May-1414

Kinetic Sculpture - The Butterfly Wall

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Contents

Introduction

Project Description

Inside the San Francisco International Airport is an interactive piece of artwork known as *The Butterfly Wall*. It allows users to control the motion of mechanical butterflies using hand cranks located on the outside of the display. For this project, we will be designing a web interface and an electrical control system for a smaller version of *The Butterfly Wall,* to be displayed in Coover Hall upon completion. Our finished design will allow users to control the motion of the mechanical butterflies by opening a mobile website, which we will design. We will also design a system to process the user supplied input, and control a series of stepper motors and LEDs based on that input. Our final design will accommodate four mechanical butterflies, which will each have its own LED grid.

Deliverables

In December of 2013, we will have finished our design work and assembled one complete butterfly prototype. We will deliver a fully integrated communications network that will allow us to completely test one-fourth of the final project. We will also develop a presentation to provide an update on our progress and designs.

In May of 2014, we will complete our project. We will make any necessary amendments to the design from December, we will assemble four implementations of it, and we will integrate the communications network. We will also build a display enclosure to house our finished product.

Requirements

System Requirement Specifications (SyRS)

List of high level system requirements.

1. Smart phone control
    a. Butterfly shall react to user input via a mobile website accessible by smartphone
2. System timeout
    a. If a preset idle timer expires, the butterfly and LED's shall act according to a preset routine
3. LED display
    a. Twenty-four LEDs per butterfly shall create a light display that corresponds but is not directly controlled by the user input
4. Butterfly
    a. The butterfly shall be suspended on a wire
    b. The wire shall allow movement of the butterfly
5. Collision avoidance
    a. The butterfly shall not be able to collide with the top or bottom of the enclosure
    b. The butterfly shall not collide with any other butterflies in the enclosure

Functional Requirement Specifications (FRS)

List of technical requirements.

1. Mobile access
    a. To satisfy SyRS-1, a mobile user interface shall be available
    b. The mobile interface shall be accessible by up to 4 simultaneous users
    c. The mobile interface shall be cross-platform and accessible by most smartphones
2. Controller
    a. To satisfy SyRS-1, a controller shall be used to process input from the mobile interface
    b. To satisfy SyRS-2, the controller shall provide a predetermined input in the case of an idle timeout
    c. To satisfy SyRS-3, the controller shall have pulse-width modulation capability
3. Butterfly movement
    a. To satisfy SyRS-4, a motor shall spin a loop of wire, moving the butterfly up or down, in accordance with the user input
    b. The wire shall be seamless to ensure the wire does not get tangled in the pulleys
    c. To satisfy SyRS-5b, the stepper motors shall be separated by enough space to eliminate the possibility for butterfly collisions
4. Proximity sensor

    a. To satisfy SyRS-5a, a proximity sensor at the top and bottom of the enclosure will alert the controller of an impending collision so that the microcontroller can modify the butterfly's motion to avert the collision

Non-Functional Requirement Specifications (NFRS)

List of miscellaneous requirements.

1. Enclosure
    a. Enclosure shall be 4ft long by 1ft wide by 8ft high
    b. Enclosure shall be of clear plexiglass
    c. Plexiglass shall be joined with aluminum extrusions
    d. A QR code shall be on the exterior of the enclosure to take users to the mobile interface
    e. Enclosure shall have a void for a power cable to enter the system
    f. All components shall be inside the enclosure and secured in a manner which will allow the enclosure to be moved easily
2. Butterfly
    a. Butterfly shall be clear plexiglass
    b. Butterfly wings shall flap to emulate flying at a rate proportional to the vertical movement
3. Aesthetics
    a. The hardware required to implement the System Level Requirements shall be exposed in the final design
    b. The hardware shall be installed in a neat, professional, and aesthetically pleasing manner

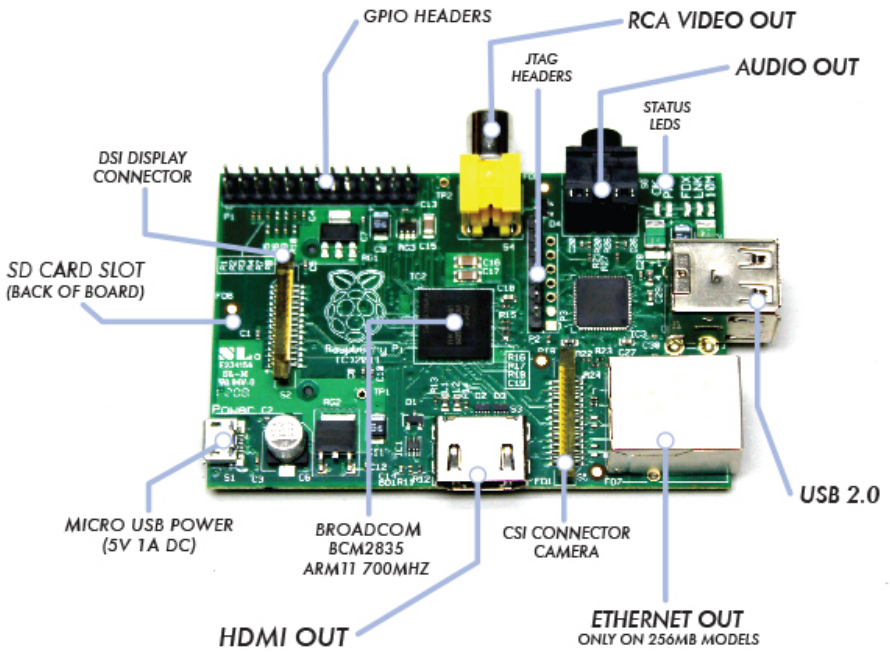
Hardware

Hardware Decomposition

This section should contain detailed descriptions for each component we are using. Summarize the whitesheet, include all I/O pins, ect. Use heading 3 for each component name.

Raspberry Pi

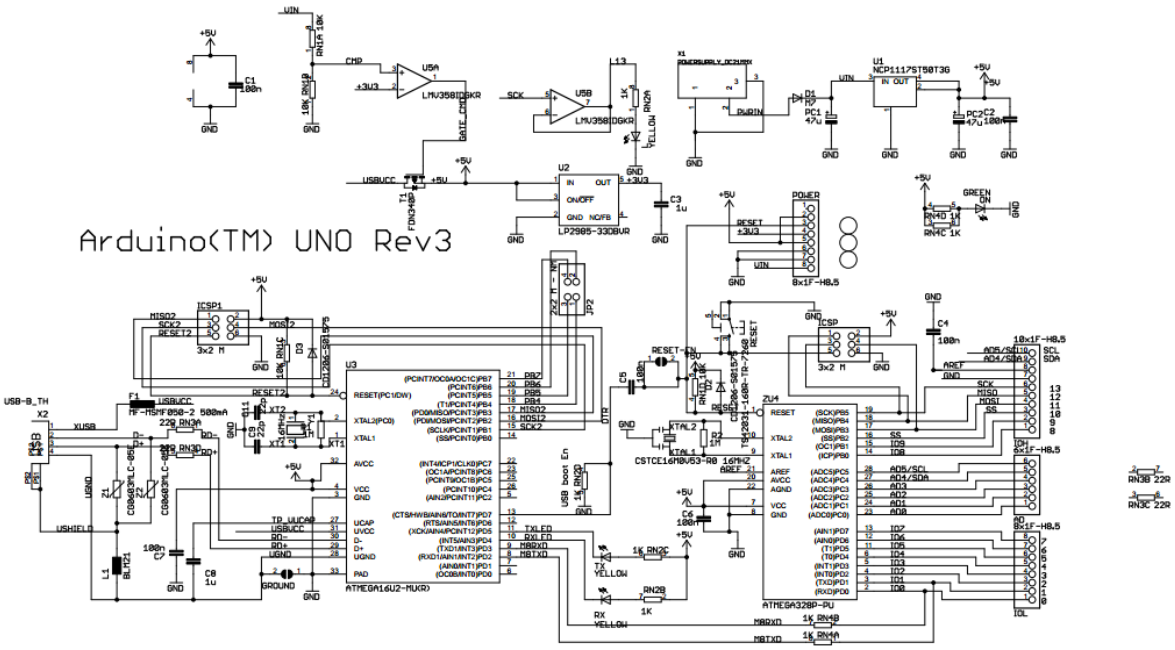
This platform was chosen to host the web server because of its size, cost, portability, and power. The Raspberry Pi model B boasts 512MB SDRAM, 2 USB 2.0 ports, 700 MHz ARM1176JZF-S core processor, and an onboard 10/100 ethernet adapter. The Raspberry Pi is able to offer all of these features, capable of running a web server, at a cost of only $35.



