ANIMATRONIC ROBOT DEVELOPMENT
USING PULSE WIDTH MODULATION MICROCONTROLLER
PROGRAMMING

A SENIOR PROJECT
PRESENTED TO
THE FACULTY OF LIBERAL ARTS AND ENGINEERING STUDIES
CALIFORNIA POLYTECHNIC STATE UNIVERSITY, SAN LUIS OBISPO

IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE
BACHELOR OF ARTS

BY
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INTRODUCTION

Walt Disney Imagineering was founded by Walt Disney in 1952 as WED Enterprises as per the need to develop and create Disneyland Park. Walt Disney took his successes in the film industry of cartoon animation as well as a vision for fantasy and adventure to create a team of talented individuals ready to help make his dream a reality. This original team would eventually be known as the Legends of Imagineering, the individuals who spent over 50 years with the company and helped to build it from the ground up. One of the revolutionary technologies first implemented to attract intrigue and interest of the guests were animatronics. Audio animatronics are robotic characters that move with pre-recorded movements and sounds. These characters can sing, speak and gesture via computer programming and predetermined motions. The original audio animatronics produced for public viewing included Abraham Lincoln for the attraction, Great Moments with Mr. Lincoln and the singing tropical birds from The Enchanted Tiki Room. These animatronics were largely popular with the guests who visited the parks. The demand for more characters that could “come to life” resulted in the implementation of characters in every land of Disneyland Park. The world of animatronics has continued to advanced since the opening of the Tiki Room in 1963. An attention to detail has been continually emphasized and characters in the Disneyland parks can even be uncannily modeled to look like the actors who portray them in the movies such as the swashbuckling Jack Sparrow from Pirates of the Caribbean. With the advancement of sculpting methods, exterior material understanding, and computer programming opportunities, Imagineers can make individual fingers move, cheeks jiggle, and eyelids blink on characters as they encounter guests such as with Ursula in Ariel’s Undersea Adventure at Disney’s California Adventure. Mr. Potato Head at California Adventure’s Toy Story Midway Mania ride, interacts with guests and is on the forefront of the up and coming Autonomatronic technology. These characters will independently gather sensory data from guests in the park and interact with them in an unscripted fashion. The goal for this project is to create an animatronic character, pre-programmed with human, biometric gestures to act as a guest greeter for the Spring 2013 Theater and Dance Department’s production of Charles Mee’s “Trojan Women 2.0.” The project encompasses a range of disciplines including mechanical engineering system design, sculpture, and theatrical entertainment. As a senior project for the Liberal Arts and Engineering Studies program at Cal Poly, San Luis Obispo, this project will serve as a guide for future students seeking a step-by-step set of directions on how to create and customize a robotic character for theatrical use.

TARGET MARKET

The Cal Poly, San Luis Obispo University’s Theater and Dance Department caters to a wide range of audience members for each of their productions. The Spring 2013 production of “Trojan Women 2.0” is designed as shock-theater and is specifically targeted at adult audience members with vivid, violent content not suitable for children. The content of the show involves the prominent royal ladies of Troy as they are about to be given away as gifts to the victorious soldiers after the infamous battle of Troy. As such, this animatronic character will be designed to match the harsh, post-apocalyptic battle set design that has been created specifically to evoke a visceral set of emotions from the audience members. The target market includes adults over the age of 18.

CUSTOMER

This project is a representation of the work completed by a senior level student in the Liberal Arts and Engineering Studies major at California Polytechnic State University, San Luis Obispo. While the project is a reflection of the major, the actual customer contracted for the project is Josh Machamer, Department Chair for the Theater and Dance Program as well as the Director for the production of “Trojan Women 2.0.”

NEEDS ANALYSIS

The current norm for advertising a Cal Poly theater production includes the use of social media and public relations methods; however, when the production begins there are no additional enticing products placed at the entrances to the production. Students on campus can witness lines of people traveling into the theater and speaking with ushers at the door but no additional effort is made to attract guests on the night of any one production. Any addition to the production of a show must be seamlessly integrated to the scenic design of that production to accomplish a cohesive feel for the environment.
**PROBLEM STATEMENT**

The Spring 2013 production of Trojan Women 2.0 evokes a set of visceral responses from each audience member. Consequently, the show would benefit from the implementation of an animatronic character to spark intrigue and interest in the audience members for the dark, shocking theme of the production before they even step foot in the doors.

The goal of this animatronic character will be to emphasize the dark nature of the production by seamlessly matching the interior, modern-industrialized set design. The character must be easily moved from a selected storage location within Cal Poly’s Alex G. Spanos Theater when the show is not in session, to a location outdoors that will draw attention to the entrance. Since the show will occur at night, the character must be illuminated so that no single detail is lost. The character must be easy to move by average college aged students enrolled in the Theater Stagecraft course and who are responsible for the arrangement of props involved in the show. As per the restrictions of the space allotted by the customer, Josh Machamer, the character must fit within a 3’x3’ space. Also, since the character will be outdoors for the duration of its usage, it must be made of weather-resistant materials. The location of the entrance limits open flow of traffic and required that no sharp edges of the design were exposed toward the entrance so as to preserve the safety of any audience members in attendance of the show. The final constraint of the character was that it must be easily turned on and off electronically by the stage crew so that the responsibilities of the crewmembers were not impeded by a fault in the technology.

