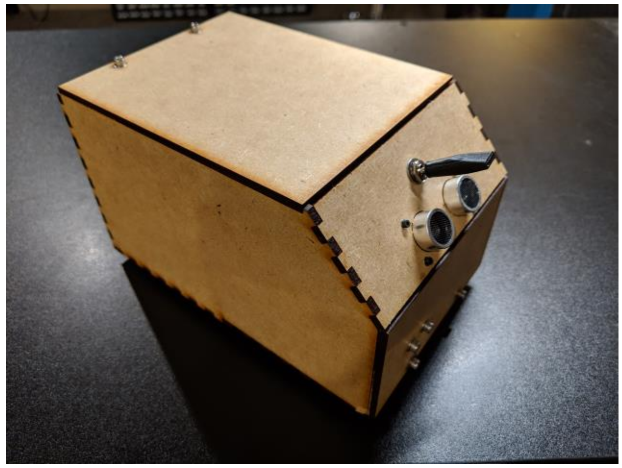

Exceptionally Useless Box

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Summary of Project

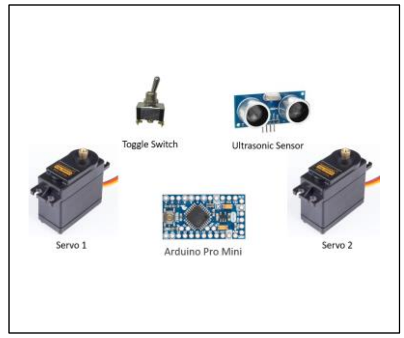
There is a novelty toy called a “useless box” where a box features a mounted switch that the user toggles. Upon toggling the switch, something comes out of the box to toggle the switch back to the original position. The goal of this project was to make an *exceptionally* useless box. In order to do this, the user should not even get to toggle the switch in the first place. Therefore, the box needed to watch for the user’s hand approaching and preemptively toggle the switch when the hand gets close enough followed by the usual sequence of resetting the switch as in the original useless box design.

To detect the hand, the device features an ultrasonic sensor connected to an Arduino Pro Mini. The microcontroller uses this input as a way to detect the proximity of the hand and translate that distance into rotating a servo. In doing this, the servo motion “follows” the hand as it approaches or backs off. Connected to this servo is an arm made up of a 5-bar linkage that when fully extended can toggle the switch and similarly fully retract into the box. A second servo with another arm serves the purpose of resetting the toggle switch once it has been engaged by the other arm.

The team hoped that such a simple concept would leave plenty of time to execute and perfect complete mechanical and electrical designs with well-performing code. Unfortunately, with the complexity involved in the 5-bar linkages, iterating the mechanical design took a large portion of the semester. Since the mechanical design needed to be complete before tuning the coding, the performance of the device was not able to be honed. However, the device in its present state meets our expectations in its functionality and aesthetic appearance. Early on in the project, having the motion of the servo follow the distance measurements made by the sensor was intended to be controlled with PID. Currently, this function is performed instead by a mapping function and rolling average filter. Future testing will be performed to implement PID control for much faster response and a reduction in the jittery motion sometimes brought on by the sensor. Lastly, it would be ideal to make a circuit board to get rid of the breadboard electronics which will reduce the amount of wiring inside the device and thus reducing noise in the system.

Table of Contents

1 Component Validation



Component selection was straightforward in that they were already defined when the concept of the project was determined. It was known that two servos, one ultrasonic sensor, a toggle switch, microcontroller, power switch, and batteries would be necessary. An Arduino Pro Mini was chosen for the microcontroller since it was on hand through the lab materials of the MECH-457 course. The ultrasonic sensor that was selected was an HC-SR04 module, which are plentiful and cheap, and were curated through Amazon. The power switch and battery packs (for AA batteries) were already on hand and were used for the project. These components worked well and were used in the final project.

Originally, an SG90 micro servo was used in the design to drive the arms due to their small size. This proved to be a mistake as it not only had too low of torque, but the nylon servo horns that it came with were difficult to join the arms to. After observing this, larger servo motors were ordered that included standard teeth (25T) for the servo horn. These motors had 15 times the amount of torque that the micro servos had, so was clear that that problem would be solved. Because of the 25T tooth profile on the servo meant that a special, metal servo horns could be used to join the arms using threaded holes in the horn. This ended up being the perfect solution for converting the torque of the motor to the arms.