3.3V	1	2	5V
I2C1 SDA	3	4	5V
I2C1 SCL	5	6	GROUND
GPIO4	7	8	UART TXD
GROUND		10	UART RXD
GPIO 17	11	12	GPIO 18
GPIO 27	13	14	GROUND
GPIO 22	15	16	GPIO 23
3.3V	17	18	GPIO 24
SP10 MOSI	19	20	GROUND
SP10 MISO	21	22	GPIO 25
SP10 SCLK	23	24	SP10 CE0 N
GROUND	25	26	SP10 CE1 N

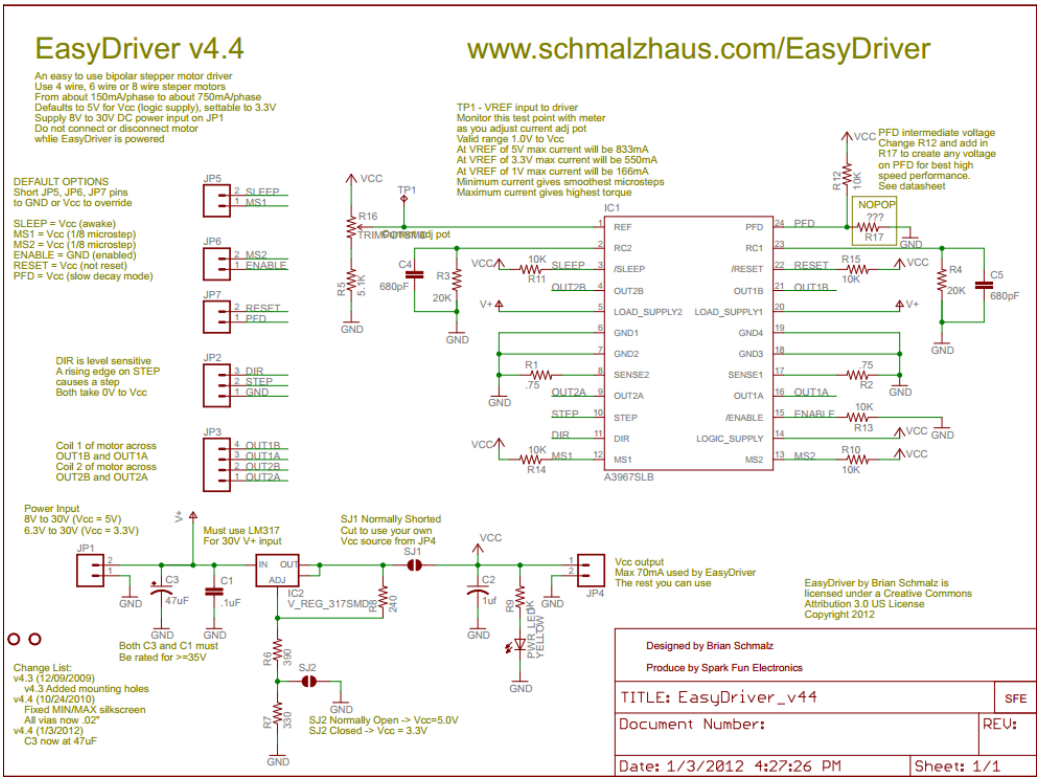
Arduino Uno Microcontroller

The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins(6 of which can be used as PWM outputs), 6 analog inputs, and a 16 Mhz ceramic resonator. The image below shows the schematic for the Arduino Uno Microcontroller.

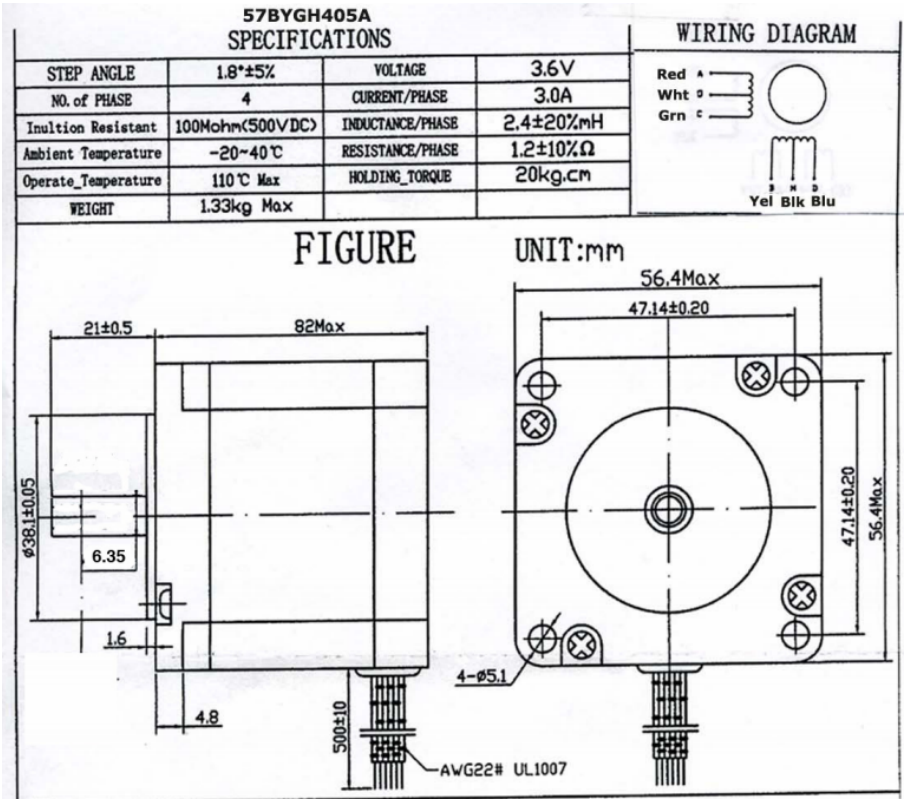


Stepper motor driver (easy driver)

The EasyDriver is a stepper motor driver that is compatible with anything that can output a digital 0 to 5V pulse. It requires a 7-30V DC power supply to power the motor and has an on board voltage regulator for the digital interface which can be set to 5V or 3.3V. Features include: a A3967 microstepping driver, MS1 and MS2 pins enable adjusting of microstepping resolution, compatible with 4, 6 , and 8 wire stepper motors, adjustable current control from 150mA/phase to 750mA/phase. The image below shows the schematic for the driver.