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Constraints (Go/No-Go Conditions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>System will weigh less than 80lbs</td>
<td>No sharp exposed edges</td>
</tr>
<tr>
<td>Cost less than a total of $1000</td>
<td>Cannot be so heavy has to be immovable</td>
</tr>
<tr>
<td>Shelf will support the robot</td>
<td>Fit within a 3’x3’ footprint</td>
</tr>
<tr>
<td>Made of common material for manufacturability</td>
<td>Use weather resistant materials</td>
</tr>
<tr>
<td>Roll on wheels for easy transportation</td>
<td>Character will match the scenic design of the production</td>
</tr>
<tr>
<td>Structurally sound to support weight of material</td>
<td>Simplistic enough to turn on and off by users w/o assistance</td>
</tr>
<tr>
<td>Use colors that match the derelict theme of the</td>
<td></td>
</tr>
<tr>
<td>production</td>
<td></td>
</tr>
<tr>
<td>Aesthetics include industrial/modern materials</td>
<td></td>
</tr>
<tr>
<td>Motion of robot mimics human biomechanics</td>
<td></td>
</tr>
<tr>
<td>Spark interest of entering audience members</td>
<td></td>
</tr>
<tr>
<td>Simplistic on/off controls for stage crew usage</td>
<td></td>
</tr>
</tbody>
</table>

**PROPOSAL**

The cost, construction requirements, and size requirements of the final product were taken into consideration and an animatronic, human-like character was pre-programmed with biometrically valid motions for display at the entrance of the Cal Poly, San Luis Obispo Theater production of Trojan Women 2.0, directed by Josh Machamer. The cost limit was predetermined by the restrictions of the Liberal Arts and Engineering Studies senior project funds, amounting to a total of $1,000. The size restrictions were predetermined by Josh Machamer as a 3’x3’ footprint so that the case would fit easily in the space allotted outside of the theater’s entrance. Construction of the final product required a full wood and metal shop; consequently, the Theater Scene Shop and the Liberal Arts and Engineering Studies Lab provided all of the necessary electronics and power tools required to complete this product. The character was programmed with an Arduino Uno microcontroller via Arduino open source software. It’s motion was powered through the implementation of nine Parallax 180° servo motors. The arms of the character gestured in correspondence with natural human biomechanics and the head swiveled from left to right to add dimension to the character. The final aesthetics of the project were designed in conjunction with the derelict scenic design of the production to enhance the appropriateness of integration at the entrance of the building. The character was placed inside a display case mounted on four 3” locking caster wheels, this not only aided in the ease of relocation while the show was not in progress, but also allowed for permanency when the case was set in place, thereby preserving the safety of passers-by. The final product had jagged, torn metal pieces on the front and side, which were bent back away from the pathway of audience members so that the safety of the guests was further
maintained. Finally, the programming code involved multiple different gestures as well as a sequencing that purposefully mimicked a faulty program, so as to accentuate the damaged nature of the production’s environment.

IDEATION: GENERATION OF IDEAS

A research plan was developed to take data from the most well known place of animatronics, Disneyland Resort in Anaheim, CA including both Disneyland Park and Disneyland – California Adventure. A list of data acquisition questions was prepared prior to departure including details such as “how many animatronics are in this attraction?” and “what kind of motions do the characters have?” The trip was helpful in realizing the vast expanse of opportunities with robotic animation. While some of the characters in the rides were statues that simply swiveled on a rotary base, others such as Ariel at the beginning of “Ariel’s Undersea Adventure” had motion implemented within her hair to mimic the flow of water. Through additional research of multiple Walt Disney Imagineering books, it was realized that most animatronics function off of large hydraulic or pneumatic piston-cylinder systems. To scale down this system design in order to fit within a $1,000 budget (of which hydraulic and pneumatics would greatly overrun), research was completed to reveal that Parallax Servo Motors would provide the needed torque to move the character’s head and arms, while simultaneously fitting the reduced-human size of the character. Other methods used to move toward the final assembled product included the development of a decision matrix, which helped determine whether a standalone character would be more or less beneficial than an encased character as well as whether interactivity would be better or worse than a pre-programmed robot. For the aesthetics of the robot and the display case that was designed for it, multiple meetings with both show director Josh Machamer and the scenic design, Matt Herman - a senior Cal Poly Theater student, were conducted.

STRUCTURED SELECTION PROCESS

Table 2. Decision Matrix

<table>
<thead>
<tr>
<th>Datum</th>
<th>Weight Factor</th>
<th>Rating</th>
<th>Wt'd Rating</th>
<th>Rating</th>
<th>Wt'd Rating</th>
<th>Rating</th>
<th>Wt'd Rating</th>
<th>Rating</th>
<th>Wt'd Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>4</td>
<td>-1</td>
<td>-4</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mobility</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Weather Resistance</td>
<td>2</td>
<td>-1</td>
<td>-2</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Price</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>3</td>
<td>-1</td>
<td>-3</td>
<td>1</td>
<td>3</td>
<td>-1</td>
<td>-3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Size</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>-1</td>
<td>-2</td>
<td>-1</td>
<td>-2</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The weight factors shown in Table 2 (above) were chosen by order of importance based on meetings with the customer and through experience with system design and construction. Mobility was given the highest weight factor of “5” due to the constant relocation requirements of the project before and after the show for a total of over fourteen times while the production was running. Aesthetics was also given the highest priority since the final display of the project would be a direct reflection on the show itself and would provide an initial impression to guests of what the interior design might entail. Safety was given the next highest priority; the project was located immediately adjacent to the entrance doorway which required guests to pass directly by the project on their way indoors, their safety needed to be preserved. The ease of use was granted a median weight factor of 3 since the stage crew would need to be able to turn the system on and off as well as move the entire product around, but the weight factor was not higher than 3 since there was ample time to give
instruction on how to accomplish these tasks without fail. Size and weather resistance were given weight factors of 2. The size was a restriction of the customer but was not the most important factor in the design and weather resistance was a concern since the project resided outdoors but it was placed underneath a building awning and was thus protected from most of the elements. Price was given a weight factor of 1. Research was completed prior to this decision matrix that revealed that hardware and parts for the robot would not cost more than $200, leaving an excessive $800 to spend on hardware and materials for the optional display case disputed in this matrix.

SOLUTION
The main requirement of this project was to program an animatronic robot using a Pulse Width Modulation Microcontroller, while also fulfilling the constraints provided by the customer for a character that fit cohesively with the design of the production. Through meetings with the customer and a structured selection process, it was decided that a pre-programmed, encased robotic character was the best option for accomplishing the goals of this project. The character was designed as fully encased within the display and accordingly protected from the elements. The electronics system was not made available to guests for live programming due to the bottleneck possibilities at the entrance to the theater as well as the potential exposure of the electronics to damaging outdoor weather. The system was moved from its storage location within the scene shop of the Davidson Music Building on the Cal Poly campus, to just outside the side door of Spanos Theater that was used as the main entrance for this production. The display case was mounted on casters so as to be easily relocated, had materials that were cohesive with the theme of the production, and was built in a manner that did not impede the safety or flow of guests as they entered the facility. I was solely responsible for the conceptual design, microcontroller programming, construction, and final aesthetic modifications. The final product was achieved through constant consultation with both Josh Machamer (the customer and show Director) as well as Matt Herman (the Scenic Designer of the show).

