ROBOTIC ARM KIT

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by

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I would like to thank Nick Malott for all of his contributions to this project. Nick allowed me access to his homemade 3D printer, and provided all of the instruction necessary to operate it. Nick also programmed the Arduino to control the servo motors. As a final contribution, Nick developed and programmed the Android application that allows an operator to control the robot over Bluetooth with their Smart phone.
ABSTRACT

The objective of this project was to create an educational learning kit that teaches the basics of robotics to beginner level enthusiasts. When looking at many other robotics kits on the market, many do not offer significant levels of customization. For products that offer customizability, limits exist regarding the original parts included in the kit. These limits force the user to buy additional kits or individual parts increasing project cost. Additional kits or special parts could prove cost prohibitive for an individual just beginning to learn about robotics. The solution to controlling cost is to develop a kit utilizing 3D printing. By making the entire kit 3D printed, the consumer is given complete design control over customizing their robot to the specific application that they desire. By designing the individual parts the end user is able to understand much more about a parts function and utility within the entire assembly. The advantages that a 3D printed robot offers include lightweight construction, durable frame, and very low cost to the customer.
INTRODUCTION

PROBLEM STATEMENT

As technology continues to advance, engineering and robotics have become more common amongst hobbyists and enthusiasts. These groups of people tend to gravitate towards learning tools that are educationally based because it helps them to understand the mechanics of how and why the product works. For those interested in learning more about the concepts of robotics, there are many different fields of engineering that come into play. Being able to build, and understand the mechanics of a robot gives a user better insight into primary subjects of mechanical engineering and computer programming.

This project was chosen in order to give those who desire it, a learning tool that will help teach them a wide variety of engineering skills and understanding of the fields related to robotics. This will be accomplished through an instructional guide that will include background information on each of the different components used and their purpose within this project.
PRODUCT RESEARCH

To determine the best method of how to design and develop a robotic arm, research was performed to understand what features customers would want. The type of customers questioned had a wide degree of knowledge in regards to robotics. The survey was done in order to obtain a better understanding of what the general population would want out of this product. Furthermore, research was performed on several different types of robotic arms and hands, including those that use similar technology as the proposed product.

Figure 1 - MechaTE Robot Right Hand

This hand, which costs USD $900.00, is constructed out of anodized aircraft aluminum. It operates through fourteen points of motion over five degrees of freedom, four fingers and a thumb. It requires no programming to achieve compliance, and is controlled by any PWM servo controller, microcontroller, or simple RC system. Its main intention is for animatronics, giving it an optimal realistic motion for performance. However, this means that it does not have a substantial gripping force. The positive features that this robot has to offer are that it comes preassembled, has a very realistic hand motion, each finger moves independently, and the frame is made of a very strong durable material. The drawbacks of this product are that the hand does not deliver enough gripping force, and it is very expensive.
This Banshi Robotic Arm, which costs USD $180.56, comes with a CD that includes WinAVR, RobotLoader, and RACS software. It also includes a complete 72-page manual as well as several sample programs. Furthermore, the product comes with a 12V power adapter, assembly tools, keyboard controller, and USB programmer interface & cable. This robot arm is operated with six degrees of freedom, has an arm length of 260mm; fully extended height of 340mm; base diameter of 150mm; and weight of 1.3lbs. The final product comes unassembled as a kit. The biggest contributions this robot has to offer are that it has 6 DOF, gives full range of motion to the operator, has a sturdy base to support the arms long reach, and has a wide gripper which allows for large objects to be picked up.
This robot, which costs USD $692.01, has the following USB SSC32 Servo Controller specifications: This product is a USB interface, and has no serial port to facilitate desktop and laptop use. This robot has the following specifications: Gripper size of 65mm x 60mm x 27mm, maximum size of mouth opening of 40mm, maximum size of mouth with pads of 34mm, robotic arm specification voltage of 4.8V-6.8V, max current greater than 5000mA, arm height of 320mm, weight of 600g, interface of USB/TTL (baud rate 2400/9600/38400/115200bps), size of 58.5mm x 76.2mm, resolution of 1uS 0.09°,1uS/second, 0.09°/second, and a servo range of 180° and 360°. Furthermore, it can control up to 32 servo motors (PWM/TTL), has compatible lynxmotion RIOS Arm Control and SEQ Visual Sequencer software, provides 4 analog / digital signal input terminal, and can be set at rest or latch. It also has a bluetooth module and APC220 which provides wireless data transmission interface for remote control. It provides an ISP download port, for the use of development, baud rate using the two DIP switch settings, and support for Futaba, Hitec and most common Servo. Finally, it has a supply voltage of 6V - 12V or USB power (with self-recovery fuse, easy to use for debugging), a servo supply voltage of 4.8V - 7.2V, can withstand current on each side 10A, 32 Road, the maximum 20A, and includes Lynx SSC-32 Terminal USB-SSC32 Command Formatting Lynx SSC32 USB Driver. The biggest drawbacks of this robot are that it is a single pinch gripper, and is very expensive.
The Dagu, which costs USD $275.26, is a 6 Degrees of freedom robotic arm, that is made from 3mm thick aluminum sheeting. It has a length of 390mm, and uses four DGservo S06NF STD servos for the base and the arm. It has a serial interface and PC software included, and can control 32 servo motors. Finally, it utilizes a dual power supply 6 ~ 12 V SCM power, 4.8 ~ 6 V servo motor power. On the plus side, this robot has a very long reach and comes preassembled. However, it only has a single pinch gripper, and is somewhat expensive.
The Robotiq which costs USD $18,000.00, has the following mechanical specifications: Overall dimensions of 9 x 9 x 9 inches, overall weight of 2.1 kg, Gripper opening of 1-169mm, Gripper weight of 2.3kg, Recommended encompassing grasp payload of 10kg, Recommended friction grasp payload of 3kg, Max gripping force (Fingertip Grip) of 40N, Max break away force of 100N, Max. closing speed (Fingertip Grip) of 110mm/sec, Min. ambient temperature of -10°C, Max. ambient temperature of 50°C Finger Position Repeatability (Fingertip Grip) of 0.065 ± 0.008mm, 3 fingers, 3 phalanxes per finger, 4 grasping modes, and an IP class of 3. It has the following control specifications: Interface options including Ethernet/IP, Modbus RTU, Modbus TCP, DeviceNet or EtherCAT, grasping programmable parameters that include force, speed and partial closing/opening, status LEDs for power, communication and error, and feedback for finger contact detection, motor encoders and motor current. Furthermore it has the following electrical specifications: Nominal supply voltage of 24VDC, quiescent power (minimum power consumption) of 4.1W, peak power (at maximum gripping force) of 35W, and a maximum RMS supply current (supply voltage at 24V) of 1.4A.

Major benefits of Robotiq include the robotic gripper is adaptable to all parts, 3 articulated fingers, 4 grasping modes adaptable to a variety of sizes and shapes, simple control over Ethernet/IP, Modbus RTU, DeviceNet or EtherCAT, an extremely high gripping force, and ease of incorporation to existing robotic arms. The robots only drawback is the extremely high cost.
This robot, which costs USD $100.99, features a complete life-sized robotic hand. It opens and closes at the touch of a switch, and uses only one AA battery. This robot is completely self-contained, and is easily customizable. Finally, it is capable of grasping objects, has adjustable fingers, and does not come preassembled. The disadvantages of this robot are that the fingers move together, not independently, and the components do not appear to be made of a durable material.
The OWI robot arm, which costs USD $39.67, includes a search light design on the gripper and an audible safety gear indicator. It has the following specifications: Product dimensions of 6.3 x 15 x 9 inches, weight of 2.5 pounds, radial wrist motion of 120°, elbow range of motion of 300°, base rotation of 270°, base motion of 180°, vertical reach of 15 inches, horizontal reach of 12.6 inches, and a lifting capacity of 100g. The positives of this product are that it is made of a hard, durable plastic, and is very inexpensive. The shortcomings of this product include the following: It doesn’t have any sensors and will break if you push it beyond its range of motion, it does not come pre-assembled and is somewhat difficult to assemble with lots of small parts, the gripper cannot rotate (it can only pick up objects perpendicular to the base, i.e. limited functionality), it does not come with any programmable components (would have to be modified with add-on Arduino), and it has insufficient instructions for remote controller and trouble shooting.
PRODUCT RESEARCH SUMMARY

After researching multiple types of robotic arms, a list of customer requirements began to be formed. With these product features in mind, engineering characteristics were decided upon that would best fit the product features in order to create a final product that would provide the greatest satisfaction to the customer. The preliminary product features were as follows:

1. Gripper Opening Distance
2. Load Capacity
3. Speed
4. Reach
5. Axis of Rotation
6. Mobility
7. Remote Controllability
8. Remote Battery Power
9. Preassembly
10. Open Source
CUSTOMER FEEDBACK, FEATURES AND OBJECTIVES

SURVEY RESULTS AND ANALYSIS

Satisfaction with a product that a customer will purchase makes customer feedback a very important detail to obtain. Knowing this, it was necessary to have a wide range of customers take the survey in order to get a large sample of customer input and satisfaction levels. The survey was distributed to twenty people, who had either little to none, some, or a good amount of knowledge about robotic arms.

