Robotic Lamp

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Contents

1 Introduction

1.1 Objective

Home automation continues to be on the forefront of technological advancement in 2016 and in 2017. While we have seen software interaction, such as Google Assistant, Siri, and Alexa, and we have seen automation in the form of smart lighting, thermostats, and more, we have yet to see many products that bring automation and interaction together. Specifically, we wanted to look at the office setting - lamps. We spend a lot of time at our office desks working on our computers, scribbling on our papers, and 46% of that time is spent after daylight hours[1]. While lighting in the office typically is through the use of lamps, these lamps are stationary, heavy, out of reach, and take effort to move around when we need them to, especially for those that are moving from one area of the table to another. This can be an annoyance for many office workers - constantly having to move lamps for their intended needs.

Our solution - a robotic lamp - aims to provide automated interactivity for anyone who spends their time at the office. The robotic lamp provides automation - turning itself on as soon as you are near it, and can set the tone of light based on the time of day. It also provides interactivity - following your hands as you write and work, to provide optimal lighting on your workspace, as well as gesture controls.

Through this project, we aim to bring smart technology and interactivity to something as conventional as a desk lamp and hopefully inspire other people to think of ways to bring such interactivity to other conventional devices used in our daily lives.

1.2 Background

There are currently no commercial robotic lamps on the market, but rather only "smart lighting" (such as Philips Hue) and lamps that are easy to adjust. There are many "do it yourself" projects online that have created a robotic lamp, but are not feasible products, as they use expensive, using unnecessary technology such as Arduino variants [2]. Lamps are currently lacking flexibility of use, and a robotic lamp is what many people are looking for [3]. We want to provide a cost-effective solution, while providing fullness of interactivity and automation.

We took inspiration from a Robotics project done at MIT a few years ago [4], which uses OpenCV and Machine Learning to provide the user an interactive desk assistant in the form of a robotic lamp, which keeps the user engaged in their work. The lamp adjusts the gestures based on the user's behavior and mood patterns and has additional functionality such as changing the temperature/color of the light as well. We wanted to use the research done and make a cost-friendly interactive robotic lamp assistant for the users.

1.3 High-Level Requirements

- The lamp must interact with a single person within a 5 ft. distance within it's field of view (greater than 45° by 30°), while never coming into contact with the individual's arm or hand.