FEATURES/DESIGN CONSIDERATIONS

HUMAN FACTORS
A human factor considered during the early design of this product was the usability of the final design for the stage crewmembers responsible for moving the display case into place for each of the seven productions of the show. A slider switch was programmed into the system so that the robot merely needed to be plugged in and the switch turned on in order to function. This switch controls the voltage to the microcontroller, if the switch is set to “off” the robot would not receive commands from the microcontroller but if the switch was in the “on” position, the code would run through the microcontroller and the servos would move accordingly. Another usability factor included the use of the light flutes. The LED light flutes were internally battery operated, and each had their own power button located on one end of each housing. In order for the stage crew to turn these lights on, and illuminate the interior of the display case, the lid of the display case was not permanently attached to any of the side walls and could be opened from the top so that a crew member could turn the lights on with the simple use of a ladder. The main human factor was that of mobility. Four 4” caster wheels were attached to the bottom of the display case so that it could roll along multiple terrains. The larger diameter of the wheels aided in traversing flooring dividers and door floor jams that existed between the outdoor location for display and the indoor storage location. These casters removed the need for the box to be lifted, a beneficial factor since the final product weighed over 100lbs.

MATERIALS
The materials were selected with respect to the constraints of the tools available as well as the ease of material acquisition. Table 3 (below) provides a complete list of the materials and tools required to complete this project. It was important to choose materials that would compliment the materials used in the scenic design of the production. Upon discussion with the scenic designer, it was decided that the main materials used included: steel, aluminum, wood, and concrete. As per this list, the materials used for the display case included aluminum roofing shingles, plywood, and Plexiglas to emphasize the industrial modernity of the show.
The materials for the robot were chosen on a different basis. The base structural material used was a plastic skeleton; this skeleton held its shape, was easy to customize for the addition of servo motors, and held the proper proportions of an accurate human frame. Figure 1 shows a sequencing of development for the robot body. In order to build up the skeleton to a body that resembled the mannequins used in the interior set of the show, a combination of compacted paper materials and heavy duty Gaffers Tape were used. The benefit of these materials is that it protected the wiring of the system that ran along the spine of the character from the neck to the bottom of the torso and provided a flat surface in which to mold on top of. After the main body had been built, white Model Magic foam clay was used to create a more realistic form for the character. This type of clay dries quickly, can be glued or painted, and is light weight enough that it would not place additional weight forces on the servo motors. The final material used on the robot before a layer of paint was lightweight Spackling. After this spackling dried, it could be sculpted with a medium grit sand paper to form the desired shape and details.

Table 3. Materials List for both the display case and the robot respectively.

<table>
<thead>
<tr>
<th>Display Case</th>
<th>Tools</th>
<th>Hardware</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pneumatic Staple Gun</td>
<td>3/8” Socket bit and drill bit</td>
</tr>
<tr>
<td></td>
<td>Makita Power Drill</td>
<td>Power Handheld Sander</td>
</tr>
<tr>
<td></td>
<td>2-3/8” Socket Wrench</td>
<td>Jigsaw</td>
</tr>
<tr>
<td></td>
<td>1/4” Plywood A1000</td>
<td>3/8” Self-Drilling Hex Screws</td>
</tr>
<tr>
<td></td>
<td>¼” Acrylic Plexiglas Sheets</td>
<td>2” Woods Screws</td>
</tr>
<tr>
<td></td>
<td>32 – 12”x18” Aluminum Housing Shingles</td>
<td>3/8”x1” Staples</td>
</tr>
<tr>
<td></td>
<td>4 - LED Light Flutes</td>
<td>DAP Flexible Clear Sealant in “Crystal Clear”</td>
</tr>
<tr>
<td></td>
<td>4 - Locking Casters</td>
<td>Spray Adhesive</td>
</tr>
<tr>
<td></td>
<td>2 – Hinges</td>
<td>White and Black Acrylic House Paint</td>
</tr>
<tr>
<td></td>
<td>1 – Rod and Slot Locking Mechanism</td>
<td>Elmer’s Wood Glue</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Animatronic Robot</th>
<th>Tools</th>
<th>Hardware</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fine Wire Strippers</td>
<td>Spools of Electric Wire</td>
</tr>
<tr>
<td></td>
<td>Heat Gun</td>
<td>Wire Heat Shrink</td>
</tr>
<tr>
<td></td>
<td>Computer</td>
<td>Solder</td>
</tr>
<tr>
<td></td>
<td>Soldering Iron</td>
<td>Fine Sculpting Wire</td>
</tr>
<tr>
<td></td>
<td>Dremel</td>
<td>Hot Glue Sticks (Clear)</td>
</tr>
<tr>
<td></td>
<td>Dremel Cutting Bit</td>
<td>Computer</td>
</tr>
<tr>
<td></td>
<td>Hot Glue Gun</td>
<td>9 - 180° Parallax Servo Motors</td>
</tr>
<tr>
<td></td>
<td>Hand Saw</td>
<td>Plastic Skeleton</td>
</tr>
<tr>
<td></td>
<td>Computer</td>
<td>White and Black Gaffers Tape</td>
</tr>
<tr>
<td></td>
<td>Soldering Iron</td>
<td>Model Magic Clay (white)</td>
</tr>
<tr>
<td></td>
<td>Dremel</td>
<td>Fine Sculpting Wire</td>
</tr>
<tr>
<td></td>
<td>Plastic Skeleton</td>
<td>Red Devil OneTime Lightweight Spackling</td>
</tr>
<tr>
<td></td>
<td>White and Black Gaffers Tape</td>
<td>Charcoal Gray Paint</td>
</tr>
<tr>
<td></td>
<td>Arduino Uno Microcontroller</td>
<td>Circuit Breadboard</td>
</tr>
<tr>
<td></td>
<td>2 - 5V DC Power Supplies</td>
<td>9 - 180° Parallax Servo Motors</td>
</tr>
<tr>
<td></td>
<td>Arduino 1.0.1 (or higher)</td>
<td>Circuit Breadboard</td>
</tr>
</tbody>
</table>