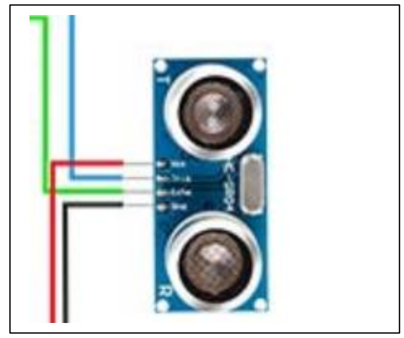
On the subject of torque, a larger toggle switch was originally purchased for having a longer lever to solve some clearance issues in the kinematics of the arms. Unfortunately, the force required to flip the toggle switch was very high and the housing behind the lever of the switch (the part that is hidden inside the enclosure) was too bulky and caused many different clearance issues. A mini toggle switch was then purchased which had a lower force to flip and was much smaller in size. A 3d printed part was designed to slip onto the lever for increasing the length of the lever as well, which lowered the force needed to toggle the switch even further.

The enclosure was intended to be laser cut from 0.125” material and would be appropriate regardless of the type of material (that can be cut with a low power laser) since the joints would be bolted connections and finger joints with an adhesive. For this project, MDF was used because it was low in cost and easy to cut on the laser with reliable, flat surfaces that did not warp during the manufacturing process. However, Delrin was used for the linkages for their high strength and rigidity. Delrin also cuts well on the laser, but with larger parts, it can have some warping. This was not an issue, however, since the linkages were quite small.

The mounts of the servo motors and arm were originally made from MDF, but after prototyping, it was obvious that it would not be rigid enough, so Delrin was also used for these parts as well. The pins that were used for joining the arm linkages were machined from 1/8" stainless rod stock since they were non-standard lengths. Retaining the linkages on the pins were friction-based snap ring clips, which allowed for adjustment in the amount of play between the linkages. Another benefit to using Delrin for the linkages was the material's low coefficient of friction, which kept the linkages from binding throughout their motion.

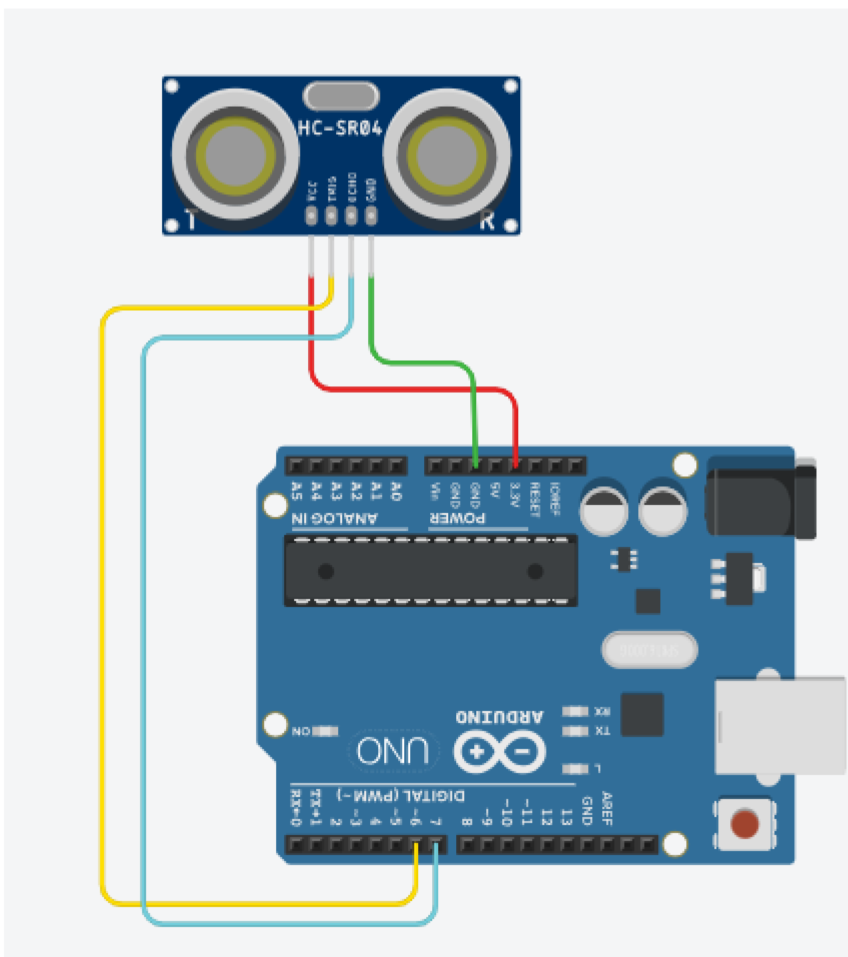
All fasteners involved in the project were determined during the modeling process and ordered from McMaster-Carr when the design was ready. Finally, piano hinge material was used to join the top and front "doors" to the enclosure.