The first part of the survey asked customers how important, on a scale of zero to five with five being the highest, each of the product features would be to them if they were planning on purchasing a robotic arm for themselves. The second part of the survey determined the customer satisfaction level by asking the customer how satisfied they were with other similar products they have seen on the market. The final question in the survey asked the customer how much they would be willing to pay for a robot of this quality. The results of these questions can be found in Table 1 and Table 2 below.

Table 1 - Customer Survey Results Analysis

<table>
<thead>
<tr>
<th>Product features</th>
<th>Customer importance</th>
<th>Current Satisfaction</th>
<th>Planned Satisfaction</th>
<th>Improvement ratio</th>
<th>Modified Importance</th>
<th>Relative weight</th>
<th>Relative weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote Battery Power</td>
<td>3.2</td>
<td>1.0</td>
<td>4.0</td>
<td>4.0</td>
<td>16.0</td>
<td>0.23</td>
<td>23.1%</td>
</tr>
<tr>
<td>Remote Control</td>
<td>2.4</td>
<td>1.0</td>
<td>4.0</td>
<td>4.0</td>
<td>16.0</td>
<td>0.23</td>
<td>23.1%</td>
</tr>
<tr>
<td>Reach</td>
<td>4.0</td>
<td>3.0</td>
<td>4.5</td>
<td>1.5</td>
<td>6.8</td>
<td>0.10</td>
<td>9.8%</td>
</tr>
<tr>
<td>Open Source</td>
<td>2.1</td>
<td>3.0</td>
<td>4.5</td>
<td>1.5</td>
<td>6.8</td>
<td>0.10</td>
<td>9.8%</td>
</tr>
<tr>
<td>Load Capacity</td>
<td>4.2</td>
<td>3.5</td>
<td>4.5</td>
<td>1.3</td>
<td>5.8</td>
<td>0.08</td>
<td>8.4%</td>
</tr>
<tr>
<td>Axis of Rotation</td>
<td>4.3</td>
<td>3.6</td>
<td>4.2</td>
<td>1.2</td>
<td>4.9</td>
<td>0.07</td>
<td>7.1%</td>
</tr>
<tr>
<td>Preassembled</td>
<td>4.0</td>
<td>3.4</td>
<td>4.0</td>
<td>1.2</td>
<td>4.7</td>
<td>0.07</td>
<td>6.8%</td>
</tr>
<tr>
<td>Gripper Opening Distance</td>
<td>4.1</td>
<td>4.5</td>
<td>4.5</td>
<td>1.0</td>
<td>4.5</td>
<td>0.07</td>
<td>6.5%</td>
</tr>
<tr>
<td>Speed</td>
<td>3.9</td>
<td>4.2</td>
<td>4.0</td>
<td>1.0</td>
<td>3.8</td>
<td>0.06</td>
<td>5.5%</td>
</tr>
</tbody>
</table>

The planned satisfaction for each category was calculated on the improvements that were estimated to occur through the design process. By changing the final design to include a larger gripper, and longer extension arm, the categories of gripper opening distance, load capacity, and reach were able to be estimated to obtain a planned customer satisfaction of 4.5.
Table 2 - Customer Price Range Preferences

<table>
<thead>
<tr>
<th>Price Range</th>
<th>Number of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0 - $49</td>
<td>3</td>
</tr>
<tr>
<td>$50 - $99</td>
<td>8</td>
</tr>
<tr>
<td>$100 - $199</td>
<td>6</td>
</tr>
<tr>
<td>$200 - $499</td>
<td>3</td>
</tr>
<tr>
<td>$500 - $1000</td>
<td>0</td>
</tr>
<tr>
<td>Average Price:</td>
<td>$131.25</td>
</tr>
</tbody>
</table>

Customer Survey Summary

Based on the survey results, the number of axis that the robot is able to rotate was considered the most important product feature; enabling the robot to be remote controlled was the lowest. Furthermore, customers seemed to be most satisfied with the axis of rotation and least satisfied with remote battery control and remote control. With design goals in mind and to give the customer what they really want, the biggest areas of improvement will come from giving the product an extended reach, a higher load capacity, and larger gripper opening.
**PRODUCT FEATURES AND OBJECTIVES**

After analyzing the Product Features, the product objectives were determined that would accomplish each feature and the overall design goal of the project. The Product Objectives with their corresponding product features and relative weight can be found below in Table 3 and in Appendix D.

Table 3 - Product Features and Product Objectives

<table>
<thead>
<tr>
<th>Feature</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Remote Battery Power</strong></td>
<td>23.1%</td>
</tr>
<tr>
<td>Powered by a rechargeable mobile internal battery source</td>
<td></td>
</tr>
<tr>
<td>Custom made battery housing case</td>
<td></td>
</tr>
<tr>
<td><strong>Remote Control</strong></td>
<td>23.1%</td>
</tr>
<tr>
<td>Mobile application controlled from a blue tooth enabled android device</td>
<td></td>
</tr>
<tr>
<td>Simple and intuitive user interface</td>
<td></td>
</tr>
<tr>
<td><strong>Reach</strong></td>
<td>9.8%</td>
</tr>
<tr>
<td>Distance from the body an object can be picked up exceeds six inches</td>
<td></td>
</tr>
<tr>
<td><strong>Open Source</strong></td>
<td>9.8%</td>
</tr>
<tr>
<td>All 3D models can be accessed and modified for reprinting parts</td>
<td></td>
</tr>
<tr>
<td>Arduino DUE has capability to add additional sensors</td>
<td></td>
</tr>
<tr>
<td>Software can be changed to allow for preprogramed functions</td>
<td></td>
</tr>
<tr>
<td><strong>Load Capacity</strong></td>
<td>8.4%</td>
</tr>
<tr>
<td>Max load capacity will exceed 1 pound when fully extended</td>
<td></td>
</tr>
<tr>
<td>Lightweight 3D printed Assembly</td>
<td></td>
</tr>
<tr>
<td>Main arm will be driven by a very high torque motor</td>
<td></td>
</tr>
<tr>
<td><strong>Axis of Rotation</strong></td>
<td>7.1%</td>
</tr>
<tr>
<td>Two drivetrain motors</td>
<td></td>
</tr>
<tr>
<td>Arm</td>
<td></td>
</tr>
<tr>
<td>Wrist</td>
<td></td>
</tr>
<tr>
<td>Gripper</td>
<td></td>
</tr>
<tr>
<td><strong>Preassembled</strong></td>
<td>6.8%</td>
</tr>
<tr>
<td>Minimal amounts of assembly required by the customer</td>
<td></td>
</tr>
<tr>
<td>Customer will not have to solder or wire anything</td>
<td></td>
</tr>
<tr>
<td><strong>Gripper Opening Distance</strong></td>
<td>6.5%</td>
</tr>
<tr>
<td>The maximum distance the gripper can open to pick up an object exceeds four inches</td>
<td></td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td>5.5%</td>
</tr>
<tr>
<td>Maximum speed exceeds three inches per second</td>
<td></td>
</tr>
<tr>
<td>Lightweight frame</td>
<td></td>
</tr>
<tr>
<td>High Torque motors geared for faster speed</td>
<td></td>
</tr>
</tbody>
</table>
The remote battery power and remote controller achieved the highest relative weight because they had the lowest customer satisfaction. Despite them being two of the lowest in the category of customer importance, they were still product features that could have seen the most improvement by adding them into the final design.
**ENGINEERING CHARACTERISTICS**

After analyzing the quality function deployment it was determined that having a clamp gripper and using servo motors were the two designer decisions most impacted by the engineering characteristics. By using a clamp gripper, the robot will be able to have a large gripper opening distance, and carry a heavier load. However, by not using a hand with multiple fingers and joints, the amount of axis that the robot can rotate would decrease.

By using servo motors, the robot will be able to handle a high load capacity, as well as move and support its base structure at fast speeds. Furthermore, with the increased capability and small profile of the motors, the robot could be outfitted for more axis of rotation.

The drivetrain was determined to be the least important engineering characteristic, primarily affecting the axis of rotation and overall speed. Both of these had low customer importance, but by utilizing a drivetrain with an omnidirectional wheel the product can achieve a zero degree turn radius.

The load capacity was the most affected engineering characteristic because with the end goal for the robot ability to pick up objects with the gripper, most design decisions will in some way affect the load capacity of the gripper. The placement of the main arm determines if the robot tips over while picking up a heavy object. The type of servo motor chosen directly determines how much weight can be lifted. Finally, the material selection factors into how heavy the overall structure is, and how good of a static friction there will be between the gripper and the object being lifted.

The detailed Quality Function Deployment can be found in Appendix C.