Figure 1. From Left to right, from top left, sequencing of materials used on character.
The servo motors selected to control the motion for this product are the Parallax Standard Servo (#900-00005) seen in Figure 2. Each servo can be programmed to move to a degree designation between 0° and 180°. The servos require a pulse-width modulation command where a high pulse provides voltage to the motor and causes consequent motion, whereas a low voltage (or zero voltage), causes no motion. To attain functional motion, each servo requires at least a 4VDC power source; for this reason, a 5V DC Power source was run through the breadboard to simultaneously power the nine servos used in the final design. In order to send commands to the servos, an Arduino Uno R3 Microcontroller was used. The code implemented can be seen in Appendix C where the comments are descriptive of each step in the program. The main body of the code implements a matrix function where each row represents a step in the presentation show and each column represents one of the nine servos used in the robot. The value in each respective row and column states an absolute degree value for which the servo is commanded to move to. It is important to note that the servos on the left side of character are mounted opposite from the servos on the right side of the character so that the degree designations must be inverted. For example, if symmetry is desired, a left servo may be commanded to travel to an absolute 150° from 0° and the counterpart servo on the right side would then be commanded to move to an absolute 30° from 0°. In initial testing, giving commands of greater than 10° increments between each step (row) of the show matrix caused abrupt, jarring motion as the servos high voltage command sped the servo from one degree to the next. In order to smooth the motion of the show and gain control over the speed of the motion, an arithmetic approach was used in the programming. The calculations were completed within the system where regardless of what degree was designated, the code computed the difference between the two steps and divided into appropriate increments so that it was no longer necessary to manually add in incremental steps. This addition removed tedious programming and allowed for an ease of adjustment to the final show.

DURABILITY
The resistance to unpredictable environmental elements was a concern for the final product. The durability of the robotic character was a concern since the servos would require a considerable range of motion, so the following precautions were taken to protect it from unforeseen complications. The display’s final outdoor location required that the electronics and the robotic character itself be enclosed to prevent any type of potential moisture or dust damage to the system. As such, the display case utilized three Plexiglas sidewalls that fit into the base frame of the plywood box, as well as a lid of Plexiglas. The Plexiglas was fused at the two front corners so that no excessive moisture, falling debris, or accidental hazards could harm the character on the inside during use. A hole was cut into the shelving that the character sat on so that the microcontroller, breadboard, extension cord, and power supplies would be completely protected. Additionally, a ¼” plywood was used to create the back face and base of the box. This type of wood is heavy duty and could easily be manipulated with the proper tools to suit the needs of the project. The strength of this would at ¼” thickness easily held the weight of the Plexiglas as well as its own weight suspended on the four caster wheels it was mounted to.

AESTHETICS
The final aesthetics were largely dependent on the scenic design for the show laid out by senior Theater major, Matt Herman in conjunction with consultation from the Director Josh Machamer. While the technology was set in a way that was inflexible with required wiring and construction, the final aesthetics related directly to the production set. “Trojan Women 2.0” is set as a modern, post-apocalyptic battle scene. Everywhere across the set was organized chaos and perfect destruction; the mangled metal and broken stone formations molded the dark and derelict stage. With respect to the industrial materials used in the set design, a distressed design was developed for the exterior of the display case. As with every theater production, every detail has its own story that fits into the final “look” of a production. The story for the display case was that it was once a pristine welcoming character for people to enter the city of Troy; however, battle hit the city and while the interior of the casing remained untouched due to the Plexiglas sidings, the exterior of the case had became victim to a dramatic explosion that tore the metallic siding from the corners. A diluted black acrylic paint provided the main exterior color for the plywood to mimic the effect that rain and excessive sunlight have on wood that resides next to a metal. Galvanized steel shingles were attached with hex screws to simulate rivets and industrialize the look of the exterior of the case. These shingles were distressed just as the wood was to enhance the destructive effect that
the battle had on the object as a whole. Overall, the size of the display case was 2’x3’x6’, this size fit within the customer-allotted 3’x3’ footprint and also allowed for the robotic arms to have the full range of motion necessary for the programmed show to run accurately. Within the box, additional materials from the actual set design were added to remove empty space within the box that made the entire display seem unfinished. The metal grates were bent and added in an orientation that did not prevent the motion of the robot. The final aesthetic decision was to add a “Trojan Women 2.0” poster to the back wall of the display case. Since the display was used mainly as a source of intrigue for the entering guests, it was appropriate to add one of the promotional posters to unify the design.

COST AND VALUE
The cradle-to-grave approach of project sustainability was an important factor in creating this project. Initial conceptual design included distressing the Plexiglas sheets to match the fragmented design of the final casing. It was decided after purchasing the Plexiglas from Aggson’s Glass in San Luis Obispo that the glass should remain intact and as scratch free as possible so that it could be recycled into future Liberal Arts and Engineering Studies projects. The value of the acrylic material is beneficial to the wide range of interdisciplinary projects that students in the major focus on, as such, the acrylic cost was high, but the value will continue to increase as the material is reused. The hardware used throughout this project was purchased at a relatively low cost as seen below in Table 4. Just like the recyclability of the acrylic Plexiglas, the screws, LED light flutes, and electronics can be reused in future projects which increases their value as a purchase for this project. Other materials such as the foam clay, steel shingles, and plywood are not reusable following the disassembly of this project, however their utilization as per the requirements of the servo torque capacity and the seamless integration of the materials into the rest of the set design, give them a value of their own.