NEMA-23 Stepper Motor



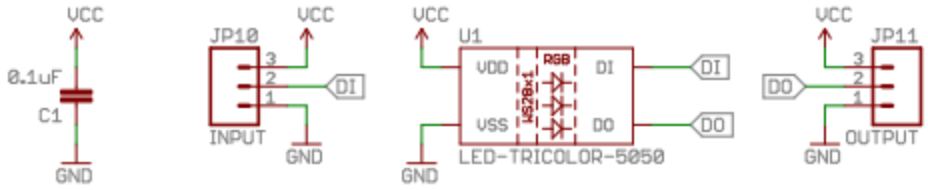
57BYGH405A

SPECIFICATIONS

STEP ANGLE	1.8°±5%	VOLTAGE	3.6V
NO. of PHASE	4	CURRENT/PHASE	3.0A
Inultion Resistant	100Mohm(500VDC)	INDUCTANCE/PHASE	2.4±20%mH
Ambient Temperature	-20~40℃	RESISTANCE/PHASE	1.2±10%Ω
Operate_Temperature	110℃ Max	HOLDING_TORQUE	20kg.cm
WEIGHT	1.33kg Max		

LED part number WS2812

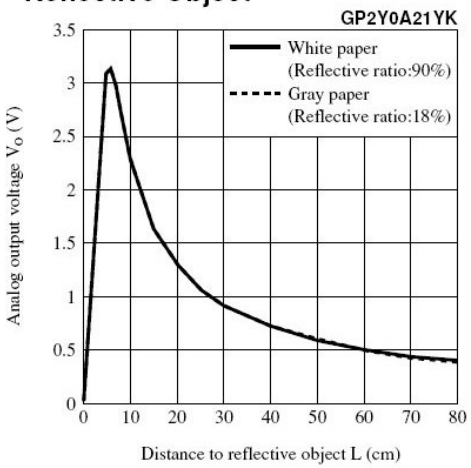
This is a breakout board for the WS2812 RGB LED. Several of these breakout boards can be chained together in series to form a display or an addressable string.

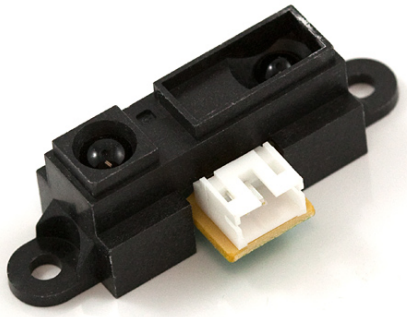


Infrared Proximity Sensor

The proximity sensor has an analog output that varies from 3.1 Volts at 10 cm to .8 Volts at 80 cm.

Fig.5 Analog Output Voltage vs. Distance to Reflective Object



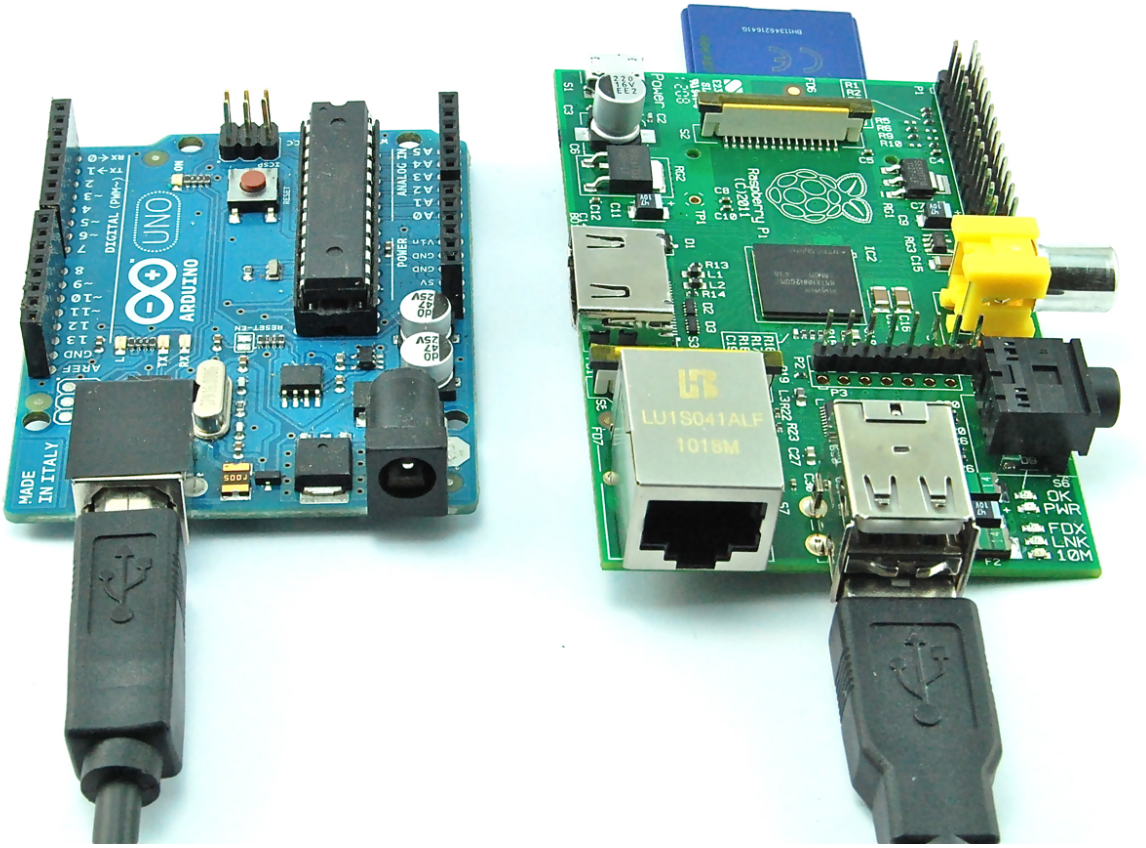


Hardware Interface

This section contains descriptions for how each component will be connected together. Include diagrams, schematics, ect. Use heading 3 for each new section.

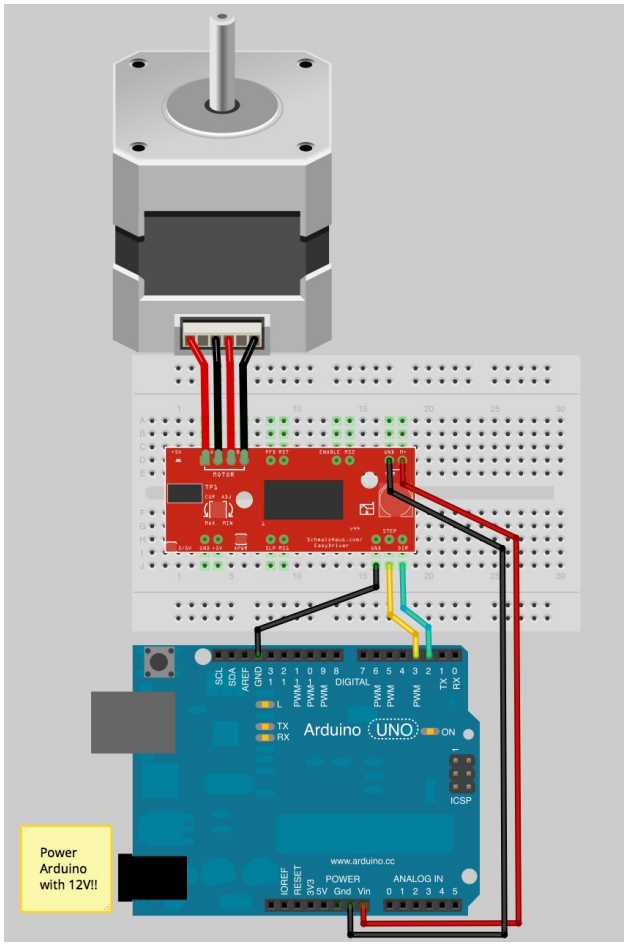
Raspberry Pi -> Arduino Uno

The Raspberry Pi shall be connected to the Arduino Uno via a standard USB cable.