2 Sensor Wiring



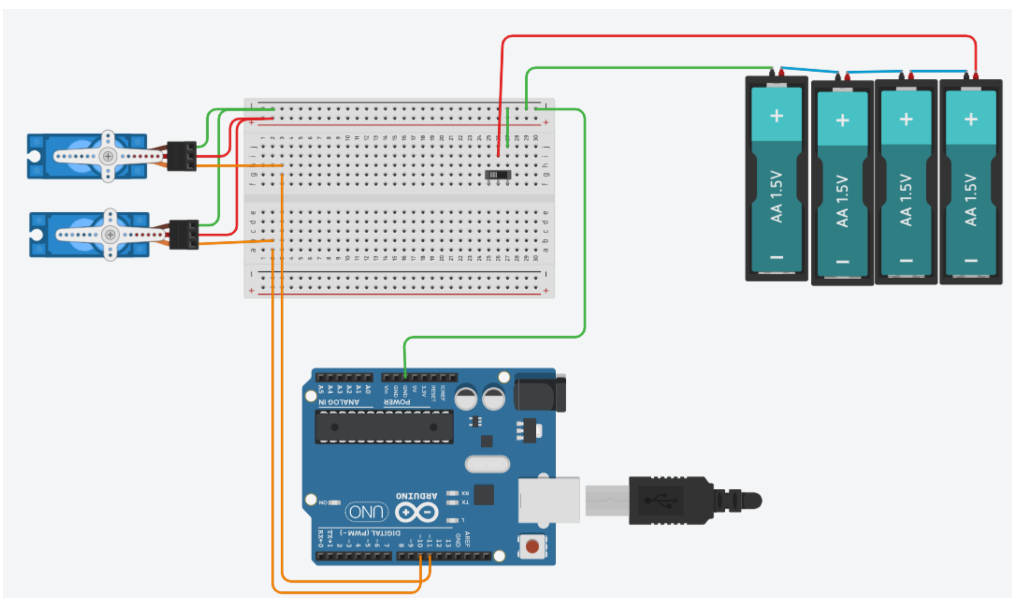
Wiring an ultrasonic sensor is straightforward and is made even easier with a datasheet provided by the manufacturer. There are 4 pins: input voltage (VCC), ground (GND), trigger (TRIG), and echo (ECHO). Voltage from the “RAW” pin of the microcontroller was connected to VCC. GND on the sensor was connected to the GND of the microcontroller. TRIG and ECHO pins needed to be connected to any digital pin, which for this project were pins 6 and 7, respectively.

Most manufacturers of the HC-SR04 also provide the equation that is needed to calculate the distance from the readings of the sensor. So, it was not necessary to determine this ourselves.