Table 4. Cost of Purchased Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Price ($/unit)</th>
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</thead>
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<tr>
<td>1/4&quot; Plywood Sheets</td>
<td>3</td>
<td>13.27</td>
<td>39.81</td>
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<tr>
<td>8’ - 2&quot;x4&quot; Wood</td>
<td>6</td>
<td>4.17</td>
<td>25.02</td>
</tr>
<tr>
<td>8’ - 1&quot;x3&quot; Wood</td>
<td>2</td>
<td>7.13</td>
<td>14.26</td>
</tr>
<tr>
<td>1/4&quot; Acrylic Plexiglas Sheets (by sq. foot)</td>
<td>30</td>
<td>11.90</td>
<td>357.00</td>
</tr>
<tr>
<td>12&quot;x18&quot; Galvanized Steel Shingle</td>
<td>32</td>
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<td>31.36</td>
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<tr>
<td>DAP Flexible Clear Sealant</td>
<td>1</td>
<td>7.95</td>
<td>7.95</td>
</tr>
<tr>
<td>#12 3/4&quot; Self Drilling Hex Screws</td>
<td>1</td>
<td>9.87</td>
<td>9.87</td>
</tr>
<tr>
<td>#8 2.5&quot; Wood Screws</td>
<td>1</td>
<td>8.47</td>
<td>8.47</td>
</tr>
<tr>
<td>Sylvania LED Light Flutes</td>
<td>4</td>
<td>11.97</td>
<td>47.88</td>
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Display Case Cost: $541.62

<table>
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<th>Price ($)</th>
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<tr>
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<td>4</td>
<td>11.97</td>
<td>47.88</td>
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</table>

Display Case Cost: $541.62

Animatronic Robot

<table>
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<tr>
<td>Lightweight Spackling (1 qt)</td>
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<td>Parallax Servo Motors</td>
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<td>11.69</td>
<td>105.21</td>
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<td>24.99</td>
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<td>Arduino Uno R3 Microcontroller</td>
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</tr>
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</table>

Robot Cost: $172.22

TOTAL COST: $713.84
THE MODEL

ANIMATRONIC ROBOT

The interior structure of the robot comprised of a single human-like plastic skeleton. The plastic in the rib area was easily cut away using a rotary Dremel tool to make way for the insertion of the servo motor that would eventually become the shoulder axis of forward and backward rotation. When holes were cut on each side, the servos were mounted using a combination of heavy strength fine sculpting wire and hot glue for additional rigidity within the body. The shoulder to elbow segment of each arm was attached using the same method of wrapping wire around the propeller of the servo and what represents the ball in the ball and socket joint of a shoulder. Careful consideration for the possible range of rotational motion was taken when these limbs were attached so as to mimic actual human biometrics (i.e. an arm would not rotate behind the body, but instead in front of the body if only 180° of rotation were available). Following this attachment, additional servo motors were attached with the same wire and glue approach to the elbow joint. The servos on the left mirrored the servos on the right side of the body, this mirroring was later taken into consideration when the programming was completed. Prior to the attachment of the final elbow to hand limbs, testing was done with multiple degree commands to find which 0° to 180° configuration of propellers was appropriate to attach the limb to. It was desired that the arm had the range of motion to allow for straight arm extension, as well as the hand being folded up toward the shoulder, once again in front of the body, not behind. The elbow to hand limbs for each side were attached to the servo and tested for rigidity. Finally, the back of the skeleton head was cut off using the Dremel cutting bit. A horizontal wooden dowel with a notch the width of one servo was feed through the head and attached with hot glue and Gaffers Tape. A notch was also cut into the top of the spinal column of the skeleton and a servo was wedged in and mounted with hot glue and wire into this location. The propellers for the servo mounted in the neck were then glued onto the horizontal dowel. The motion produced was a left to right horizontal head swivel. Note that consideration was also taken here with respect to 180° range of motion in which the desired direction was for the head to look fully to the left, rotate around the front of the body, and look fully to the right.

Each servo motor has three wires, a red (for power), a black (for ground), and a white wire (for command). These wires were run along the spinal column to the bottom of the torso and taped into place. Each wire was spliced with an extension of electrical wire (white for command, blue for power, and black for ground). In order to ensure proper connection and to prevent interference, a soldering iron was used to solder these splicing connections (a total of 27 splices) as well as an electrical heat shrink to cover each of the connections. Each of the command wires were inserted into the pulse width modulation (PWM) pins on the Arduino Uno R3 Microcontroller as Figure 3 above. A breadboard was also implemented since the microcontroller could not supply the necessary voltage to each of the nine servos being used. The black
(ground) port of the breadboard was attached to the black (ground) wire of the 5VDC power supply; conversely, the red (power) port of the breadboard was attached to the red (voltage) wire of the 5VDC power supply. A simple wire was used to designate the far right column of the breadboard to the ground of the power supply and the second to the left column as the voltage of the power supply. The black servo wires were plugged into the ground column and the blue (power) servo wires were connected to the power column as seen in Figure 4. The microcontroller itself used power from the laptop whilst new programs were being uploaded but was ultimately given its own separate 5VDC power supply so that the laptop did not have to be present in order for the robot to be turned on and off. Each of the two 5V power supplies were plugged into a power strip and extension cord combination for final usage that was ultimately plugged into a wall power source.

The aesthetics of the robot were the final step made in completion of the animatronic. The robot was wrapped in alternating layers of heavy-duty Gaffers tape and paper products to create a solid body for the system. Once the basic shape of the robot was attained, white model magic foam clay was used on the arms, torso, and head to further progress the shape of the robot to the desired mannequin silhouette. Once the foam clay had dried, a lightweight spackling was adhered excessively to the head and arms. This spackling was used since it dried quickly, added little weight to the arms and was easily sanded down and sculpted after drying. The spackling on the arms was shaped down using a combination of 80 and 100 grit sandpapers. Finally, the character was painted using a charcoal gray acrylic paint that had be utilized throughout the set of the production. A last touch included the utilization of an extra steel shingle, cut and shaped to resemble armor and attached with hot glue to the robot (Figure 5).