Arduino Uno -> Stepper Motor Driver -> Stepper Motor

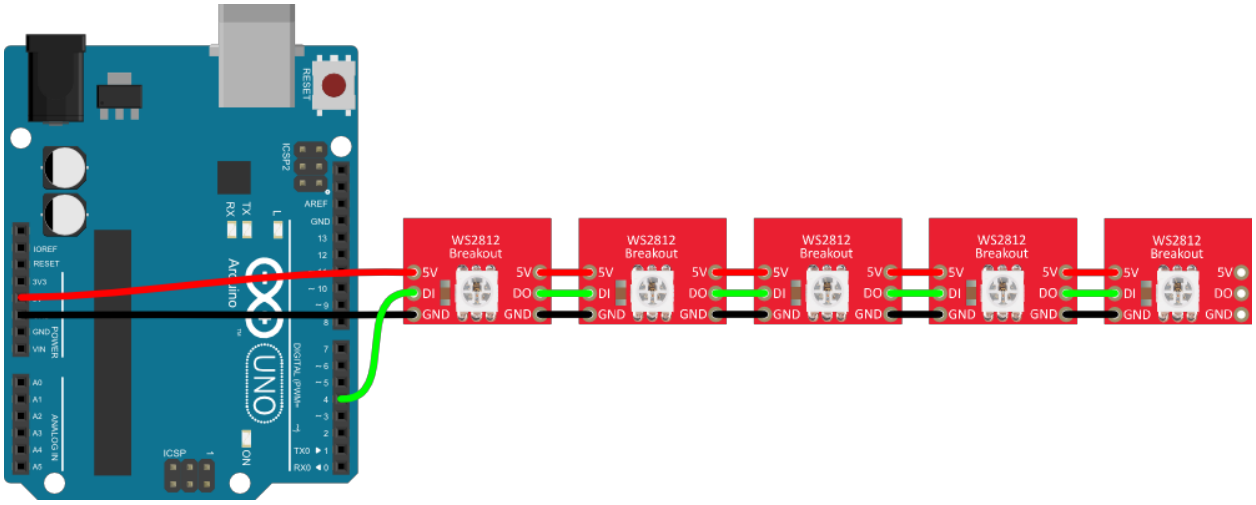
The arduino shall connect to the stepper motor driver, and the driver shall connect to the motor as shown in the diagram below. Additionally, consult the chart below the diagram for information on connecting the driver to the stepper motor. Use the bipolar half coil connection entry.



6 LEAD WIRES	1	2	3	4	5	6
Color Code 1	Red	White	Blue	Green	Yellow	Black
Color Code 2	Brown	Black	Orange	Red	White	Yellow
Color Code 3	Red	Black	Red / White Stripe	Green	White	Green / White Stripe
Bipolar Drive Half Coil Connection	A	$\overline{A}$		B	$\overline{B}$	
		$\overline{A}$	A		$\overline{B}$	B
Bipolar Drive Series Connection	A		$\overline{A}$	B		$\overline{B}$
Unipolar Drive	A	A/C Comm	C	B	B/D Comm	D

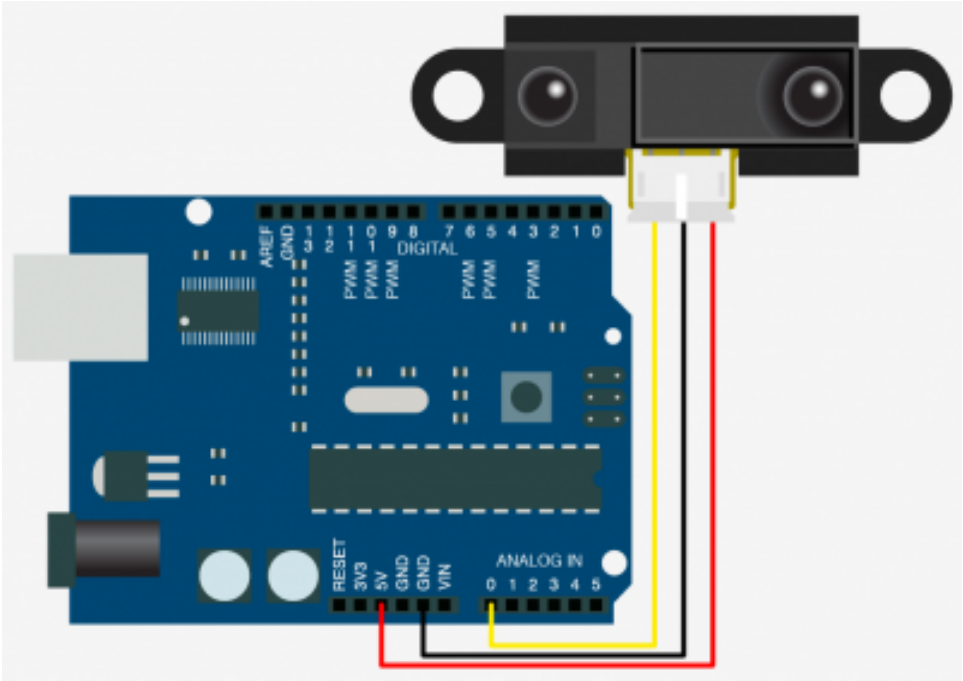
Arduino Uno -> LEDs

The image below illustrates how to connect the LEDs in series to the Arduino. Approximately 500 LEDs can be daisy-chained in this configuration before the delay in addressing them becomes noticeable to the human eye.