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- The lamp must identify the following gestures after entering gesture recognition mode (person's palm is facing the camera and all fingers are straight, "stop" position):
  - Hand up (increase brightness of light)
  - Hand down (decrease brightness of light)
  - Hand side (lamp head turns the same side)
  - 1 Finger up, 4 Fingers down (lamp moves vertically upward)
  - 2 Fingers, 3 Fingers down (lamp moves vertically downward)
  - Turn Hand around (lamp toggles motion tracking on/off)
- Entering gesture recognition part should not exceed 150ms.
- The lamp response time should not exceed 2s.
- The lamp power input should not exceed 5V at 1A.
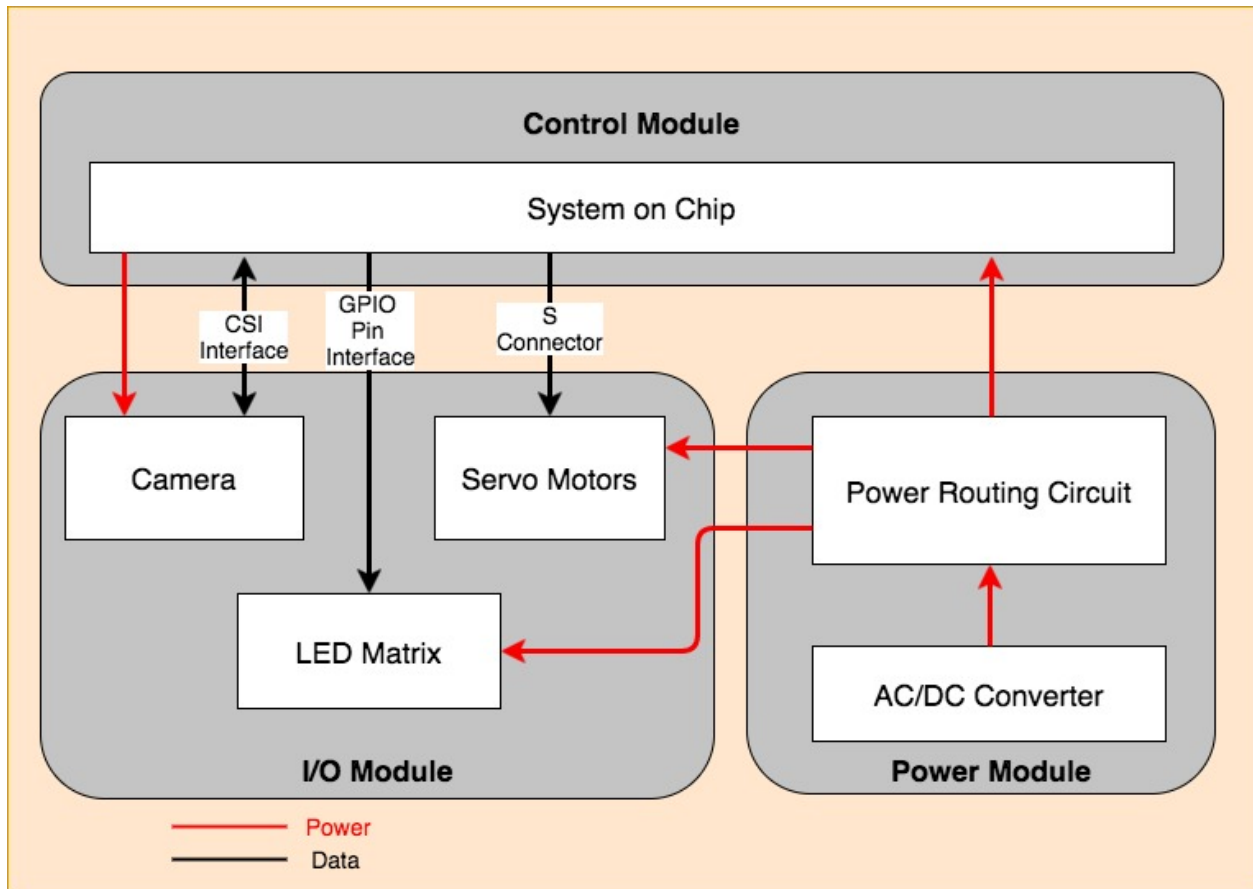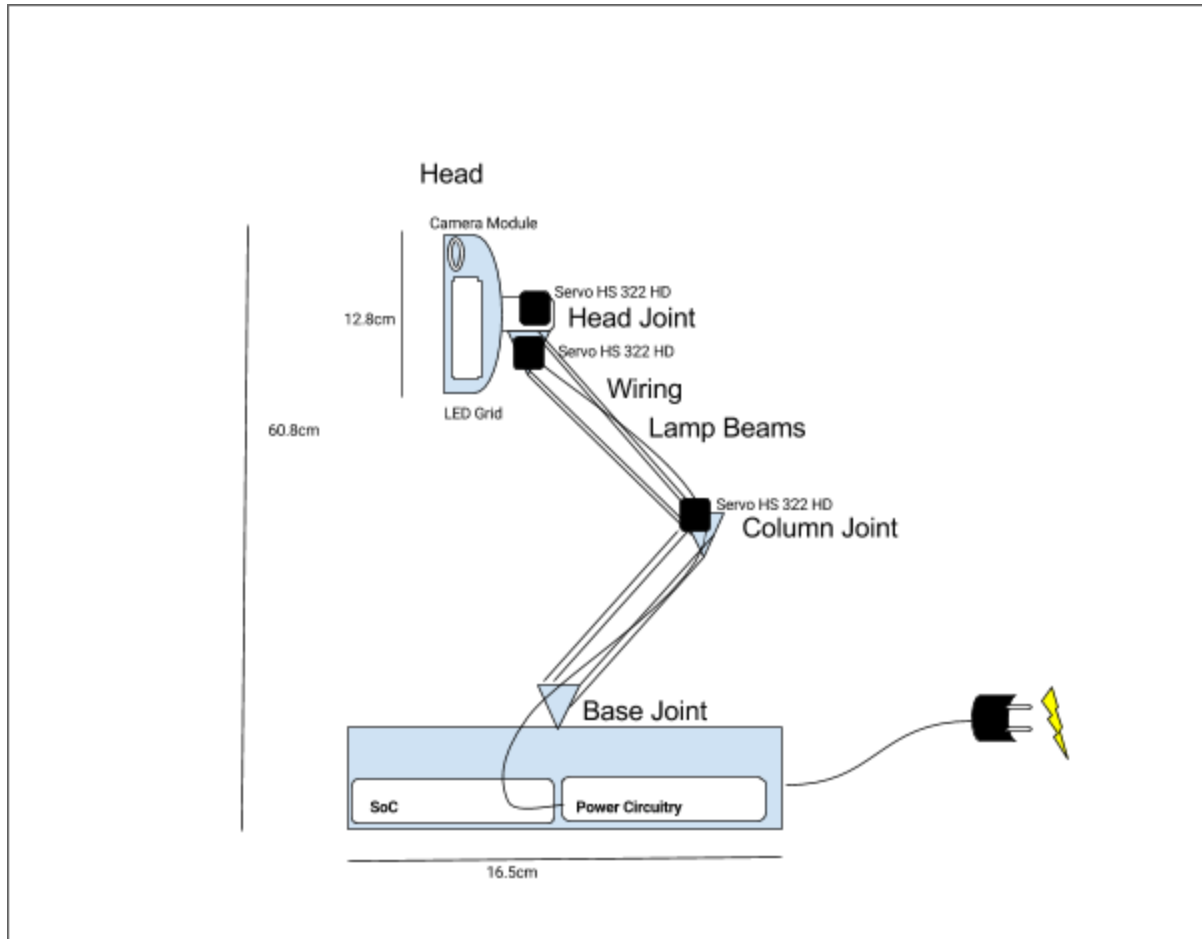- The lamp must output at least 100 lumens.