Table 4 – Designer Decisions impacting Engineering Characteristics

<table>
<thead>
<tr>
<th>Relative Importance</th>
<th>Designer Decisions</th>
<th>Engineering Characteristics greatly impacted by Designer Decision</th>
</tr>
</thead>
<tbody>
<tr>
<td>26%</td>
<td>Clamp Gripper</td>
<td>Load Capacity, Axis of Rotation, Gripper Opening Distance</td>
</tr>
<tr>
<td>25%</td>
<td>Servo Motors</td>
<td>Load Capacity, Axis of Rotation, Speed</td>
</tr>
<tr>
<td>18%</td>
<td>Material Selection</td>
<td>Load Capacity, Speed</td>
</tr>
<tr>
<td>14%</td>
<td>Placement of Main Arm</td>
<td>Reach, Load Capacity</td>
</tr>
<tr>
<td>11%</td>
<td>Arduino Bluetooth</td>
<td>Remote Control</td>
</tr>
<tr>
<td>6%</td>
<td>Drivetrain</td>
<td>Axis of Rotation, Speed</td>
</tr>
</tbody>
</table>
CONCEPT GENERATION AND SELECTION

*MOTOR DESIGN SELECTION*

Figure 8 - Servo Motor

Figure 9 - Stepper Motor

Figure 10 - DC Motor
With size constraints being a large issue in this design Servo Motors became the best decision for their ease of usability in small class robotics.

Table 5 - Design Criteria for Motor Selection

<table>
<thead>
<tr>
<th>Motor Types</th>
<th>Performance</th>
<th>Accuracy</th>
<th>Programmability</th>
<th>Use in Robotics</th>
<th>Cost</th>
<th>Size and Profile</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Servo Motor</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>4.2</td>
</tr>
<tr>
<td>Stepper Motor</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4.0</td>
</tr>
<tr>
<td>DC Motor</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3.3</td>
</tr>
</tbody>
</table>

**Performance** – Ability to output a high amount of torque

**Accuracy** – Does it have precise position and angular control?

**Programmability** – How difficult is it to program?

**Use in Robotics** – How easily can they be integrated into robotics?

**Cost** – For a robot application, how expensive are they?

**Size and Profile** - Does it have a large profile or would it be difficult to mount?


**Gripper Design Selection**

In this design the motor would be directly attached to the right gripper. As the motor turns, mated teeth between the two grippers would allow them open and close around an object.

Figure 11- Direct Attachment
For this design, the worm gear would be directly attached to the motor with both of the gears to the grippers setting on each side of the worm gear. As the worm gear turns, the gripper gears would turn; following the curve of the worm gear.

Figure 12 - Worm Gear
In this design one bevel gear would be directly attached to the motor. As the bevel gear moves it would turn another bevel gear, and in turn a spur gear, that are respectively attached to each of the grippers.

Figure 13 - Bevel Gear
This design utilizes a shaft with two worm gears that directly attached to the motor. As the shaft turns, the worm gears turn spur gears that are mated to them.

Figure 14 - Worm Gear Shaft
Due to the complexities of the designs, and the use of additional gears, the direct attachment was the clear choice for this category.

Table 6- Design Criteria for Gripper Mechanism

<table>
<thead>
<tr>
<th>Gripper Mechanism</th>
<th>Design Simplicity</th>
<th>In-Line</th>
<th>Torque</th>
<th>Gripper Simplicity</th>
<th>Average</th>
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<tbody>
<tr>
<td>Direct Attachment</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>9</td>
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</tr>
<tr>
<td>Worm Gear</td>
<td>5</td>
<td>9</td>
<td>4</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Bevel Gear</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>4</td>
<td>5.75</td>
</tr>
<tr>
<td>Worm Gear Shaft</td>
<td>5</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>4.75</td>
</tr>
</tbody>
</table>

Simplicity of Overall Design – How easy will the designs be to calculate and modify

In Line with Center Axis – Is the gripper or attached mechanism offset from the center of the motor? Will the torque have to be transferred over a different axis?

High Torque Output – How well will the torque be transferred from the motor to the gripper?

Simplicity of the Gripper Design – Is the gripper design limited in any way? Does the gripper mechanism force the gripper to be designed in a specific way?
**DRIVE TRAINE DESIGN SELECTION**

This drivetrain utilizes multiple individually driven omnidirectional wheels. These wheels consist of several additional wheels that rotate freely; allowing for very little traction when moving in any direction. The final version of this drivetrain used only one omnidirectional wheel in the back, and two normal wheels in the front.

Figure 15 – Example of Slide Drivetrain

Pros: Very easy and cheap to design, build, and program. They are also agile.

Cons: Required to have an additional wheel, motor, and gearbox for sideways movement.
The tank drivetrain utilizes tank treads. These treads form a single track that wraps around several driving wheels, and idler wheels.

Figure 16 – Example Tank Drivetrain

Pros: Simple and cheap to design, build, and program. They are also easy to control.

Cons: Less agile than other drivetrains, and take longer to turn
This drivetrain consists of four Mecanum wheels, which are wheels made of several rollers offset 45° to the plane of the wheel. In this design each wheel must be a Mecanum wheel and each has to be independently driven.

Figure 17 – Example of Mecanum Drivetrain

Pros: Fairly easy to design and build, and is agile.

Cons: Challenging to program and operate. Requires extra gearboxes, and the wheels are expensive.
This drivetrain consists of four omnidirectional wheels that are offset 45° from each other. Each of these wheels must be independently driven.

Figure 18 - Example of Holonomic Drivetrain

Pros: Agile

Cons: Very challenging to program and learn how to drive well. Requires extra gearboxes
Given the difficulties with overcoming a large amount of traction in a small robot and the large profile that the tank drivetrain created; the hybrid slide drivetrain was chosen.

Table 7 - Design Criteria for Drivetrain

<table>
<thead>
<tr>
<th>Drivetrain Type</th>
<th>Agility</th>
<th>Number Of Motors</th>
<th>Programming</th>
<th>Drive</th>
<th>Traverse</th>
<th>Design</th>
<th>Average</th>
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</thead>
<tbody>
<tr>
<td>Hybrid Slide</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4.5</td>
</tr>
<tr>
<td>Tank</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>4.2</td>
</tr>
<tr>
<td>Mecanum</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3.2</td>
</tr>
<tr>
<td>Holonomic</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>2.5</td>
</tr>
</tbody>
</table>

**Agility** - Mobility in the X and Y axis as well as being able to rotate about the Z axis.

**Number of Motors** - Being able to operate using as few motors as possible

**Programming** - Difficulty of programming. Not requiring advanced algorithms to calculate individual wheel speed/power

**Ease of Drive** - Intuitive and easy to use controls. Ability to utilize drivetrains maximum capability

**Traverse Obstacles** - Ability to traverse difficult obstacles such as ramps, bumps or steps.

**Design** - Ease of design, manufacturability, assembly, and maintenance. Low cost and low weight
3D MODELS AND DRAWINGS

See Appendix H for all 2D Drawings

Figure 19 - Full Assembly Isometric View
Figure 20 - Full Assembly Top View
LOADING CONDITIONS

A Finite Element Analysis was conducted on the entire assembly in order to determine the maximum level of stress and overall safety factor. The hypothesis was that the gripper would see the highest amount of stress.

Total weight of all components = 2.6 lbs
Max Load for object picked up = 1 lbs

After applying a load that was two times larger than the maximum load capacity, the stress analysis revealed that the entire assembly was under very little stress. All parts were over engineered to ensure that there would be no points of failure in any of the individual components.
Yield Strength of PLA Plastic is approximately 9,500 psi
Load Force: 2 lbs
Max Stress: 1,162 psi
Max Displacement: 0.022 in

Min Safety Factor: 8.45
Max Safety Factor: 15
DESIGN ANALYSIS

The solution to the originally stated problem was to create a completely open source 3D printed robot. With access given to all of the part models and STL files, users can easily make modifications to design the robot to their needs. Furthermore, by using the Arduino Due microcontroller, the robot is adaptable and reprogrammable for many different applications.

All of 3D models were designed using the AutoDesk Inventor CAD program. By 3D printing nearly all of the components in the robot, there were very few limitations in regards to the design of the entire assembly. The initial design intent of this project was to make each aspect of the design simple to modify, and easy to access should mechanical changes need to be made.

The biggest limitations faced were due to the size of the print bed being used. The print bed limited the working space of 7” x 7”. However, by forcing the assembly design to be smaller, more creative methods were used to get the same desired results. What was initially a limitation, in the end, made the final product much more efficient in its design and capabilities.
FACTORS OF SAFETY

Given that the material yield strength of PLA plastic is approximately 9,500 psi it was hypothesized that there would be very few points of failure in this assembly. The stress analysis showed that the assembly had a minimum safety factor of 8.45, and a maximum stress of 1,262 psi at point of load contact. Given this data, no additional factors of safety were necessary.
Utilizing a 3D printer, each of the components could be rapidly prototyped, allowing for quick turnaround time when testing new designs. The 3D printer in the picture above is a Rep Rap Prusa Mendel i2. It prints parts using PLA (Polyactic Acid), which is a biodegradable thermoplastic. The printer is capable of printing parts with a layer height as small as 0.1mm. The total print time of the entire assembly was approximately 25 hours.