DISPLAY CASE

The first step to creating the display case was to assemble the left, right, and front faces of the plywood base of the box. A pneumatic nail gun and Elmer’s wood glue were used through one sheet of plywood and a 1”x3”. The small beam provided additional width and structural integrity to the 90° face attachments. The same procedure was used on the other front corner of the box for a three sided configuration. A caster wheel was then bolted to thick pieces of wood cut at 90° to fit in each of the eventual four corners of the rolling display case (Figure 6). Each caster’s wooden block was mounted high enough on the interior of the box so that a 1.5” clearance existed between the bottom edge of the plywood faces and the floor. This clearance was essential to navigating over door jams and the lip between the interior flooring and the exterior of the theater building. Next, a Jigsaw was used to cut a 2’x2’ square out of the back of the 6’ plywood sheet to provide a doorway from the back of the case into the underside of the shelf that would eventually hold the animatronic and electrical components. This square piece of wood was attached back onto the long board with two hinges and a rod and slot slider locking mechanism to hold the door closed. The front face of the box was laid downward on top of two scrap pieces of 2”x4” plywood so that the front did not get damaged by any debris on the floor. At this time, the back length of plywood was placed front side down on top of the three-face arrangement and attached with wood glue and pneumatic staple gun staples. The back two caster plates were already mounted to the side faces so the final step for basic assembly required an additional few lines of wood glue and staples to secure it in place. With the four sides of the display box assembled, the box was inverted to rest solely on the four casters, of which it was structurally sound. Supports were attached inside the box at the front and back of the case to create a slant for the shelf that would eventually hold the animatronic. A horizontal shelf was pneumatically stapled into the front and back faces of the box and a hole was cut in the black shelf so that the robot could slip easily into this hole and sit secured on the shelf without moving undesirably.
The aesthetics of the box required a diluted 1:10 ratio of black acrylic paint to water, which was painted on all exterior faces of the case. As per the storyline behind the box, the interior was painted with a pristine white acrylic paint. The animatronic’s shelf was painted with an equally pristine black acrylic paint to emphasize the perfection retained within the box during the destruction of battle. Once all paint had dried, the box was laid on its backside and the steel shingles were attached with a combination of clear sealant glue and self-drilling hex screws to simulate rivets and hold the shingles to the plywood. An overlapping pattern was used at the request of the Scenic Designer and the top left corner of the box was left without any shingles since this area was designated as being physically closest to the interior of the production at its position at the entrance to the theater, hence experiencing the highest level of destruction. A power handheld sander was used on the surface of all shingles once they had been secured to each of the left, right, and front faces of the display case. This technique of distressing minimizes the clean, reflective nature of the galvanized steel and emphasized the dilapidated design of the final aesthetics. The shingles closest to the corner that was left bare, were bent and torn with a combination of hammers, pliers, and hand manipulation to replicate the effect that an explosion would have in tearing apart metal objects, just as was used in the set design of the production.

The Plexiglas was precut at the distributor to determined dimensions to fit within the 2’x3’ design. The design required that the three-face assembly slide into the display case and rest on supports mounted to the inner corners of the box. Due to incorrect measurements cut by the distributor, additional length was removed from each of the acrylic piece using a standard table saw blade. Once the pieces were cut to their appropriate sizes, they were adhered at 90° angles to one another and fused with DAP flexible clear sealant.

For the final steps of assembly, the robot was set in place on the shelf with wire extensions, microcontroller, and breadboard secured to the underside of the shelf where they were easily accessible through the back door of the case. A spray adhesive was used on the white face of the back plate of the box, and the “Trojan Women 2.0” poster was successfully adhered. The three-face Plexiglas configuration was set into the box and rested on the mounts in each of the four corners of the box interior. Two light flutes were hot glued into the interior corners of the box with their power buttons facing the top of the box so that the stage crew could more easily turn them on and off during the show run time. Each LED flute had a pronounced beam of light that was crossed from the corner it was mounted in, to the diagonally opposing corner so as to provide an intriguing array of shadows on the back of the case when the robot gestured. Finally, the Plexiglas lid of the box was set in place and taped down with white Gaffers tape to secure it. The white tape was also used around the rest of the Plexiglas to create a frame around the display and to hide the existence of the light flutes so that the magic of the system was further emphasized.
CONCLUSION

The final product met the needs of the customer, Josh Machamer, largely by falling within the size restrictions, being easily relocated by the stage crewmembers, and most importantly, by following a cohesive set design of the production. The robotic character gestured on a loop for 30 minutes prior to the show start time for three consecutive nights and two consecutive weekends during the production run time. Hundreds of guests became audience members to this shock theater production of “Trojan Women 2.0” and each of those guests were able to see an affective implementation of interdisciplinary conceptual design and engineering. The final product combination of the robotic human character and the display case met all constraints outlined in the original needs analysis and customer requirements list, as well as the objectives desired for final design. The main objective of this senior design project for the Liberal Arts and Engineering Studies major was to learn how to program a microcontroller to send commands to a servo for controlling an animatronic character; this main objective was successfully fulfilled. The opportunity to contract with students and faculty of the Theater department, which varies substantially from the Engineering departments at Cal Poly, provided insight for future involvement in the entertainment industry. It was beneficial as well, to be exposed to the timeline of a theater production from concept to final critique and how to relate an engineering design project into the field of theater that requires technology to seem more magical than real and existing. The success of this final product will stand as an example to future students who desire to forge a path into the animatronics industry. A leap pad into future technologies for students who pass through Cal Poly, San Luis Obispo is the ideal outcome of this Animatronic design and implementation.
BIBLIOGRAPHY


APPENDIX A: SERVO SPECIFICATIONS

From the Parallax Standard Servo Specifications Sheet,

The Parallax Standard Servo provides 180° range of motion and position control to a project.

Features

- Holds any position between 0 and 180 degrees
- 38 oz.-in torque at 6 VDC
- Accepts four mounting screws
- Easy to interface with any Parallax microcontroller or PWM-capable device
- Simple to control with the PULSOUT command in PBASIC
- High-precision gear made of POM (polyacetal) resin makes for smooth operation with no backlash
- Weighs only 1.55 oz. (44 g)

Key Specifications

- Power requirements: 4 to 6 VDC*; Maximum current draw is 140 +/- 50 mA at 6 VDC when operating in no load conditions, 15 mA when in static state
- Communication: Pulse-width modulation, 0.75–2.25 ms high pulse, 20 ms intervals
- Dimensions approx. 2.2 x 0.8 x 1.6 in (5.58 x 1.9 x 40.6 cm) excluding servo horn
- Operating temperature range: 14 to 122 °F (-10 to +50 °C)

<table>
<thead>
<tr>
<th>Pin</th>
<th>Name</th>
<th>Description</th>
<th>Minimum (V)</th>
<th>Typical (V)</th>
<th>Maximum (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (White)</td>
<td>Signal</td>
<td>Input Command</td>
<td>3.3</td>
<td>5.0</td>
<td>Vservo + 0.2</td>
</tr>
<tr>
<td>2 (Red)</td>
<td>Vservo</td>
<td>Power Supply</td>
<td>4.0</td>
<td>5.0</td>
<td>6.0</td>
</tr>
<tr>
<td>3 (Black)</td>
<td>Vss</td>
<td>Ground</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Power Precautions

- Do not use this servo with an unregulated wall-mount supply. Such power supplies may deliver variable voltage far above the stated voltage.
- Do not power this servo through the BASIC Stamp Module's Vdd pin.
Figure 6. Example of PWM output, voltage is high (or on) for 1.5ms and low (or off) for 20 ms so that the servo is only undergoing rotational motion for the 1.5ms increments.
APPENDIX B: PROGRAMMING IN ARDUINO

Language is a modification of C programming.