Proximity Sensor -> Arduino Uno

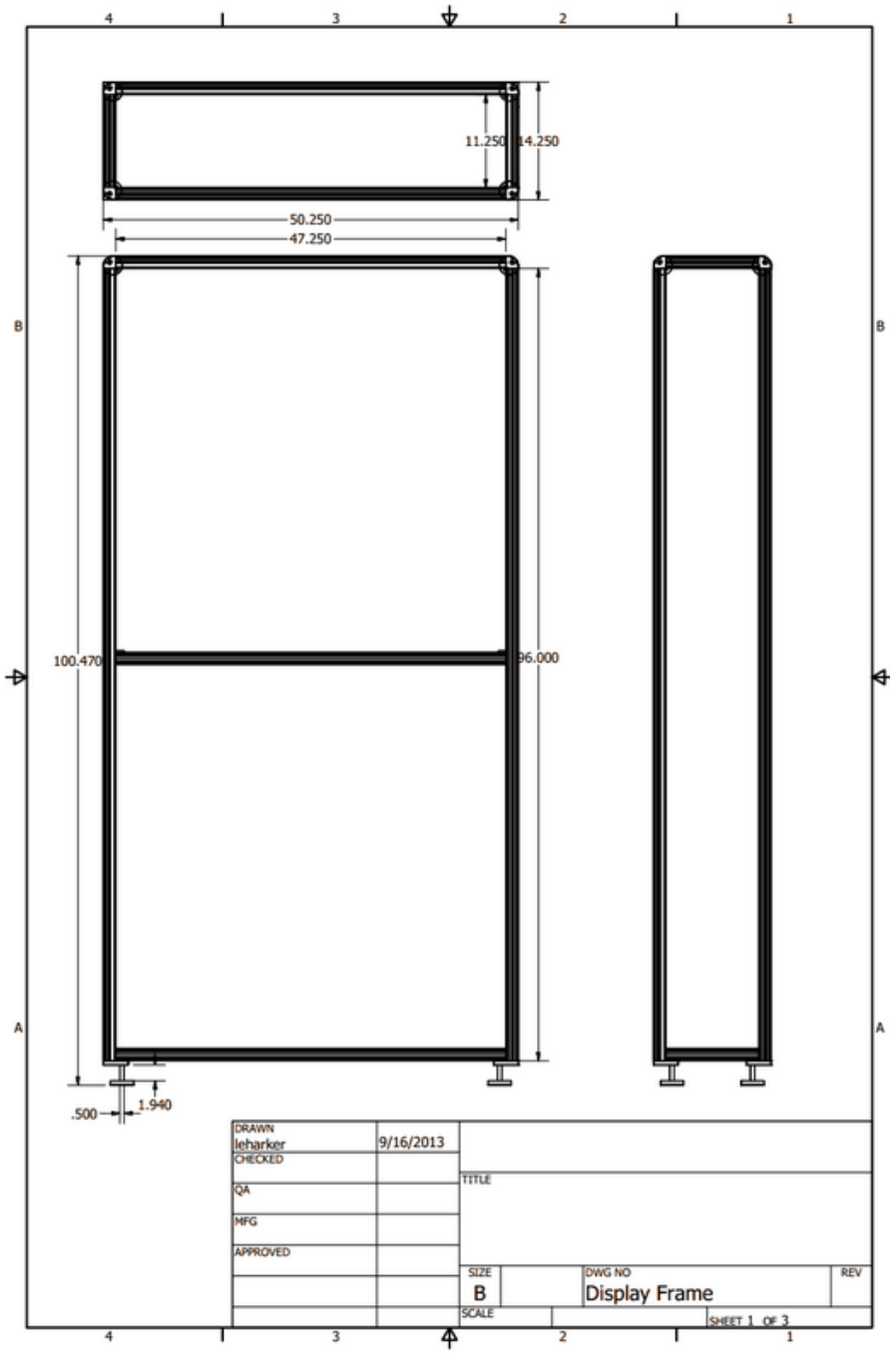
The image below illustrates how to correctly connect the proximity sensor to the Arduino Uno. The Proximity sensor requires one analog input and a 5 Volt supply voltage. The proximity sensor will send analog data about the object position that will be interpreted by arduino and translated to distance.