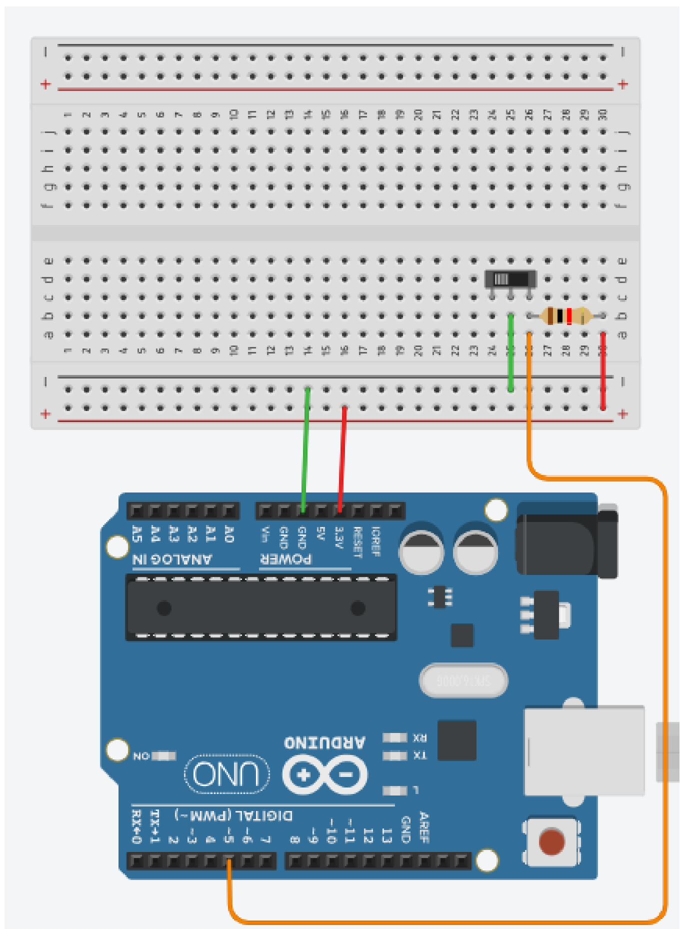
3 Servo Wiring

Servos typically have just three leads to connect; input voltage, ground, and signal. The respective wires will vary from motor to motor, so consulting the datasheet was be necessary to determine which lead is what. For this project, the red wire was Vin, the brown wire was GND, and the yellow wire was signal. It was important to connect the Vin and GND wires to a *separate* power supply than the one that powers the microcontroller. This avoided frustrating noise issues that are difficult to troubleshoot. The magnitude of the input voltage also varies from motor to motor and must be sought out from the datasheet. For this motor, 6V were required with up to 2A of current. So, a battery pack with four AA batteries connected in series were connected to the Vin and GND wires of the servo motors. The signal pins for each motor were then connected to a PWM-enabled digital pin on the microcontroller (pin 10 for the bottom arm servo, pin 11 for the top arm servo). A rocker switch was also connected between the series circuit of the batteries and servos to control when the motors were given power.

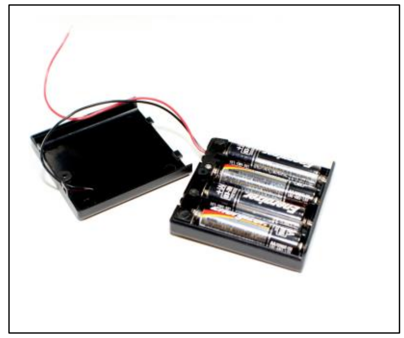


4 Toggle Switch Wiring

The toggle switch that was to be flipped back and forth by the device was connected from a digital pin (pin 5 for this project) to the GND pin of the microcontroller. Since the switch would be normally open, a pull-up resistor was required from the digital pin to the 3.3V output of the microcontroller. The value of this resistor was mostly arbitrary barring abnormally high or low resistances. A 10 kΩ resistor was used for this project.