Code Function: Loads servo as a motor pin connected to pulse width modulation (pwm) lines (3,4,6,9,10,11) on the Arduino Uno Microcontroller. The servo is given voltage via the computer via USB cord or via external 5V power source. The microcontroller is also given a time to travel (rotate) before stopping, turning the opposite direction, and returning to zero degrees of rotation from the initial position.

LEARNING SERVO LIBRARY FUNCTIONS

To call a function from an Arduino library:

Library Name Desired Function
Servo.write(1);

Angle

Ex: Library Function
Servo.attach(9);
Pin # slot on microcontroller board

Ex: servo.attach(pin,min,max)
Where pin is the slot number the servo is wired into
Min: pulse width (µs) that correspond to the minimum (0°) angle on the servo (servo library defaults to 544µs)
Max: pulse width (µs) that corresponds to the maximum (180°) angle on the servo (servo library defaults to 2400µs)

2400µs = 180° of physical location of servo rotation capabilities
1744 µs = 90°
544 µs = 0° of physical location of servo rotation (position)

{Every time value between 544 and 2400 µs will correspond to a single position of degree rotation.}

Ex: \[
\frac{2400\mu s}{180°} \cdot \frac{x}{47°} = 626.67 \mu s
\]

However, we assume 544 µs is 0°, not 0 µs so,

\[
\frac{2400\mu s}{180°} \cdot \frac{(x-544)\mu s}{47°} = 1171 \mu s = 47° ALWAYS.
\]

Meaning…
If a servo is at 15°, and a 1171 µs command is given, the servo will not add 47° to its current 15° location, but will instead move to 47° relative to 0° position.

LEARNING ARRAY PROGRAMMING

0 is the first index number in an array
An array with 10 elements will have elements 0 through 9.

Ex: myArray[10] = {9,3,2,4,3,2,7,8,9,11};
# of elements Data value in each element
myArray[9] accesses the data stored in the tenth element of the array, this data is the data value “11.”
#include <Servo.h>  //include the servo library

//Define pins
Servo rtshoulderxaxis;  //defines servo object "right shoulder joint" on xaxis (line of action through shoulders)
Servo rtshoulderzaxis;  //defines servo object that rotates right arm about the zaxis (out from the body i.e. waving arm)
Servo rtelbow;  //defines servo object as "right elbow joint"
Servo ltshoulderxaxis;
Servo ltshoulderzaxis;
Servo ltelbow;
Servo neck;

const int SWITCH = 13;  //defines on/off switch object in pin 13
int timer = 40;  //defines integer of time delay between steps in milliseconds
const int NumberofServos = 7;  //defines the total number of servos in the show
const int NumberofSteps = 56;  //defines the total number of steps in the show

/*
 * define matrix. 5 rows (steps of action) and 6 columns (servos)
 * define matrix. 5 rows (steps of action) and 6 columns (servos)
 */

