatarwah	Parts Assembly	Webmaster
Ka Kei Yeung	Testing and Debugging	Document Preparation
Daniel Phan	Power Management and Safety	Presentation Preparation

8.2 Schedule

To meet our deadlines, the team would decide on the parts to obtain by the end of week 5. Oral presentation preparation and interface coding assembly process should proceed simultaneously during week 6. The core of the project, namely the assembly, testing, and debugging would begin as soon as oral presentations are over. The final product will aim to be finished approximately one week before Design Day.

9. Budget

9.1 Budget Table

	Unit Price	Quantity	Item Total
Arduino Fio	\$25	2	\$50
XBee Radio	\$23	1	\$23
Linear Actuator (40" and 20")	\$130	2	\$260
Standard Servo	\$17.99	1	\$17.99
Force Sensing Resistor	\$5.00	2	\$10.00
Joysticks	\$25	3	\$75
Miscellaneous Components	\$40	1	\$40
Hitec Spline Metal Servo Horn (Tapped)	\$3.25	1	\$3.25
Force Sensing Resistor	\$5.00	2	\$10.00

Standard Servo	\$17.99	1	\$17.99
Robot Hand – A signal (no servos)	\$17.89	1	\$17.89
USB cable A/male to B/male Model	\$9.01	2	\$9.01
Arm Rotor	\$40	1	\$40
Total:			574.31

9.2 Justification

This project requires implementation of robotic arms that are able to lift heavy loads (20lbs or more). This requires more expensive robotic parts that put a severe limitation on the choices. While choosing between LEGO NXT and Arduino boards, the team chose Arduino based on its apparently lower cost. The choice of a 40" linear actuator is due to the limitation on budget. This dimension is only for the design sample to show case its functionality. When sufficient funds are available to purchase a larger actuator, the scaled up product shall be implemented in Doug's kitchen. A manually constructed actuator track could be available to 40" X track.

10. Reference

1.
<http://news.ucf.edu/UCFnews/index?page=article&id=0024004107a42ec8a01289848d7ab07cd1>
2.
<http://www.arduino.cc>