2. Design

2.1 Block Diagram

Fig. 1. Block Diagram

2.2 Physical Design

Fig. 2 Physical Design Mock-up

2.3 Control Module

The control module is the part responsible for the gesture recognition and processing the feedback gestures based on the user input. The control module gets input from the camera module in the I/O Module and then sends signals to the LED matrix to adjust lighting and servo motors to adjust the lamp arm respectively.

2.3.1 Raspberry Pi Zero SoC

2.3.1.1 Functional Overview

We will use the Raspberry Pi Zero as our System on Chip solution to take input from the camera, process the visual data, and control the motors and LEDs to provide feedback to the user in the form of light intensity and gestures. The Raspberry Pi Zero SoC is a 1GHz single-core processor with 512MB RAM, which will provide enough computing power to do the video processing and gesture selection. It is powered by the power module and consumes about 5V at 1A of power.

2.3.1.2 Requirements and Verifications

Requirements	Verification

1. Can receive video stream from the camera module at a data rate of at least 0.9216Mbps (for 240p at 12fps) and process it in no more than 150ms.	1.
	  a. Connect the camera module to the CSI interface on the Raspberry Pi.
	  b. Run the testBitRate.py script. This script is used to test the bitrate of the camera module.
	  c. The program records a 10 second video at 240p resolution and shows the time it took to transfer the video to the Raspberry Pi
	  d. Ensure that the time does not exceed 150ms.

2. Can identify the gesture and starts movement in the lamp arm in 2 seconds.	2.
	  a. Connect the camera module to the CSI Interface on the Raspberry Pi.
	  b. Put a marker image in front of the camera and run the testGesture.py script. to initialize gesture recognition and action.
	  c. The program initializes gesture recognition and action.
	  d. The program then outputs how long it took to recognize the marker
	  e. Ensure that the output time under 2 seconds.

3. Can complete response gesture in the lamp arm in 10 seconds.	1. Connect the camera module to the CSI interface on the Raspberry Pi.
	   Put a marker in front of the camera.
	   Wait for the motor to start moving.
	2. (Start timer) When the motor starts moving.
	3. Wait for the movement to finish.
	4. (Stop timer) When the motors stop moving.
	5. Ensure that the time taken does not exceed 10s.

2.4 Input/Output Module

The I/O Module are the outfacing, interactive parts of the lamp. While the camera is taking images to input into the control module for processing and recognition, the LED Matrix and Servo Motors outputs are the physical interactions with the user, providing different scenarios and configurations based on recognition from the camera.