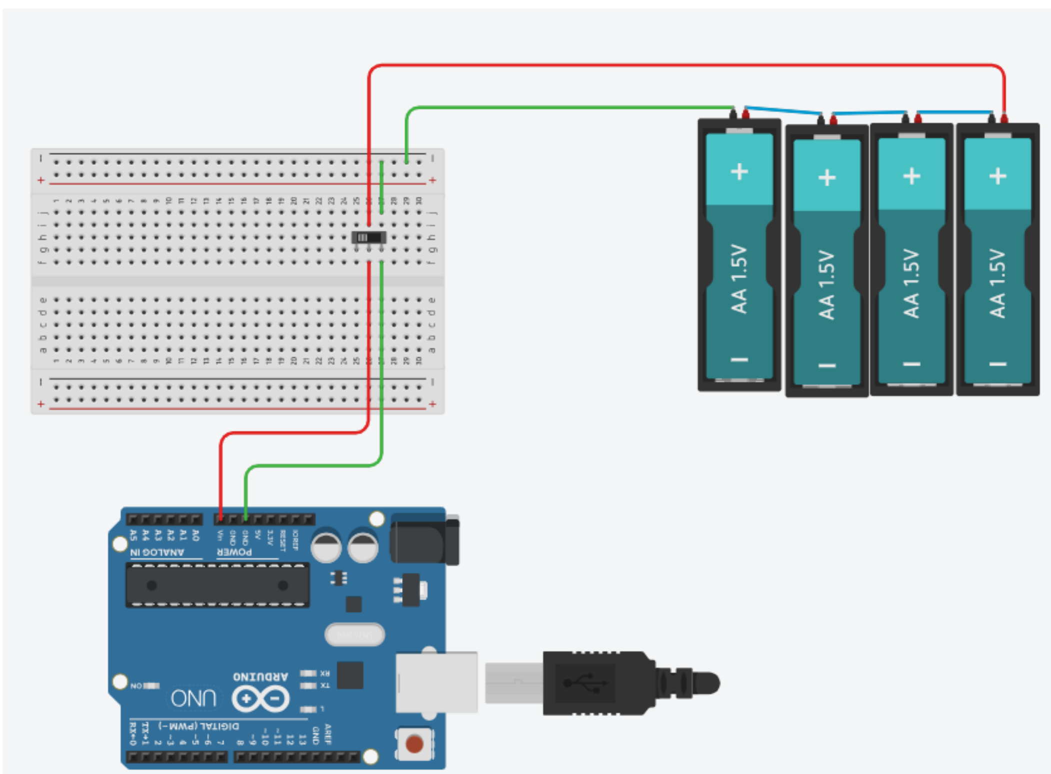


5 Microcontroller Power Wiring

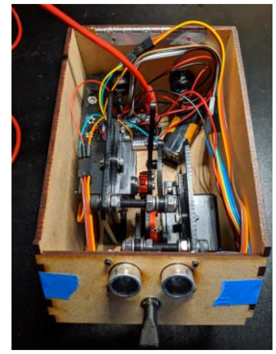


The microcontroller needed to be supplied with a *separate* power supply from the servo motors as indicated in step 4. From the datasheet, the input voltage for the microcontroller would need be from 3.3V to 12V. So, another 4 AA batteries were placed into a battery pack whose leads were then connected to the RAW pin (positive side of battery terminals) and GND pin of the microcontroller.

As was done before, another switch was placed between the positive lead of the battery pack and the RAW pin. This would allow for independent power cycling of the microcontroller and sensor so that the device could be unpowered when not in use. It was also useful to be able to power the microcontroller without the servos activated so that if code that was previously uploaded and caused crashes, it could be safely rectified.



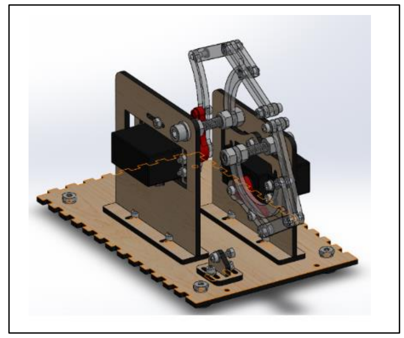
6 Electronics Testing



With the electronics connected, they were tested before assembling into the enclosure itself. Prototyped code was uploaded to the microcontroller using the Arduino IDE. It was important to ensure that the correct processor is selected before uploading. This caused for some headache when initially working with this board. For this project, we used the 3.3V 8 MHz version of the Arduino Pro Mini.

With the code uploaded, we pointed the sensor in a direction with a lot of space. Some noise was heard from the servos when the program loads, indicating that they were energized. Then, a hand was placed in front of and a couple feet from the sensor and slowly approached the sensor. The bottom then rotated as the hand became closer to the sensor. When the hand was close enough, the servo suddenly moved, and both servos remained still thereafter. After flipping the switch one direction, the other (top) servo was observed rotating. After flipping the switch in the other direction, the top servo rotated once again. Finally, the bottom servo was again responding to input from the ultrasonic sensor.