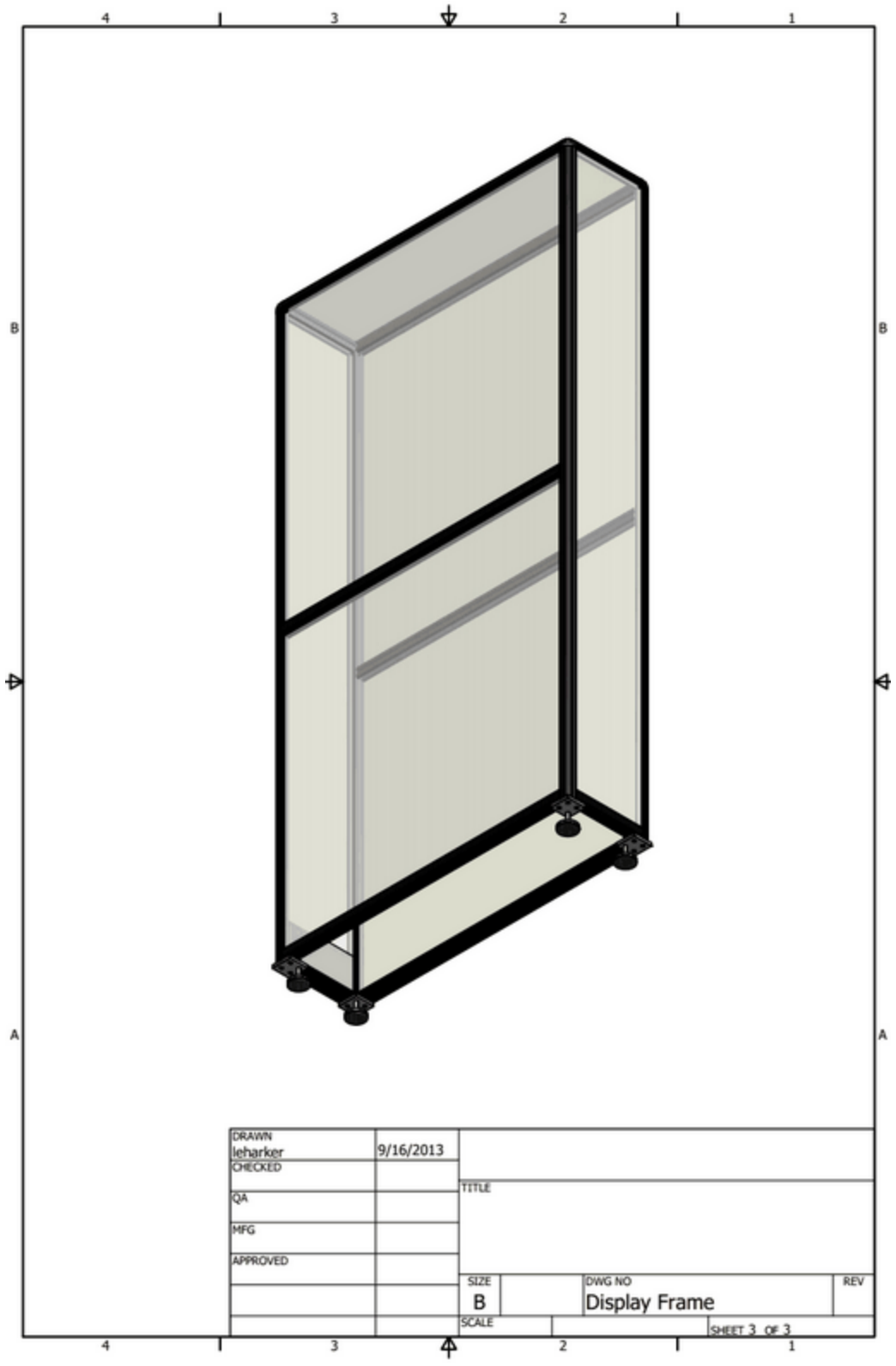
Mechanical

Enclosure

Dimensions



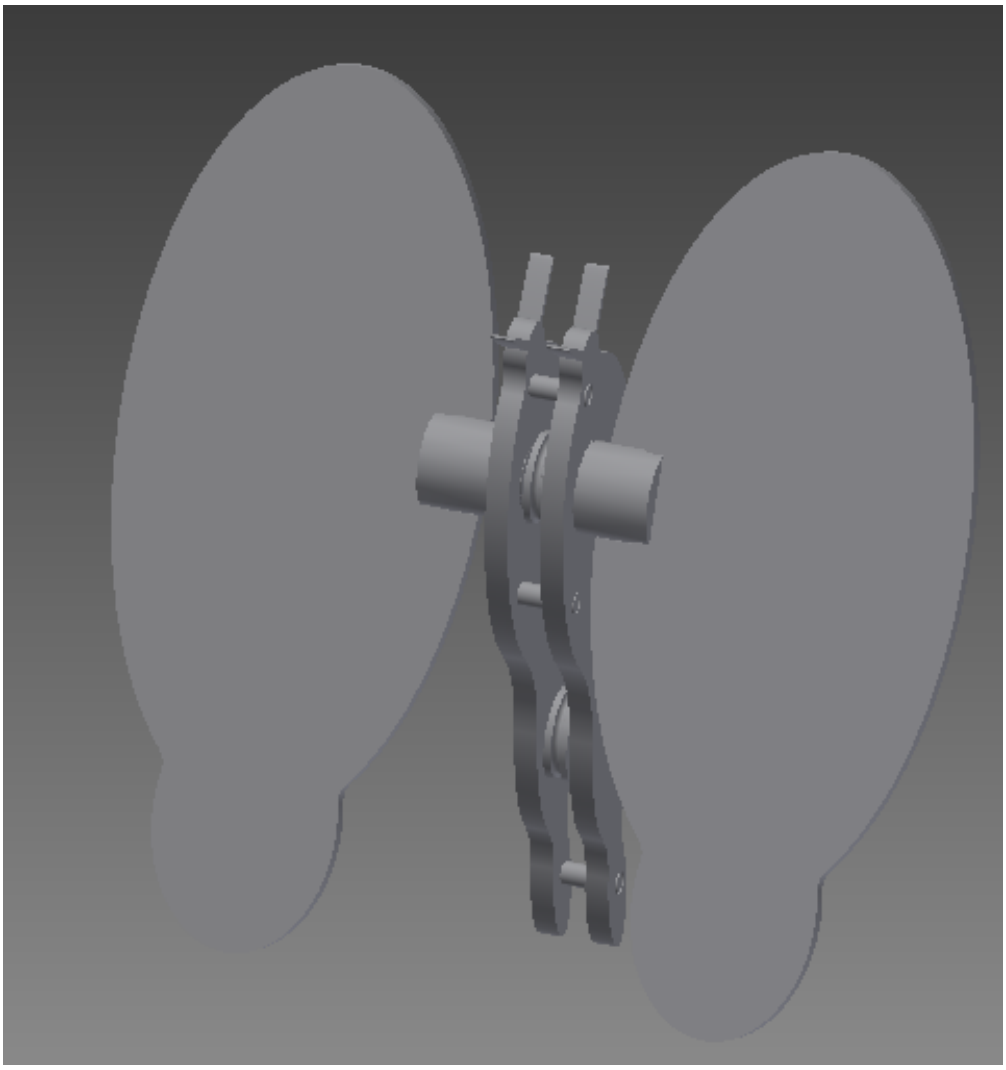
Isometric View



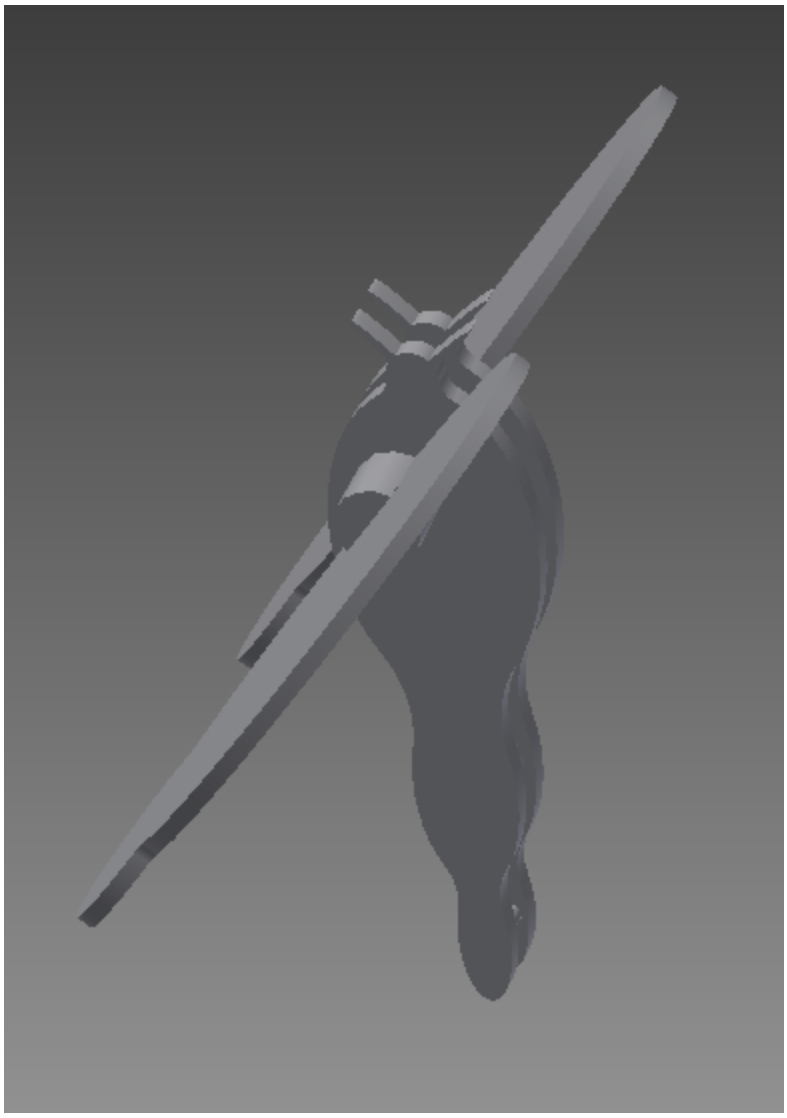
Butterfly

The butterfly will be suspended from a line which will zig-zag through the three pulleys. The wings will attach to the shaft connected to the middle pulley. As the pulley spins due to the movement of the line, the shaft will spin, which will spin the wings.