int ShowMatrix[NumberofSteps][NumberofServos] = {
    //defines a matrix for the servos to run during the show.
    //values for rtshoulderxaxis are in column 1, rtshoulderzaxis in column 2,
    //rtelbow in column 3. each value is a desired servo position defined as a number of degrees from 0
    //arm straight down at side
    {40, 115, 120, 110, 50, 30, 80},  //arm straight down at side
    {120, 115, 130, 30, 50, 20, 80},  //arm straight out front (zombie)
    {170, 100, 80, 0, 35, 110, 80},  //arm straight up (as much as it can be)
    {120, 20, 120, 40, 70, 20, 60},  //straight out to side (bike turn signal)
    {120, 25, 100, 60, 70, 20, 60},  //gesture in front with arms bent
    {120, 25, 100, 60, 70, 20, 100},  //gesture in front with arms bent
    {120, 25, 100, 60, 70, 20, 100},  //gesture in front with arms bent
    {40, 90, 20, 85, 65, 105, 90},  //gesture in front with arms bent (rt is good). It is good.
    {60, 55, 0, 90, 70, 170, 80},  //arms out welcoming
    {60, 90, 70, 90, 80, 100, 60},  //arms out welcoming
    {60, 90, 70, 90, 80, 100, 70},  //arms out welcoming
    {60, 90, 70, 90, 80, 100, 80},  //arms out welcoming
    {60, 90, 70, 90, 80, 100, 90},  //arms out welcoming
    {60, 90, 70, 90, 80, 100, 100},  //arms out welcoming
    {60, 90, 70, 90, 80, 100, 110},  //arms out welcoming
    {60, 90, 70, 90, 80, 100, 100},  //arms out welcoming
    {60, 90, 70, 90, 80, 100, 90},  //arms out welcoming
    {60, 90, 70, 90, 80, 100, 89},  //arms out welcoming
    {60, 55, 0, 90, 70, 170, 85},  //arms re-bent over chest
    {60, 55, 0, 90, 70, 170, 85},  //arms re-bent over chest
    {60, 75, 0, 90, 55, 170, 80},  //both arms out, equally bent
    {80, 20, 75, 145, 70, 120, 75},  //one arm (rt arm) gesture out, left arm bent and back
    {80, 20, 75, 145, 70, 120, 75},  //one arm (rt arm) gesture out, left arm bent and back
    {80, 20, 75, 145, 70, 120, 72},  //one arm (rt arm) gesture out, left arm bent and back
    {80, 20, 75, 145, 70, 120, 72},  //one arm (rt arm) gesture out, left arm bent and back
    {80, 20, 75, 145, 70, 120, 75},  //one arm (rt arm) gesture out, left arm bent and back
    {80, 20, 75, 145, 70, 120, 75},  //one arm (rt arm) gesture out, left arm bent and back
    {80, 20, 75, 145, 70, 120, 80},  //both arms out, equally bent
    {60, 90, 70, 90, 90, 100, 90},  //one arm (rt arm) gesture out, left arm bent and back
    {50, 90, 30, 105, 40, 165, 15},  //left arm cocked back at side, right arm gesturing bent forward
    {50, 90, 30, 105, 40, 165, 15},  //left arm cocked back at side, right arm gesturing bent forward
    {40, 90, 20, 80, 85, 65, 120},  //both arms out, equally bent
    {120, 20, 120, 70, 150, 20, 120},  //glitching begins here
    {25, 100, 40, 90, 90, 70, 125},  //glitching begins here
    {32, 85, 15, 85, 35, 65, 0},  //left arm straight, crosses across body. right arm locked in L position
    {27, 90, 20, 80, 25, 75, 30},  //left arm straight, crosses across body. right arm locked in L position
    {30, 105, 40, 90, 30, 60, 45},  //repeat original twitch position
    {25, 95, 30, 75, 20, 70, 110},  //repeat original twitch position
    {35, 90, 35, 85, 30, 80, 180},  //repeat original twitch position
    {25, 100, 10, 90, 25, 70, 165},  //left arm cocked back at side, right arm gesturing bent forward
    {32, 85, 15, 85, 35, 65, 80},  //left arm cocked back at side, right arm gesturing bent forward
    {27, 90, 20, 80, 25, 75, 100},  //left arm straight, crosses across body. right arm locked in L position
    {30, 105, 40, 90, 30, 60, 90},  //left arm straight, crosses across body. right arm locked in L position
    {27, 90, 20, 80, 25, 75, 30},  //left arm straight, crosses across body. right arm locked in L position
    {30, 105, 40, 90, 30, 60, 45},  //repeat original twitch position
    {25, 95, 30, 75, 20, 70, 110},  //repeat original twitch position
    {35, 90, 35, 85, 30, 80, 180},  //repeat original twitch position
    {25, 100, 10, 90, 25, 70, 165},  //left arm cocked back at side, right arm gesturing bent forward
    {32, 85, 15, 85, 35, 65, 80},  //left arm cocked back at side, right arm gesturing bent forward
};
int BlendMatrix[3][NumberofServos] = {
    {110, 15, 15, 140, 180, 140, 80}, //This row defines where we currently are
    {0, 0, 0, 0, 0, 0, 0}, //This row defines where we want to go
    {0, 0, 0, 0, 0, 0, 0}  //This row defines how large the steps will be to take us from where we are to where we want to go
};

Servo ChannelMatrix[NumberofServos] =
{rtshoulderxaxis, rtshoulderzaxis, rtelbow, ltshoulderxaxis, ltshoulderzaxis, ltelbow, neck}; //calls out channels rtelbow from pin 2 and rtshoulder from pin 3 relative to columns in showMatrix

Servo ChannelMatrix[NumberofServos] =
{rtshoulderxaxis, rtshoulderzaxis, rtelbow, ltshoulderxaxis, ltshoulderzaxis, ltelbow, neck}; //calls out channels rtelbow from pin 2 and rtshoulder from pin 3 relative to columns in showMatrix

void setup(){
    rtshoulderxaxis.attach(3); //attach the right shoulder servo to pin 3 on the board
    rtshoulderxaxis.write(110); //tells the right shoulder servo to move to 15 degrees from 0
    rtshoulderzaxis.attach(4); //attach the right shoulder servo to pin 4 on the board
    rtshoulderzaxis.write(15); //tells the right shoulder servo to move to 15 degrees from 0
    rtelbow.attach(5); //attach the right elbow servo to pin 5 on the board
    rtelbow.write(15); //tells the right elbow servo to move to 15 degrees from 0
    ltshoulderxaxis.attach(6); //attach the right elbow servo to pin 6 on the board
    ltshoulderxaxis.write(140); //tells the right elbow servo to move to 15 degrees from 0
    ltshoulderzaxis.attach(7); //attach the right elbow servo to pin 7 on the board
    ltshoulderzaxis.write(180); //tells the right elbow servo to move to 15 degrees from 0
    ltelbow.attach(8); //attach the right elbow servo to pin 8 on the board
    ltelbow.write(140); //tells the right elbow servo to move to 15 degrees from 0
    neck.attach(10); //attach the neck servo to pin 9 on the board
    neck.write(80); //tells the neck servo to move to 5 degrees from 0
    pinMode(SWITCH, INPUT); //defines the mode output/input of the digital pin, in this case, that the switch is located in pin13 and it gives an input signal to the arduino
    //servos do not need to be defined as output object because this feature is embedded in the servo.attach function of the servo library
}

void loop(){
    int switch_status = digitalRead(SWITCH); //creates an integer command that reads from the digital port that the switch is connected to so that 1 can be used to symbolize "ON"
    if (switch_status == 1) {
        int stepnumber = 0;
        for (int p = 0; p < NumberofServos; p++){
            BlendMatrix[1][p] = ShowMatrix[i][p]; //Pulls the next set of "master steps" from the ShowMatrix that will be blended too
        }
        for (int j = 0; j < NumberofServos; j++){
            int x = 0;
            int y = 0;
            x = BlendMatrix[1][j] - BlendMatrix[0][j];
            if (x < 0){
```c
int h = 0; h < NumberofServos; h++;
    BlendMatrix[2][h] = (BlendMatrix[1][h] - BlendMatrix[0][h]) / stepnumber; //Stores values into the last row of the BlendMatrix which are the step size
}
```

```c
for (int k = 0; k < stepnumber; k++){
    for (int m = 0; m < NumberofServos; m++){
        ChannelMatrix[m].write(BlendMatrix[0][m]);
        BlendMatrix[0][m] = BlendMatrix[0][m] + BlendMatrix[2][m];
    }
    Servo.Write commands
    delay(timer);
}
```

```c
else {
    the SWITCH does NOT equal 1, a.k.a. it =0, do nothing.
}
```