7 Mechanical Design



The most difficult part of the design in this project was being able to fit the servos as close to the switch as possible. Because the arms needed to contact the switch directly in line (such that they were both rotating or moving in the same plane), both servos could not be positioned in the same place with respect to the switch. To avoid this headache, one could simply position them in the same place yet separated along their axes of rotation far enough away to give clearance for the arms and at the end of either arm, a perpendicular piece to contact the switch lever with could be added. However, this would add a much larger torque to the linkages and rigidity issues will have arisen when attempting to make such a small form factor. It is this fact that there were two servos instead of one that made this project exceptionally challenging.

The mechanical design was begun by modeling the switch and fixing it in a position that was indicative to where it will be in the final design. Using circles as guides, the best combinations of lengths for the 5-bar linkage were experimentally determined until the end of the arm that meets the switch could fully retract into what would be the enclosure as well as extending a good amount of distance *past* the toggle switch so that flexure in the parts could be compensated for. This was where most of the time was spent in the design. It was important to give plenty of room for everything. The more that the size of the enclosure was limited, the more difficulty there was in designing the linkages. This process was done for the bottom arm only. The top arm was dependent on the physical size and shape of the bottom arm and required its complete model before designing the top arm linkage.

With the bottom linkage prepared, a mount that can hold the servo with adjustability in the translation of the servo in all three axes was modeled. Doing this allowed for adjustability in the actual prototype to make up for defects and ended up being extremely useful. The mount itself was the ground for the 5-bar linkage and allowed for adjustability in the positions of the two ground points with respect to one another. The mount was designed for rigidity where possible, knowing that a torque will be placed on the ground points.

Once an adjustable servo mount had been designed, the enclosure was modeled for affixing the mount, toggle switch, and ultrasonic sensor. The sensor needed to be positioned so that it is pointed where the user would be. It was important to not let the arms interfere with the sensor measurements as well. One thing that was not accounted for in our design was an angular adjustability in the ultrasonic sensor. While a 45 degree angle with respect to the surface that the device rested on worked, a lower angle would have resulted in better distance measurements since the hand tends to approach the device from an angle more directly in front of it, rather than above.

With the sensor and bottom servo arm mechanism mounted and fixed in place, the top arm to toggle the switch back was designed using the same procedure as was done with the bottom arm. It was critical to keep track of where the bottom arm will be during all points of its rotation so that the top arm can always perform without interference. A lot of time was spent here as well since the clearances for everything were very difficult to determine until complete models were made whose motions could be observed in an assembly to inspect for flaws.

Some way to retract the front door was also necessary. A tension spring was used for this project, but a torsion spring could have been used, but it was more trivial to find joinery that would easily accommodate the tension spring. The top door automatically closed by virtue of its own weight, so a return mechanism was not needed. A way to join the hinges to the enclosure and both doors was also be necessary. For this project, holes were drilled in the hinges and then bolted to their respective pieces. Modeling was also necessary for this feature as well because slots in the enclosure parts were needed for bolt clearances that accommodated some tolerancing in the hinge’s position.

When designing the enclosure, enough room was needed to be made for not only the servo arm subassemblies, but also for the electronics. Room was accommodated for a mini breadboard with 2 battery packs and means for mounting the two power switches. Lastly, this project did not include an access panel for changing batteries, but would have been beneficial to include for the lifetime of the product when battery changes were needed.

Since the majority of the mechanical parts were to be laser cut, it was extremely useful to have the entire product modeled (excepting the microcontroller, breadboard, and wiring). In doing this, changes to the design could quickly be made, verified, exported to a laser job file, and fabricated. Modeling in this way was most likely critical to the success of this design because of the amount of iteration that was involved in prototyping.

When the parts were completely modeled, the prototype was assembled without the front and top doors attached. Some simple code to extend and retract each arm one by one was uploaded. While observing the motion of the links, adjustments were made to the servo mounts positions with respect to the toggle switch until both arms were reliably toggling the switch lever. At the same time, the exact angle limits of each servo were experimentally determined by adjusting their values in the code. When it was confirmed that the arms were completely retracted without striking each other and that both arms could flip the toggle switch, the doors were assembled and the hinges adjusted to allow the doors to completely close without interference. Similarly, tension on the spring of the return mechanism for the front door was adjusted by sliding the spring’s mounting point further away so that the front door would completely close.

8 Finished Project