One of the most beneficial parts of 3D printing is its ability to print parts with an infill pattern. Using the standard infill settings each of the parts in this assembly were only filled in with 20% material. Even at that low of a percentage the infill allows the top layers to be easily printed overtop of it; keeping the finished part very strong. Aside from reducing the overall weight of the object material used and print-time were reduced significantly.

For additional details on how the 3D printer works, and all of the components that make it up, see the Robotics Kit Design Guide in Appendix G.
ASSEMBLY METHODS

Figure 24 - Full Model Exploded View
All parts in this project that were screwed together were assembled using 4-40 \( \frac{1}{2} \)" screws. Individual parts were modified to ensure that there would only be a single standard of screw used. Throughout the rest of the assembly there are only three bolted connections. The parts that connected with bolts are the left gripper to the gripper mounting plate, the Omni wheel to the base plate, and the Arduino mounting plate to the arm mount. The entire assembly only requires a small Philips screwdriver.
TESTING METHODS

Testing was performed to obtain actual results to compare against the desired goals. Movement speed was tested by measuring and marking a distance of 100 inches. The robot was then timed to see how long it would take to travel the 100 inches. Lifting load capacity was measured by picking up objects of different sizes and weights. For an object to qualify as being successfully lifted the robot had to do the following: Pick up the object off the ground, move the arm and wrist into their highest positions, traverse a short distance, and not drop the object at any point during this time. The gripper opening and reach from body were calculated by measuring the distance between the two grippers when they were completely open, and by measuring the distance from the base of the body to the tip of the gripper. The final weight was recorded by measuring the totaling the individual weight of each component with a scale with a precision of + or − 0.1 grams.
RESULTS

<table>
<thead>
<tr>
<th>Testing Parameters</th>
<th>Desired Goal</th>
<th>Actual Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Movement Speed</td>
<td>4 in/second</td>
<td>8 in/second</td>
</tr>
<tr>
<td>Lifting Load Capacity</td>
<td>1 lb object</td>
<td>0.75 lb object</td>
</tr>
<tr>
<td>Turn Radius</td>
<td>0°</td>
<td>0°</td>
</tr>
<tr>
<td>Gripper Opening</td>
<td>4 in</td>
<td>6 in</td>
</tr>
<tr>
<td>Reach from body</td>
<td>6 in</td>
<td>7 in</td>
</tr>
<tr>
<td>Axis of Rotation</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Total Weight</td>
<td>Lightweight</td>
<td>2.6 lbs</td>
</tr>
</tbody>
</table>

During the test phase, the performance of lifting several different objects of varying weights was recorded. Due to the profile of the gripper, the easiest objects to hold onto were round objects; with bottles being the easiest to hold onto, and flat square objects being the most difficult. When testing objects that exceeded a weight of 0.75 lbs, the robot became too front heavy and tipped forward. This result was due to the reach from the body being too far; offsetting the center of gravity.

Furthermore, at weights of over 1 lb the force exceeded the maximum torque of the arm motor. However, due to the much shorter distance, the maximum torque of the wrist was not met until the object weight exceeded 1.5 lbs.
SCHEDULE AND BUDGET

SCHEDULE

The project schedule began September 29, 2014 with a proof of design agreement and concept selection. The project will end on April 30, 2015 when the report is finalized after being presented to the senior design faculty. The schedule with full details can be found in Appendix E.

Table 8 – Schedule
BUDGET

The projected budget for this project was estimated by component. The projected cost of the project was estimated for each of the different controller systems that will be developed. The specific parts and components and their cost for each system were filled recorded during the first semester of this project as the design was modified.

Table 9 – Proposed Budget

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>3D Printer Material</td>
<td></td>
</tr>
<tr>
<td>1 rolls</td>
<td>$40.00</td>
</tr>
<tr>
<td>Electrical System</td>
<td></td>
</tr>
<tr>
<td>Arduino</td>
<td>$40.00</td>
</tr>
<tr>
<td>Arduino Bluetooth Transceiver</td>
<td>$25.00</td>
</tr>
<tr>
<td>Controller</td>
<td>$30.00</td>
</tr>
<tr>
<td>Motors</td>
<td></td>
</tr>
<tr>
<td>2 x Wheels</td>
<td>$20.00</td>
</tr>
<tr>
<td>Arm</td>
<td>$15.00</td>
</tr>
<tr>
<td>Wrist</td>
<td>$10.00</td>
</tr>
<tr>
<td>Gripper</td>
<td>$15.00</td>
</tr>
<tr>
<td>Power Supply</td>
<td>$25.00</td>
</tr>
<tr>
<td>Tank treads</td>
<td>$30.00</td>
</tr>
<tr>
<td>Tank Tread Rubber</td>
<td>$15.00</td>
</tr>
<tr>
<td>Tank Tread Sprocket</td>
<td>$10.00</td>
</tr>
<tr>
<td>Erector Set Metal</td>
<td>$50.00</td>
</tr>
<tr>
<td>Miscellaneous Hardware</td>
<td>$10.00</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$335.00</td>
</tr>
</tbody>
</table>
The major differences between the proposed and actual budgets were in the design change from the tank drivetrain to the hybrid slide drivetrain. In the end, my I came in $88.94 under budget.
RECOMMENDATIONS

After looking at what aspects I would like to redesign with this project I would make the following changes:

• Change arm location and length so that robot does not tip forward.
• Find a better power supply that would last longer.
• Add feedback sensors.
• Add another motor that will allow the wrist to rotate.
CONCLUSION

The main intent of this project was to design and 3D print a mobile Bluetooth operated robot that taught the end user skills in the areas of Mechanical and Computer Engineering. By designing each part to be 3D printed the user is given complete design freedom to customize each part towards a specific design purpose.

The design analysis showed that there were very few points of stress, and the final model was very durable and strong. The results of the testing showed that all of the design goals were met except for the lifting load capacity. However, given its size, and price range, its capabilities outperformed all other researched products in the area of lifting load capacity. The target load lifting capacity could be accomplished by mounting the arm closer to the front of the body, thus decreasing the distance that the arm reaches to pick up objects.
REFERENCES

#### APPENDIX A – PRODUCT RESEARCH

<table>
<thead>
<tr>
<th>MechaTE Robot Right Hand</th>
<th>USD $900.00</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="MechaTE Robot Right Hand" /></td>
<td>Comes Preassembled</td>
</tr>
<tr>
<td></td>
<td>Very realistic hand motion</td>
</tr>
<tr>
<td></td>
<td>Each finger moves independently</td>
</tr>
<tr>
<td></td>
<td>Hand does not deliver enough gripping force</td>
</tr>
<tr>
<td></td>
<td>Frame is made of very strong durable frame. Very expensive</td>
</tr>
</tbody>
</table>

- Constructed of anodized aircraft aluminum
- No programming is necessary to achieve compliance
- 14 points of motion, 5 degrees of freedom (four fingers and thumb open / close)
- Controlled by any PWM servo controller, microcontroller, or simple RC system
- Intended for animatronics and does not have a substantial gripping force

While this hand is designed to have optimal realistic motion for performance, it does not have a substantial grip.


09/08/2014
| Global Specialties R680 Banshi Robotic Arm | USD $180.56 |
| CD comes with WinAVR, RobotLoader, and RACS software. Also complete 72-page manual and many sample programs Included 12V power adapter, assembly tools, keyboard controller, USB programmer interface & cable 6 Degrees of Freedom. Arm length 260mm; Height (fully extended) 340mm; Base diameter 150mm; Weight 1.3lbs |
| Comes unassembled as a kit | 6 DOF gives full range of motion Sturdy base supports end of arm Long reachability Wide gripper allows for larger objects to be picked up. |

http://www.amazon.com/Global-Specialties-R680-Banshi-Robotic/dp/B00GTQ0Z0Y/ref=sr_1_4?ie=UTF8&qid=1410146859&sr=8-4&keywords=robotic+arms
09/08/2014
Gowe 6 DOF Programmable Clamp Robot Arm Kit

Gripper Size: 65mm x 60mm x 27mm
Maximum size of mouth opening: 40mm
Maximum size of mouth with pads: 34mm

Robotic Arm Specification
Voltage: 4.8V - 6.8V
Max Current: >5000mA
Arm Height: 320mm
Weight: 600g