2.4.1 Camera

2.4.1.1 Functional Overview

The camera module is in itself one piece - the camera. The OV5647 Camera [6] is a fixed-focus camera that is designed to interface specifically with the Camera Serial Interface (CSI) [7] of the Raspberry Pi Zero, providing the exact I/O of the SoC, fitting well without need for soldering (see Fig. 5). The OV5647 Camera interfaces with the use of 15 pins through a ribbon cable, while the CSI pins sit on the outer shell of the SoC. Data is transferred through two serial buses though various pins. The camera is also powered through other pins on the CSI (see Fig. 1).

2.4.1.2 Requirements and Verifications

Requirements	Verification

1. Takes images at a resolution of at least 240p (320 x 240) and a frame rate of at least 12 frames per second	1.
	  a. Connect OV5647 Camera to Raspberry Pi Zero via the CSI connector
	  b. Connect monitor via mini-HDMI to the SoC, as well as a USB Keyboard to the SoC
	  c. Using the Linux Terminal on the Raspberry Pi Zero, run the command "sudo raspi-config" to configure image resolution to a width of 320 and height of 240
	  d. Using the PiCamera Python Library, run a Python Script to connect to the camera and take an image
	  e. In the same Python Script, use the Python Image Library's wrapper to print out the resolution of the image using "Image.open(imageName).size" to verify the image resolution is equal to 640 x 480
	  f. In the same script, take a time stamp (startTime), and take 100 photos using the PiCamera Library. Take a second time stamp (endTime) after the 100 photos are taken, and calculate the time elapsed to verify that it took less than 8.3333 seconds to run

2. Provides a field-of-view of greater than or equal to 45° x 30°	2.
	  a. Connect OV5647 Camera to Raspberry Pi Zero via the CSI connector
	  b. Connect monitor via mini-HDMI to the SoC, as well as a USB Keyboard to the SoC
	  c. Using the Linux Terminal on the SoC, run the command "sudo raspi-config" to enable the camera and configure image resolution
	  d. Measure and stand 1 meter away from the center of the camera
	  e. Run the command "raspistill -v -o test.jpg" in the terminal to begin a 5-second image preview begin

	f. Use a tape measure to span the horizontal axis of the photo frame, and record this value. g. Calculate the horizontal angle field-of-view using triangle identities to verify that it is greater than 45 degrees h. Repeat the process by instead measuring the vertical axis of the photo frame to verify that the vertical field-of-view is great than 30 degrees