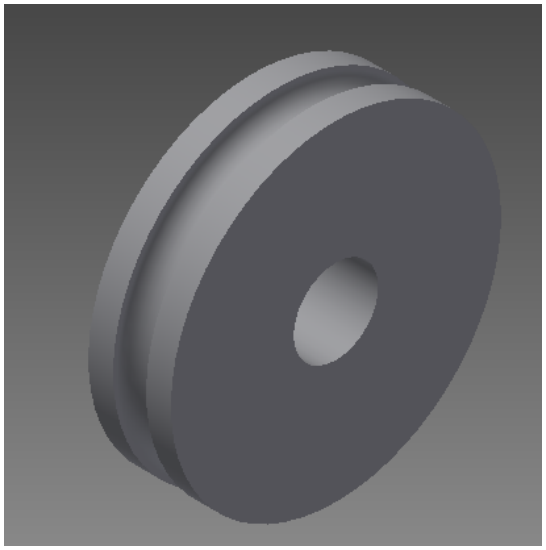
Diagonal view



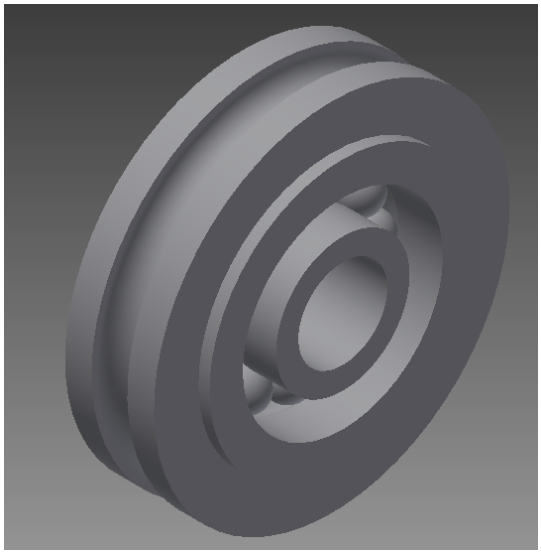
Side View



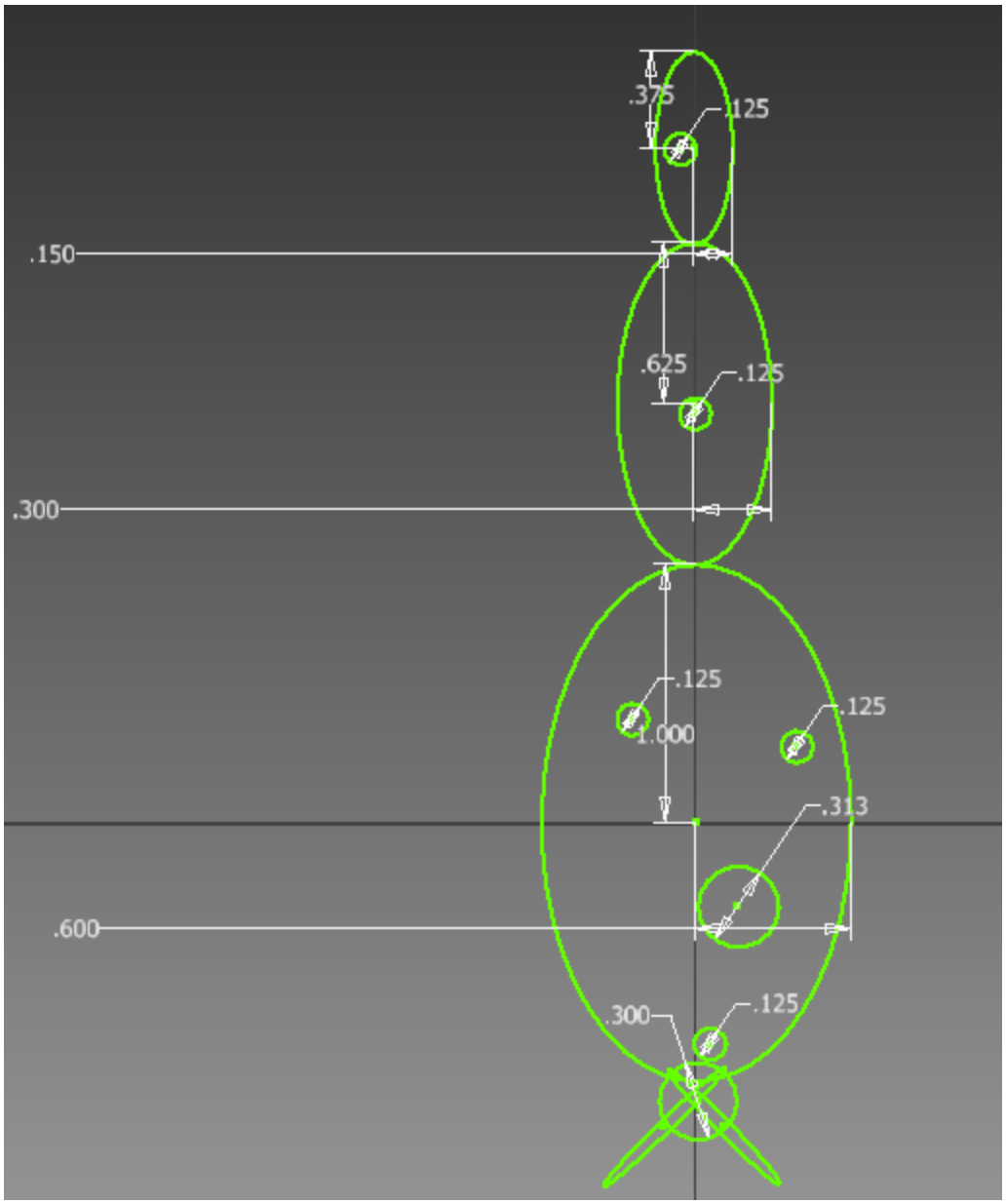
Pulley 1 (.5in no ball bearing)



Pulley 2 (.5in with ball bearing)

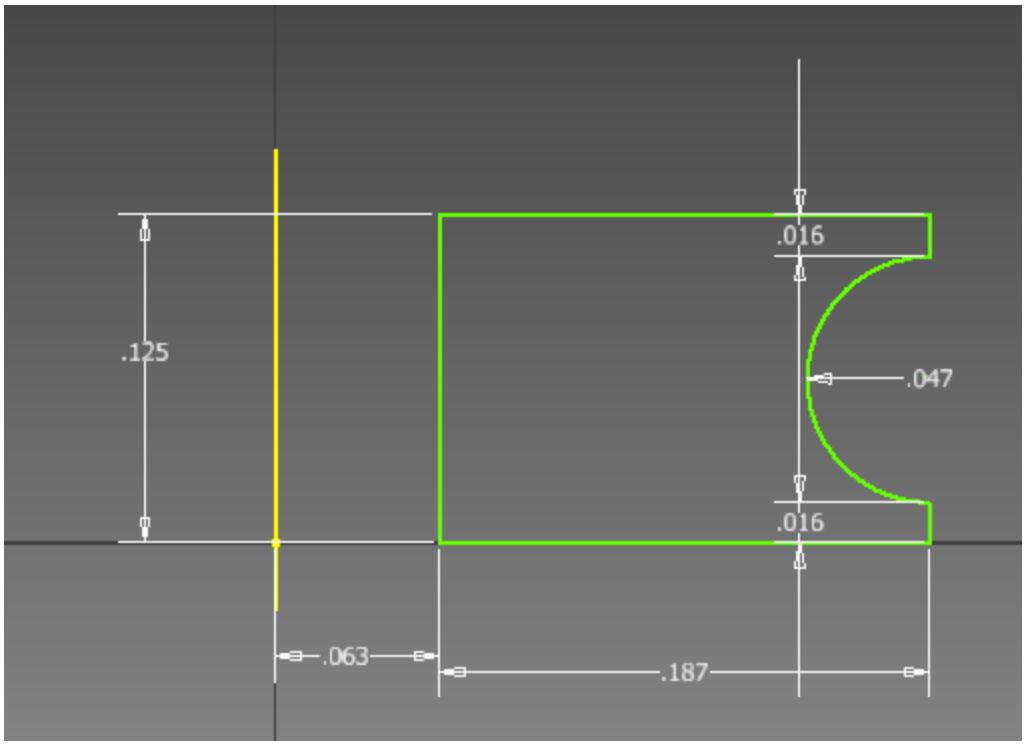


Body Dimensions



The dimension of the butterfly's body are all expressed in inches. The body of the butterfly will be made of a clear plastic that will be ⅛ inch thick. The body will be cut by us using the laser cutter at Iowa State University.

Pulley Dimensions



The pulley dimension are expressed in inches. The pulley will we made of a black lightweight acetal material. We will be ordering the pulley from stock drive products. The part number is A-6M-9-00804.

Fishing Line

This hollow fishing line is specifically designed for seamless splices. It will allow us to create a loop without a knot. This will prevent the butterfly from being dislodged from the string. It will also create a visually smoother motion.

Software

Software Decomposition

Web Server

The web server operating system is Debian GNU/Linux V7.0, in a configuration known as Raspbian. The web server is hosted by Apache 2.2.22.

Arduino

Driving the LED lights requires the use of the Adafruit_NeoPixel library which is available via the manufacturer of the LEDs. Driving the stepper motor does not require any external libraries because the EasyDriver component being utilized enables the use of the standard arduino library to control each stepper motor.

Software Interface

The web server communicates with the arduino via a serial (COM) port. As users provide input on the mobile website, predefined scripts will execute and send serial messages on the COM port which will include actions for the arduino to execute. The physical connection between the web server (hosted on the raspberry pi) and the arduino is by a standard USB cable. The messages are encoded as follows:

Definitions

DLE: Data Link Escape (0x10) - indicates that the following byte is a control character, such as STX or ETX and not the payload of the packet.