USB SSC32 Servo Controller Specification:
This product is a USB interface, no serial port to facilitate desktop and laptop use.
Interface: USB/TTL (baud rate 2400/9600/38400/115200bps)
Size: 58.5mm x 76.2mm
Resolution: 1uS 0.09°, 1uS/second, 0.09°/second
Servo range: 180° and 360°
Controls Servo: Up to 32 servo motors (PWM/TTL) Compatible lynxmotion RIOS Arm Control and SEQ Visual Sequencer software...etc
Provides 4 analog / digital signal input terminal, can be set at rest or latch.
Bluetooth module and APC220 provides wireless data transmission interface for remote control.
Provide ISP download port, for use of development. baud rate using the two DIP switch settings, to avoid the jumper is not stability. Support for Futaba, Hitec and most common Servo.
Supply Voltage: 6V - 12V or USB power (with self-recovery fuse, easy to use for debugging)
Servo Supply Voltage: 4.8V - 7.2V
Withstand current: each side 10A, 32 Road, the maximum 20A

Download:
Lynx SSC-32 Terminal USB-SCC32 Command
Formatting Lynx SSC32 USB Driver

USD $692.01
Single pinch gripper
Very Expensive

http://www.bonanza.com/listings/Gowe-6-DOF-Programmable-Clamp-Robot-Arm-Kit-Ready-to-Use-Toy-/180896621?gpid=68416460701&gpkwd=&goog_pla=1&gclid=Cj0KEQjwhLCgBRCf0qPH0431ljJwBEiQAi8P8UxjGioQRcopzSiV5cn6UWAbfKrPC4QMzq_dYkmXzcaAqNI8P8HAQ
09/08/2014
### Dagu 6 Degrees of Freedom Robotic Arm

<table>
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<th><strong>Description</strong></th>
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<th><strong>Additional Info</strong></th>
</tr>
</thead>
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<tr>
<td>Single pinch gripper</td>
<td>USD $275.26</td>
<td>Expensive. Comes Preassembled. Very large reach</td>
</tr>
<tr>
<td><strong>Url</strong></td>
<td><strong>Description</strong></td>
<td><strong>Notes</strong></td>
</tr>
<tr>
<td>[<a href="http://www.amazon.com/Robotic-Degrees-Freedom-Electronix-Express/dp/B00CLEO">http://www.amazon.com/Robotic-Degrees-Freedom-Electronix-Express/dp/B00CLEO</a> NBK/ref=sr_1_1_fkmr0_1?ie=UTF8&amp;qid=1410147102&amp;s=8-1-fkmr0&amp;keywords=dagu+6+degrees+of+freedom+robotic+arm](<a href="http://www.amazon.com/Robotic-Degrees-Freedom-Electronix-Express/dp/B00CLEO">http://www.amazon.com/Robotic-Degrees-Freedom-Electronix-Express/dp/B00CLEO</a> NBK/ref=sr_1_1_fkmr0_1?ie=UTF8&amp;qid=1410147102&amp;s=8-1-fkmr0&amp;keywords=dagu+6+degrees+of+freedom+robotic+arm)</td>
<td><strong>9/08/2014</strong></td>
<td></td>
</tr>
</tbody>
</table>

6 Degrees of freedom robotic arm
Length: 390mm
Made from 3mm thick aluminium sheet
Uses 4x DGServo S06NF STD servos for the base and the arm.
A serial interface and PC software included
Can control 32 servo motors
Dual - power supply (6 ~ 12 V SCM power, 4.8 ~ 6 V servo motor power
Comes Preassembled
## Robotiq Adaptive Gripper Hand

**Mechanical**
- Gripper opening: 1-169mm
- Gripper weight: 2.3kg
- Recommended encompassing grasp payload: 10kg
- Recommended friction grasp payload: 3kg
- Max gripping force (Fingertip Grip): 40N
- Max break away force: 100N
- Max. closing speed (Fingertip Grip): 110mm/sec
- Min. ambient temperature: -10°C
- Max. ambient temperature: 50°C
- Finger Position Repeatability (Fingertip Grip): 0.065 ± 0.008mm
- Number of fingers: 3
- Number of phalanxes per finger: 3
- Number of grasping modes: 4
- IP class: 31

**Control**
- Interface options: Ethernet/IP, Modbus RTU, Modbus TCP, DeviceNet or EtherCAT
- Grasping programmable parameters: Force, speed and partial closing/opening
- Status LEDs: Power, communication and error
- Feedback: Finger contact detection, motor encoders and motor current

**Electrical**
- Nominal supply voltage: 24VDC
- Quiescent power (minimum power consumption): 4.1W
- Peak power (at maximum gripping force): 35W
- Maximum RMS supply current (supply voltage at 24V): 1.4A
- Dimensions: 9x9x9 inches
- Weight: 2.1 kg

USD $18,000.00

Robotic gripper that adapts to all parts
3 articulated fingers
4 grasping modes adapt to a variety of sizes and shapes
Simple control over Ethernet/IP, Modbus RTU, DeviceNet or EtherCAT
Extremely high gripping force
Able to be added on to existing robotic arms
Extremely expensive

[http://www.robotshop.com/en/robotiq-adaptive-gripper.html?gclid=Cj0KEQjwhLCgBRCf0iPH043lJlwBEiQA8P8U69a9VpFTwk4PusEso3m4DZGzi1tSlV8Huz606gTizAaAm9K8P8HAQ09/08/2014](http://www.robotshop.com/en/robotiq-adaptive-gripper.html?gclid=Cj0KEQjwhLCgBRCf0iPH043lJlwBEiQA8P8U69a9VpFTwk4PusEso3m4DZGzi1tSlV8Huz606gTizAaAm9K8P8HAQ09/08/2014)
## Customizable Bionic Robotic Hand Kit

<table>
<thead>
<tr>
<th>Features</th>
<th>USD $100.99</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete life-sized robotic hand</td>
<td>Fingers move together, not independently</td>
</tr>
<tr>
<td>Opens &amp; closes at the touch of a switch</td>
<td>Components do not appear to be made of a durable material</td>
</tr>
<tr>
<td>Uses one AA battery (included)</td>
<td></td>
</tr>
<tr>
<td>Completely self contained, easily customized</td>
<td></td>
</tr>
<tr>
<td>Capable of grasping objects, adjustable fingers</td>
<td></td>
</tr>
<tr>
<td>Not Preassembled</td>
<td></td>
</tr>
<tr>
<td>Battery Operated</td>
<td></td>
</tr>
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---

Features:
- Complete life-sized robotic hand
- Opens & closes at the touch of a switch
- Uses one AA battery (included)
- Completely self contained, easily customized
- Capable of grasping objects, adjustable fingers
- Not Preassembled
- Battery Operated

---

http://www.righttoolusa.com/p/Customizable-Bionic-Robotic-Hand-Kit-50708566.html?gclid=Cj0KEQjwhLCgBRCf0fPH043lJwBEiQAf8P8U0abRTVvD1g_hWr8LEhphELAwGBaILboJG07m2OYEY1aAjnf8P8HAQ09/08/2014
OWI Robotic Arm Edge

Product Dimensions: 6.3 x 15 x 9 inches; 2.5 pounds
Radial wrist motion of 120°
Elbow range of motion of 300°
Base rotation of 270°
Base motion of 180°
Vertical reach of 15 inches
Horizontal reach of 12.6 inches
Lifting capacity of 100g
Includes a search light design on the gripper and an audible safety gear indicator.

Pros:
- Hard durable plastic (Not cheap feeling)
- Very Inexpensive

Cons:
- Doesn’t have any sensors, will break if you push beyond its range of motion
- Does not come pre-assembled; somewhat difficult to assemble with lots of small parts
- Gripper cannot rotate (Can only pick up objects perpendicular to the base. Limited functionality)
- Does not come with any programmable components (Would have to be modified with add-on Arduino)
- Insufficient instructions for remote controller and trouble shooting

USD $39.67

09/08/2014
APPENDIX B – CUSTOMER CURVEY

ROBOTIC ARM CUSTOMER SURVEY

This project will consist of designing, building, and testing a robotic arm system and comparing its performance to existing robotic arms on the market. The robot will work by using a system of servo motors to control and move the following components: 360° rotation of entire arm, 90° vertical movement of main arm, 90° vertical movement of wrist, 180° rotation of gripper, and full clamping motion of gripper. These motors will be controlled using a remote device that the user operates.

How important is each feature to you for the design of a robotic arm?
Please circle the appropriate answer. 1 = Low Importance  5 = High Importance

<table>
<thead>
<tr>
<th>Feature</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>N/A</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote Battery Power</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
<td>3.20</td>
</tr>
<tr>
<td>Remote Control</td>
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<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
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<tr>
<td>Reach</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
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<tr>
<td>Open Source</td>
<td>1</td>
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<td>4</td>
<td>5</td>
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<tr>
<td>Load Capacity</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
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<tr>
<td>Axis of Rotation</td>
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<td>3</td>
<td>4</td>
<td>5</td>
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<tr>
<td>Preassembled</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
<td>4.00</td>
</tr>
<tr>
<td>Gripper Opening Distance</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
<td>4.10</td>
</tr>
<tr>
<td>Speed</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
<td>3.90</td>
</tr>
</tbody>
</table>

How satisfied are you with robotic arms that are currently on the market?
Please circle the appropriate answer. 1 = Very Unsatisfied  5 = Very Satisfied

<table>
<thead>
<tr>
<th>Feature</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>N/A</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote Battery Power</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
<td>1.00</td>
</tr>
<tr>
<td>Remote Control</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
<td>1.00</td>
</tr>
<tr>
<td>Reach</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
<td>3.00</td>
</tr>
<tr>
<td>Open Source</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
<td>3.00</td>
</tr>
<tr>
<td>Load Capacity</td>
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<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
<td>3.50</td>
</tr>
<tr>
<td>Axis of Rotation</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
<td>3.55</td>
</tr>
<tr>
<td>Preassembled</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
<td>3.40</td>
</tr>
<tr>
<td>Gripper Opening Distance</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
<td>4.45</td>
</tr>
<tr>
<td>Speed</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>N/A</td>
<td>4.20</td>
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</table>

How much would you be willing to pay for a robotic arm that meets the above criteria?

<table>
<thead>
<tr>
<th>Range</th>
<th>3</th>
<th>8</th>
<th>6</th>
<th>3</th>
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<tr>
<td>$0-$49</td>
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<tr>
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<td>(8)</td>
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<td></td>
<td></td>
<td></td>
<td>$50.00</td>
</tr>
<tr>
<td>$100-$199</td>
<td>(6)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$100.00</td>
</tr>
<tr>
<td>$200-$499</td>
<td>(3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$200.00</td>
</tr>
<tr>
<td>$500-$1000</td>
<td>(0)</td>
<td></td>
<td></td>
<td></td>
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<td>$500.00</td>
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<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$131.25</td>
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</tbody>
</table>
APPENDIX C – QUALITY FUNCTION DEPLOYMENT (QFD)

<table>
<thead>
<tr>
<th>Robotic Arm</th>
<th>Material Selection</th>
<th>Clamp Gripper</th>
<th>Servo Motors</th>
<th>Drivetrain</th>
<th>Arduino</th>
<th>Bluetooth</th>
<th>Placement of main arm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote Battery Power</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>1</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remote Control</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reach</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>1</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open Source</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load Capacity</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>1</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Axis of Rotation</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preassembled</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gripper Opening Distance</td>
<td>1</td>
<td>9</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>9</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Absolute Importance</td>
<td>2.67</td>
<td>3.89</td>
<td>3.67</td>
<td>0.89</td>
<td>1.67</td>
<td>2.11</td>
<td></td>
</tr>
<tr>
<td>Relative Importance</td>
<td>0.18</td>
<td>0.26</td>
<td>0.25</td>
<td>0.06</td>
<td>0.11</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>Customer Importance</td>
<td>3.2</td>
<td>1.0</td>
<td>4.0</td>
<td>4.0</td>
<td>16.0</td>
<td>0.23</td>
<td>23.1%</td>
</tr>
<tr>
<td>Current Satisfaction</td>
<td>2.4</td>
<td>1.0</td>
<td>4.0</td>
<td>4.0</td>
<td>16.0</td>
<td>0.23</td>
<td>23.1%</td>
</tr>
<tr>
<td>Planned Satisfaction</td>
<td>4.0</td>
<td>3.0</td>
<td>4.5</td>
<td>1.5</td>
<td>6.8</td>
<td>0.10</td>
<td>9.8%</td>
</tr>
<tr>
<td>Improvement Ratio</td>
<td>2.1</td>
<td>3.0</td>
<td>4.5</td>
<td>1.5</td>
<td>6.8</td>
<td>0.10</td>
<td>9.8%</td>
</tr>
<tr>
<td>Modified Importance</td>
<td>4.2</td>
<td>3.5</td>
<td>4.5</td>
<td>1.3</td>
<td>5.8</td>
<td>0.08</td>
<td>8.4%</td>
</tr>
<tr>
<td>Relative Weight %</td>
<td>4.3</td>
<td>3.6</td>
<td>4.2</td>
<td>1.2</td>
<td>4.9</td>
<td>0.07</td>
<td>7.1%</td>
</tr>
<tr>
<td>Relative Importance</td>
<td>4.0</td>
<td>3.4</td>
<td>4.0</td>
<td>1.2</td>
<td>4.7</td>
<td>0.07</td>
<td>6.8%</td>
</tr>
<tr>
<td>Relative Importance</td>
<td>4.1</td>
<td>4.5</td>
<td>4.5</td>
<td>1.0</td>
<td>4.5</td>
<td>0.07</td>
<td>6.5%</td>
</tr>
<tr>
<td>Relative Importance</td>
<td>3.9</td>
<td>4.2</td>
<td>4.0</td>
<td>1.0</td>
<td>3.8</td>
<td>0.06</td>
<td>5.5%</td>
</tr>
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</table>
# APPENDIX D – PRODUCT OBJECTIVES

<table>
<thead>
<tr>
<th>Objective</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote Battery Power</td>
<td>23.1%</td>
</tr>
<tr>
<td>- Powered by a rechargeable mobile internal battery source</td>
<td></td>
</tr>
<tr>
<td>- Batteries don’t have to be removed to be recharged</td>
<td></td>
</tr>
<tr>
<td>- Custom made battery housing case</td>
<td></td>
</tr>
<tr>
<td>Remote Control</td>
<td>23.1%</td>
</tr>
<tr>
<td>- Mobile application controlled from a blue tooth enabled android device</td>
<td></td>
</tr>
<tr>
<td>- Simple and intuitive user interface</td>
<td></td>
</tr>
<tr>
<td>Reach</td>
<td>9.8%</td>
</tr>
<tr>
<td>- Distance from the body an object can be picked up exceeds eight inches</td>
<td></td>
</tr>
<tr>
<td>Open Source</td>
<td>9.8%</td>
</tr>
<tr>
<td>- Easily Modifiable</td>
<td></td>
</tr>
<tr>
<td>- Housing will contain very few integrated parts</td>
<td></td>
</tr>
<tr>
<td>- Software can be changed to allow for preprogramed functions</td>
<td></td>
</tr>
<tr>
<td>Load Capacity</td>
<td>8.4%</td>
</tr>
<tr>
<td>- Max load capacity will exceed ½ pound when fully extended</td>
<td></td>
</tr>
<tr>
<td>- Lightweight arm</td>
<td></td>
</tr>
<tr>
<td>- Main arm will be driven by a very high torque motor</td>
<td></td>
</tr>
<tr>
<td>Axis of Rotation</td>
<td>7.1%</td>
</tr>
<tr>
<td>- Two drivetrain motors</td>
<td></td>
</tr>
<tr>
<td>- Arm</td>
<td></td>
</tr>
<tr>
<td>- Wrist</td>
<td></td>
</tr>
<tr>
<td>- Gripper</td>
<td></td>
</tr>
<tr>
<td>Preassembled</td>
<td>6.8%</td>
</tr>
<tr>
<td>- Minimal amounts of assembly required by the customer</td>
<td></td>
</tr>
<tr>
<td>- Customer will not have to solder or wire anything</td>
<td></td>
</tr>
<tr>
<td>Gripper Opening Distance</td>
<td>6.5%</td>
</tr>
<tr>
<td>- The maximum distance the gripper can open to pick up an object exceeds four inches</td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>5.5%</td>
</tr>
<tr>
<td>- Maximum speed exceeds three inches per second</td>
<td></td>
</tr>
<tr>
<td>- Lightweight frame</td>
<td></td>
</tr>
<tr>
<td>- High Torque motors geared for faster speed</td>
<td></td>
</tr>
</tbody>
</table>
# APPENDIX E – SCHEDULE

<table>
<thead>
<tr>
<th>Event Description</th>
<th>Dates</th>
<th>Duration</th>
</tr>
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<tbody>
<tr>
<td>Proof of Design Agreement and Concept Selection</td>
<td>Sep 29-Oct 5</td>
<td>5</td>
</tr>
<tr>
<td>3D Model Development</td>
<td>Oct 6-12</td>
<td>2</td>
</tr>
<tr>
<td>Finalize Design and Associated Documentation</td>
<td>Nov 3-16</td>
<td>6</td>
</tr>
<tr>
<td>Ordering, Fabrication and Assembly of Parts</td>
<td>Dec 18-28</td>
<td>20</td>
</tr>
<tr>
<td>Design Presentation to Faculty</td>
<td>Dec 29-Jan 4</td>
<td>2</td>
</tr>
<tr>
<td>Design Report to advisor</td>
<td>Jan 5-Jan 11</td>
<td>5</td>
</tr>
<tr>
<td>Product Testing and Design Modifications</td>
<td>Jan 12-Feb 1</td>
<td>16</td>
</tr>
<tr>
<td>Demonstration to advisor</td>
<td>Feb 2-Feb 8</td>
<td>25</td>
</tr>
<tr>
<td>Tech Expo</td>
<td>Feb 9-Feb 15</td>
<td>16</td>
</tr>
<tr>
<td>Finalize Library Report and Submit to Blackboard</td>
<td>Feb 23-Mar 5</td>
<td>23</td>
</tr>
</tbody>
</table>
## APPENDIX F – BUDGET