STX: Start Of Text (0x02) - Control character. Must be accompanied by following ETX. Indicates that all of the bytes following are to be interpreted as unicode text, until the control character EXT is found.

ETX: End Of Text (0x03) - Control character. Must always follow a STX. Indicates the text entry has ended.

address: Integer value between 0 and 3 which indicates which object is being accessed.

speed: Integer value between -100 and 100 which indicates the vertical speed of the user action

Message Formatting

Each message will begin with **DLE** and **STX**, followed by the message payload, followed by **DLE** and **ETX**. Message payloads are listed in the payload section. An example packet format for a message of size n follows:

pkt[0] = **DLE**
pkt[1] = **STX**
pkt[2..2+n] = {payload}
pkt[n+1] = **DLE**
pkt[n+2] = **ETX**

Payload Messages

A list of messages follows. The format for messages listed is [Message type]:[args][...] which would indicate that the message type is 1 byte, and each necessary argument is an additional byte.

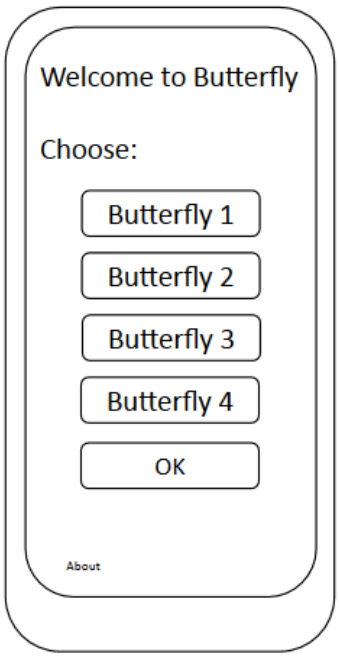
s:[address1][speed] - indicates that servo [address] should adjust its speed based on a user input of [speed]. See the following example for a packet which would indicate that servo 1 should climb vertically upward at the maximum possible speed:

pkt[0] = **DLE**
pkt[1] = **STX**
pkt[2] = 1
pkt[3] = 100
pkt[4] = **DLE**
pkt[5] = **ETX**

User Interface

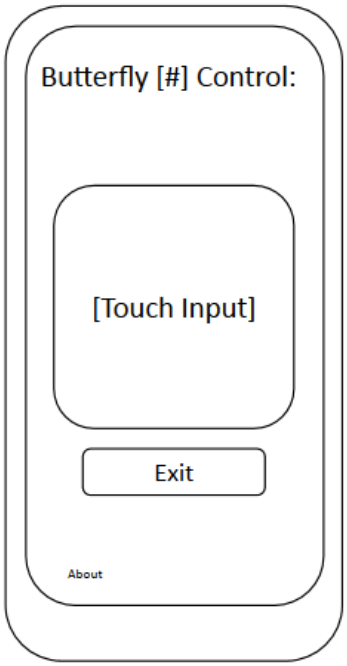
Screen Sketches

SK-1: Mobile Website Homepage



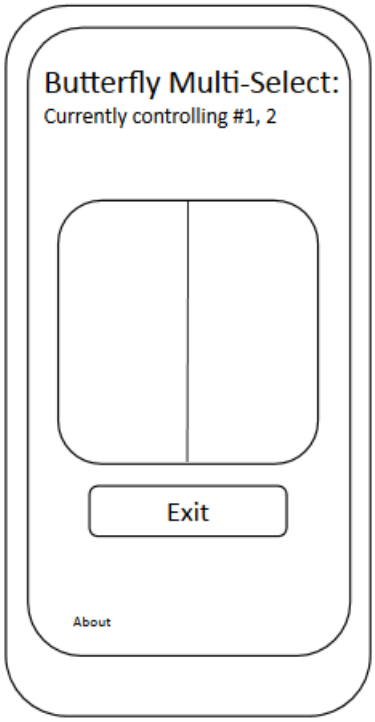
The mobile website homepage is where the user will select a single or multiple butterflies. The butterfly buttons act similar to checkboxes and will change color to indicate that they are selected. A user can select either one or multiple butterflies and press the OK button to proceed. Butterflies which are not available will be displayed “grayed out” or some other obvious means of indicating that they are not available for selection.

SK-2: Butterfly Single Select



The single select page will display the butterfly number which is being controlled (same as the physical number on the butterfly). The touch input is a location where the user can slide their finger up and down, and the vertical velocity of the swipe will be translated into the speed and direction of the butterfly.

SK-3: Butterfly Multi Select



The multi select page is similar to the single selection page. The title will display multiple butterfly numbers, as displayed in the example controlling butterflies 1 and 2. The touch input will also be vertically separated into as many areas as the number of butterflies selected, which directly correspond to a single butterfly. The vertical velocity of the user's swipe in any of the areas will be translated into the speed and direction of the corresponding butterfly.

Use Cases

UC-1: Control Single Butterfly

This provides the steps a user will take to control any of the 4 butterflies, one at a time.
Actors: Public user

Main scenario:

1. User scans QR code at butterfly case to open the mobile website
2. User chooses one of the 4 butterflies
3. User provides input on the touch interface displayed
4. Butterfly and LED lights react to the user input by performing an action
5. User terminates session with exit button

Extensions:

1A. User manually types in the mobile website address
1A1. User manually opens the mobile website

2A. User chooses butterfly which is currently in use by another user
    2A1. An error message is displayed
    2A2. User returns to mobile website and repeats step 2
2B. No butterflies are available
    2B1. An error message is displayed
    2B2. User waits for another user to timeout or exit
    2B3. User returns to mobile website and repeats step 2
5A. User does not close session
    5A1. User session will timeout and display an error
    5A2. The session is automatically terminated and other users may access

Pre-Conditions:

- Server and connected interfaces are up and running
- User possesses web-enabled, touchscreen equipped smartphone

Post-Conditions:

- User will be able to control the actions of the butterfly and LED lights
- User session will be terminated

UC-2: Control Multiple Butterflies

This provides the steps a user will take to simultaneously control 2 or more butterflies.
Actors: Public user

Main scenario:

1. User scans QR code at butterfly case to open the mobile website
2. User chooses two or more of the 4 butterflies
3. User provides input on the touch interface displayed, which is divided into areas for each butterfly selected
4. Each butterfly and corresponding LED lights will simultaneously react to user input
5. User terminates session with exit button

Extensions:

1A. User manually types in the mobile website address
    1A1. User manually opens the mobile website
2A. User chooses butterfly which is currently in use by another user
    2A1. An error message is displayed
    2A2. User returns to mobile website and repeats step 2
2B. No butterflies are available
    2B1. An error message is displayed
    2B2. User waits for another user to timeout or exit
    2B3. User returns to mobile website and repeats step 2
5A. User does not close session
    5A1. User session will timeout and display an error

5A2. The session is automatically terminated and other users may access

Pre-Conditions:
- Server and connected interfaces are up and running
- User possesses web-enabled, touchscreen equipped smartphone

Post-Conditions:
- User will be able to control the actions of each butterfly and LED lights selected
- User session will be terminated

UC-3: Accessing About

This provides the steps a user must take to access the senior design homepage for our group and other information about the project.
Actors: Public user

Main scenario:
1. User scans QR code at butterfly case to open the mobile website
2. User selects the “About” link at the bottom of the page
3. User is redirected to the senior design webpage for MAY14-14

Extensions:
1A. User manually types in the mobile website address
1A1. User manually opens the mobile website

Pre-Conditions:
- Server and connected interfaces are up and running
- User possesses web-enabled, touchscreen equipped smartphone

Post-Conditions:
- User will be directed to the senior design webpage for MAY14-14