<table>
<thead>
<tr>
<th>Item</th>
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<tbody>
<tr>
<td>3D Printer Material</td>
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</tr>
<tr>
<td>1/2 rolls</td>
<td>$15.00</td>
</tr>
<tr>
<td>Electrical System</td>
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</tr>
<tr>
<td>Arduino</td>
<td>$40.22</td>
</tr>
<tr>
<td>Arduino Bluetooth Transceiver</td>
<td>$9.99</td>
</tr>
<tr>
<td>Servo Motor Controller</td>
<td>$24.99</td>
</tr>
<tr>
<td>Motors</td>
<td></td>
</tr>
<tr>
<td>2 x Wheels</td>
<td>$25.26</td>
</tr>
<tr>
<td>Arm</td>
<td>$39.99</td>
</tr>
<tr>
<td>Wrist</td>
<td>$29.18</td>
</tr>
<tr>
<td>Gripper</td>
<td>$29.18</td>
</tr>
<tr>
<td>Power Supply</td>
<td>$10.27</td>
</tr>
<tr>
<td>Miscellaneous Hardware</td>
<td>$15.00</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$246.06</td>
</tr>
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</table>
APPENDIX G – ROBOTICS KIT DESIGN GUIDE

Designing Your Robot

Listed below are a series of topics and information that will help prepare you for whatever type of robot you would like to work on. For those with access to a 3D printer, or would like to learn more about 3D printing, CAD modeling, and designing for a 3D printer, the first three sections will be the most helpful.

1. Know the basics about 3D printing
2. Know the basics about CAD Modeling
3. Tips and tricks for modeling for 3D printing
4. What kind of hardware should you use to assemble your robot?
5. Design Analysis
   a. What is the intent and application for your robot?
   b. Designing your drivetrain
   c. Designing ideas for other applications
6. What kind of motors should you use?
7. How do you want to control your robot?
8. How are you going to power your robot?
3D printer basics

3D printing is an additive manufacturing process; making solid three dimensional parts one layer at a time from a .STL (Stereolithography) file type. These STL files are creating in a CAD (Computer Aided Design) program such as CATIA, Inventor, or SolidWorks (More on that in the next section). From here the CAD part is imported in a Slicer program such as Cura – Ultimaker, Repetier, or Slic3r. These programs take the file, and based on your printer settings, slice the part in individual layers. Within the individual layers, the program calculates and determines the fastest path that it can travel in order to print each layer. After this is done the printer will then heat up the plastic filament that you have it set up for, push it through the extruder as it traces the outline of each layer, and begin printing the part.

Main Component Descriptions

Frame – Holds the machine together. This must be rigid enough to prevent the machine from shaking as the printer head moves in the X and Y directions.

Filament – The plastic material that makes up the printed object. The most common filaments used are PLA (Polylactic Acid) and ABS (Acrylonitrile Butadiene Styrene) which are both thermoplastics. This means that they have a relatively low melting point, allowing them to become soft and moldable when heated; returning to a solid state when cooled. ABS is often the preferred choice of professionals due to its high strength, machinability, flexibility, and temperature resistance. PLA is more commonly preferred by hobbyists and those with DIY printers because of its wide range of colors available, its ability to print at faster printing speeds, and its resistance to warping. Other less common materials that can printed with include: nylon, epoxy resins, photopolymers and polycarbonate. Filament comes in 1.75mm and 3mm diameters spools. Determining which to use will be primarily determined by the type of extruder that you have.

The print head/extruder – Filament is loaded into the top of the extruder and fed through it using a hobbed bolt. Depending on the material being used the extruder will print the filament between 180° - 230° Celsius. The extruder nozzle diameter will determine the volumetric flow rate, or how much material is pushed through the extruder. The speed at which the material is extruded is determined from the printing settings that you set. The common sizes used are 0.3mm, 0.35mm, and 0.4mm diameter nozzles. Going from 0.4mm to 0.3mm may not seem like much, but it makes a very large difference in the quality of your prints. In regards to what size filament you use technically speaking it shouldn’t matter between a 1.75mm and 3mm diameter filament. However due to the gearing ratio set up for the extruder, 1.75mm filament will typically work better for a 0.3mm nozzle, and likewise for a 3mm filament and 0.4mm nozzle. Motors – Between four and five motors are necessary; one each for the X and Y axis, either one or two for the Z axis, and one for the extruder. Stepper motors are primarily used for this operation.

X, Y, Z movement mechanics – Different brands of 3D printers have different ways of moving parts in these directions. The most common operation is to have the print bed move in the Y axis, and the extruder move in both the X and Z axis. The X and Y axis movement is performed
using a timing belt which pulls either the extruder or print bed over a shaft. They slide smoothly because they are attached to the shaft with a bearing. The extruder is moved in the Z axis by simultaneously turning two threaded rods, which are indirectly attached to the extruder.
Learning how to model parts

Common Programs – CATIA, Inventor, Pro/Engineer, SolidEdge, SolidWorks, and Unigraphics

See the website below for all of the most common 3D modeling software, and Slicer tools used in 3D printing.

http://3dprintingforbeginners.com/software-tools/

For those 3D modeling for the first time, and even for advanced users Inventor has a lot of attractive features, is user friendly, and easy to pick up and learn the basics. For those unfamiliar with Inventor I recommend that you go through the list in order, until you have all of the basics down. For specific questions on some of the more advanced functions of Inventor, there are YouTube tutorial videos, and community forums on almost every single facet of the program.

Download Free 3-Year license
http://www.autodesk.com/education/free-software/inventor-professionalInventor

Overview of Inventor (Video - 1:39)

Descriptions of Different File Types

View Navigation (Video - 1:58)

Create Sketches (Video – 3:01)

Sketched Features

Assembly Basics (Video – 4:31)
Modeling Parts for 3D printing

**Printing Holes** – When printing holes that are smaller than ¼”, the holes will usually come out a bit smaller than intended unless you are printing a very high quality part. To resolve this design a small flat test part with several different size holes. From here you should be able to determine the accuracy of your printer and if you need to oversize your holes when printing.

**Printing your own bolts/hardware** – If you’re planning to use large bolts or screws that are at least ¼” in diameter, printing them can be a very inexpensive and easy option. To do so, design the shaft of the bolt, or nut, to be the diameter of your intended threads. Then use a tap and die set to create the threads on the plastic. Depending on the load bearing capacity and size of the threads for the intended part, you’ll want to increase your infill percentage to 100%.

**Printing Assemblies** – As opposed to printing many individual parts and assembling them with screws or bolts, try to make your parts as integrated as possible. Be having fewer parts in your printed assembly you’ll achieve the following:

- You will use less hardware assembling everything
- Assembly time will be decreased significantly
- Overall strength will be increased because they are solid single pieces
- You will run into less mechanical problems
  - Screw coming loose, parts becoming misaligned, ect.
- The downside of this is that if you need to make a small change such as enlarging a single section to make a part fit better; you’ll have very few options.
  - You can remove small amounts of material at a time using a dremel to cut the material away.
  - Reprint the entire part.

**Print Orientation** – Your print orientation will determine how long a part will take to print and its strength in that orientation. But most importantly, it will affect if you need to print a part with support material.

**Overhang and Support material** – Depending on the printer being used, parts can be printed with as small as a 25° - 30° angle overhang. Lower angles will require printing at much slower speeds and with a smaller layer height. Most printers can handle 60° overhang with no change to printer settings. Printing with 45° - 60° overhang will most likely require printing at slightly slower speeds and smaller layer height. Printer settings typically do not allow for different printer speeds with overhang. Because of this, if you have areas with a steep angle of overhang but you don’t want to slow down your printing speed you can use the support material option. This option will add small single lines of material that give your part an area underneath of it to build up on. This material will be thin enough that it should break away from your part easily.

**Premade Parts** - For libraries of premade parts they’re many different websites and communities online that give free access to user uploaded CAD files. These files are already set up to be immediately 3D printed. Two such websites that do this are [http://www.thingiverse.com/](http://www.thingiverse.com/) and [https://grabcad.com/](https://grabcad.com/)
Assembling your Robot

If you have individual parts that are designed to be screwed together consider the following:

- If you need to increase the size of the screw hole you’ll be most likely extending your hole into infill material. Based on your infill pattern settings, you may not be able to create a very strong hold for the threads of the screws.
- If you remove the screw, the screw will be likely to not hold as well as it did the last time

A better design solution is to create a bolted connection with a washer and a lock nut if possible. This also opens up the option for you to create adjustable pieces by creating slots instead of holes.

If you printed the parts separately for ease of printing, but would like them permanently connected then consider using an adhesive such as Weld-On 4 Acrylic Adhesive. This will melt the plastic; permanently welding the two parts together.
Drivetrain Questions

When designing your drivetrain you need to first determine what the application of your robot is going to be.

- Are you looking for something very simple that will be easy to design, and easy to control?
- Do you want your drivetrain to have a lot of driving force behind it; allowing it to move over difficult terrain, or resist being pushed from the side?
- Are you looking for something that will have the best agility and mobility, but may be more complicated to design and control?

Once you answer those questions, then consider what types of wheels you might want to use. Some of the biggest factors that will determine your robot's mobility are the following:

- How many of each wheel are you using?
- Are the wheels being driven independently?
  - This will give you greater control and mobility, but will be more difficult to program and operate due to all of the different mobility options. This will also require a motor for each wheel, which will draw much more current from your batteries
- Do you want a front/rear wheel drive that uses a chain or gears to drive the other wheels simultaneously off of the same motor?
  - This will give you less control and mobility, will be more difficult to design mechanically, will be easier to program, and draw less current from using less motors.

Omnidirectional Wheels

Omnidirectional wheels are made with small cylinders around its circumference, acting as additional wheels. These cylinders are placed perpendicular to the turning direction. This allows the wheel to be driven forward/backwards, as well as laterally with virtually no additional traction.

- These can be used individually or in replacement of any of your normal wheels.
- If multiple are used in a drivetrain, and one is placed perpendicular to the other wheels, you can achieve lateral movement.
- Due to their design they are very susceptible to being pushed laterally.
- These can be 3D printed with the only additional purchased items being M4 bolts, nuts and washers, and bearings.

Mecanum Wheels

Mecanum wheels are similar to Omni wheels in the sense that they allow a wheel to move in any direction. The difference between the two is that Mecanum wheels are conical in shape, are offset 45° from the axis of rotation of the wheel, and have an axis of rotation that is offset 45° from the plane of the wheel.

- When using Mecanum wheels, all wheels must be Mecanum wheels and driven independently.
  - If you don’t drive them independently you lose the ability to move laterally. This is due to the fact that rotating the wheels in opposite directions of each other
move the robot laterally. (Example: Front Moves Counter Clockwise, Back Moves Clockwise)

- Due to their design they are susceptible to being pushed laterally, but not as much as Omni wheels because they have a better contact with the ground.
- These can be 3D printed with the only additional purchased items being M4 bolts nuts and washers, and bearings.

**Ball bearing wheels**

A ball bearing wheel is simply a metal ball that rolls around freely inside of a casing. These can be very useful if you don’t have the space to mount a full wheel or if you would like a simple connection on the underside of your robot. Their downside is that they will only travel well on smooth flat surfaces. For this reason they are sometimes used in very small robots that are driven by two motors, but need a third wheel for support.
Drivetrain types

**Tank** - With the use of tank treads this drivetrain is very useful for driving over difficult terrain. This is because most tank treads have a rubber piece attached to them, allowing for your robot to maintain a high amount of traction over different surfaces. The downside is that this high amount of traction will be difficult to initially overcome if you are using motors that deliver a small amount of torque, or if your treads have a large area of surface contact. Because of this, this design is more typically seen in larger robots that use stepper motors instead of servo motors.

**Slide** - The traditional slide robot would either three or five Omni wheels to drive it. This design would have either one or two wheels on each side; individually driving the left and right drivetrain. The last wheel would be placed perpendicular to the other wheels, and when driven would move the robot laterally. Due to the lateral movement only being driven by one wheel, programming and control the robot would be simpler than, but not as effective as other designs that can move laterally.

**Mecanum** – This drivetrain uses four Mecanum wheels, and has the capability to move in any direction. By driving each wheel individually the robot can forwards/backwards, left/right, turn with a zero degree turn radius, and even turn while moving in any direction. Incorporating this last feature into the design is what makes the robot difficult to program, design, and learn the controls for. Given its design this drivetrain is extremely agile with great degrees of mobility and is able to move laterally with a strong amount of force.

**Holonomic** – This type of drivetrain uses four Omni wheels that are offset at 45° angles from each other. By doing this, the robot is able to drive forward/backwards, left/right, and turn with a zero degree turn radius. Given the design of this drivetrain it’s very good at being able to maneuver around obstacles, but is likely to lose traction if ever pushed from the side.
Designs for Common Applications

Being able to make a robot move effectively may be one of the biggest things needed to learn in robotics, but there are many other applications that you can design your robot for. Below is a small list of the many additional things that you can program and add into the functionality of your robot.

- **Moving objects**
  - Picking up items with a gripper
  - Transporting items with an elevator or conveyor belt
  - Launching/throwing objects accurately
- **Balancing**
  - Using a gyro and accelerometer to maintain balance on a two wheeled robot
- **Autonomous Robots**
  - Maze Solving and space mapping
    - Using an ultrasonic sensor for object detection
  - Vision systems
    - Using a camera to detect lines, correcting its trajectory as needed
- **Remote vision**
  - Attaching a camera for remote control without line of sight on the robot
- **Different types of drivetrain movement that resemble animals** (Boston Dynamics has done a lot of development in this field)
  - Walking on two legs like a human
  - Walking on four legs like a horse
  - Walking on eight legs like a spider
Choosing a controller
One of the most common controllers for robots is an Arduino. This will control the capabilities of your robot. Given your application, you will most likely need to also purchase a motor shield. This will make it much easier for you to control your motor direction and speed through the Arduino. Furthermore, it will allow you to use a power supply with a much higher voltage than the Arduino, ensuring that you don’t damage any of its electronics. Depending on what kind of motors you are using, and how you will be controlling the Arduino will determine what kind of shield you will need to purchase.
You should also consider the following:

- How many motors do you want to use?
- Do you want to add any additional sensors to the robot?
- What is the size/profile of the Arduino?
  - This may hinder the layout of your final assembly, especially if you are designing your robot to have a small profile.

Choosing a wireless control method

Radio Frequency (RF)
Communication does not require a line of sight, and distances of control can range up to several miles. This method can be very straightforward to setup, but only simple commands will be able to be sent. Finally, there’s always the possibility that somebody, or something else will be transmitting at the same frequency which would interfere with your signals.

Bluetooth
Bluetooth offers the ability for your device to connect to any Bluetooth enabled device which includes cell-phones, PDA’s, and laptops. What makes it better than normal RF communication is that you are able to send much more advanced commands. One its downsides is that at best, you can usually only transmit signals up to 10m.

Wifi
One of the greatest advantages of communicating over a WiFi signal is that you can wirelessly control your robot from anywhere in the world. The disadvantage of this however, is that you would have to program and add a WiFi unit onto the robot itself.
Motors - What is your design intent?

Servo Motor – Servo motors can be very inexpensive and can be used for precise angular control as well as for continuous rotation. They come in standard sizes with standard sized mounting holes, making mounting very easy. More powerful servo motors are available, but given their price to torque output are often not feasible to purchase for some projects. These are best when used for small robots.

Stepper Motor – Stepper motors have the capability of outputting a larger amount of torque given their size, but due to this they draw a lot of current. They can be very affordable to purchase, but the size and weight of them makes them difficult to use for small robots.

Continuous DC Motor – There are a wide variety of these to choose from, and they are easy to control. However, in order to operate for robotics you will most likely need to provide gear reduction. Furthermore, they are difficult to find standard sizes for, and mounting them is very difficult.
Batteries

What type of battery should you use?

- Lithium Ion Polymer (LiPo)
  - Small profile, lightweight, can be recharged quickly, and have a high current output
- Lithium Ion (Li-Ion)
  - Lightweight and high energy density
  - Low output current
- Nickel-Metal Hydride (NiMH)
  - High energy density and can be charged quickly
  - Very inexpensive for their size
  - Frequently used in larger robotics
- Alkaline
  - Are not rechargeable
  - Frequently used in small robots

What kind of voltage and capacity do you need?

Each component that you purchase should tell you its operating voltage and what its current draw will be at that voltage. When looking at the batteries available for purchasing consider running additional batteries in parallel or in series to achieve your desired output. For example, if you 6V to run your motors, you could use 4 AA batteries that each have a voltage of 1.5V. By running them in series you get 6V. If the capacity of these batteries is not enough, you can run an additional set of batteries in parallel, to get double the capacity. Finally, if your electronics don’t all run at the same voltage, or if some components draw significantly more current than others consider powering your components separately.
APPENDIX H – 2D DRAWINGS

Top View

Right View

Isometric View

Front View
Robotic Arm

Jonathan Jurcenko

Top View

Isometric View

Note: 0.125" Fillet around all inside edges

Left View

Front View

DRAWN
Jonathan Jurcenko

Checked

Title

Electronics Cover

Approved

C

Arduino Cover

Rev: 1 of 1
Robotic Arm

Jonathan Jurcenko

Top View

Isometric View

Left View

Note: 0.125" Fillet Around All Outside Edges

Front View

Bottom View
Robotic Arm

Jonathan Jurcenko

Right View

Front View

Isometric View

Bottom View

Note: Fillet of 0.125" for front and top edges
Front View

Isometric View

Top View

Note: 0.125" Fillet over all round Edges
Robotic Arm

Top View

Isometric View

Front View

Left View

Note: 0.125" Fillet over all round Edges

Title: Wrist Motor Holder

Jonathan Jurcenko