2.4.1.3 Supporting Material

The Control Module is used to process the images that are taken by the Camera Module. Using the OpenCV Library, we are able to easily process these images without needing to change many things except for the configuration of the built-in libraries. The software flow is seen in Fig. 9. It follows a fairly standard set of algorithms for hand recognition and motion detection[28]. A detailed low-level schematic of the Camera connection to Control Module is referenced in Fig. 5. The CSI uses PIN 2, 3, 5, 6, 8 & 9 to get visual data from the camera module.
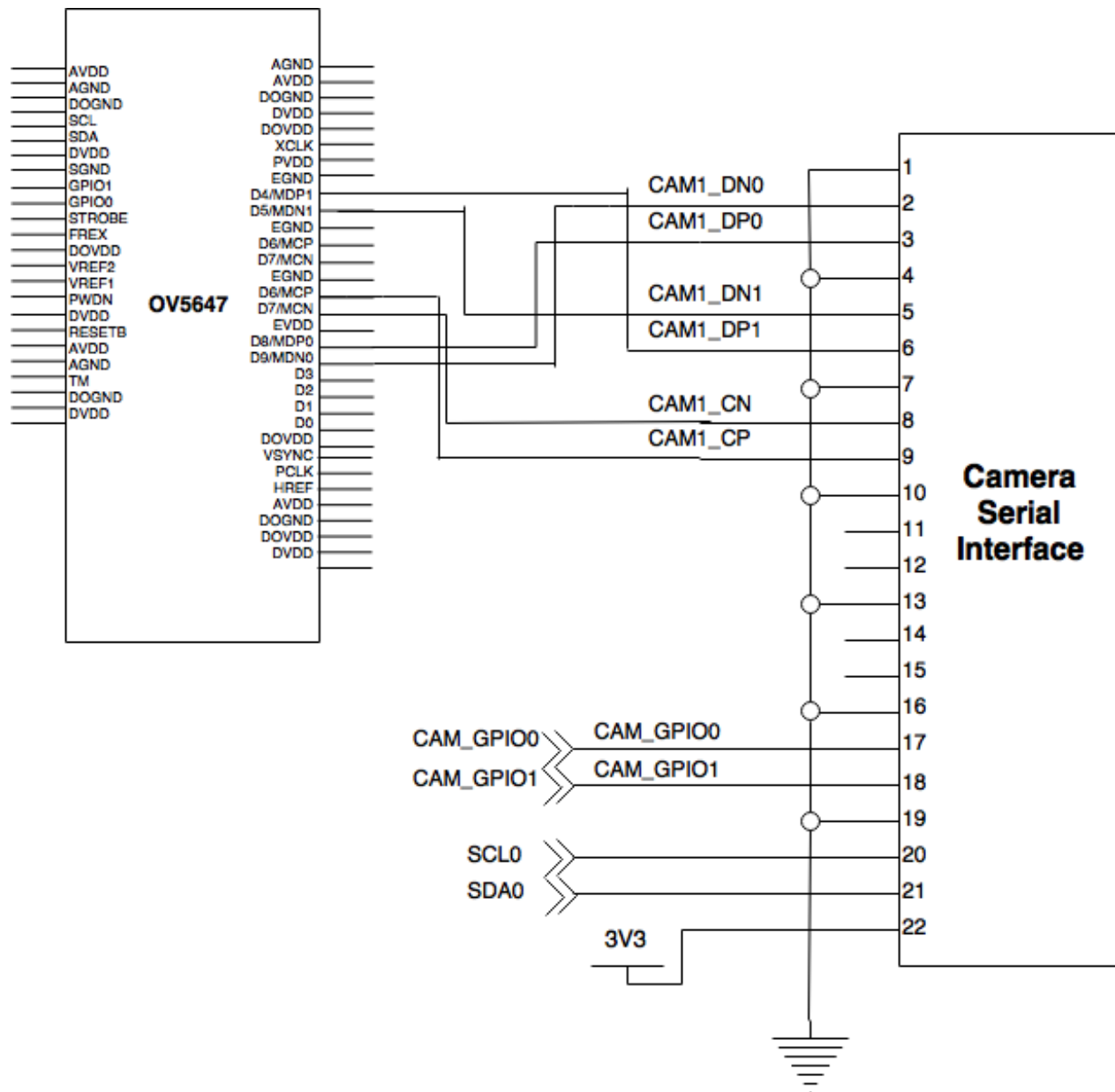
Fig. 5. Camera and Interface Connections

2.4.2 LED Matrix

2.4.2.1 Functional Overview

An 8x8 64 bit Matrix of WS2812B RGB LEDs [9] will be used as our primary lighting. It is powered by the Power Module. Data is transferred from the Raspberry Pi GPIO pins. The LEDs run in series and can be brightness can be changed addressed through the Raspberry Pi through the use of Pulse Width Modulation. Individually, these LEDs can be addressed by connecting them in a cascading manner and sending instructions of length $64 \times 24 = 1{,}536$ bits where each 24 bit instruction is used to select the color. Since the LEDs are driven by a 5V Power Supply, the Data must also be driven by a 5V Source, requiring a level converter to convert the 3.3 V Data output pin of the Raspberry Pi [10].

2.4.2.2 Requirements and Verifications

| Requirements	Verification

1. At a voltage supply range from 3.5V-5.3V All LEDs light up white at a current draw of 60 mA/LED for at least 30 minutes	1.
	    a. Connect the 5V Power Supply directly to V_{DD} of the LED, as well as Ground to V_{SS}
	    b. Connect GPIO Pin 18 of the Raspberry Pi Zero to D_{IN} on the LED. Run a Test Python Script that will be provided, which will run for at least 30 minutes.
	    c. Ensure that the LED outputs a bright white light constantly for the 30 minutes with no noticeable flickering or diminishes in brightness.

2.4.2.3 Supporting Materials
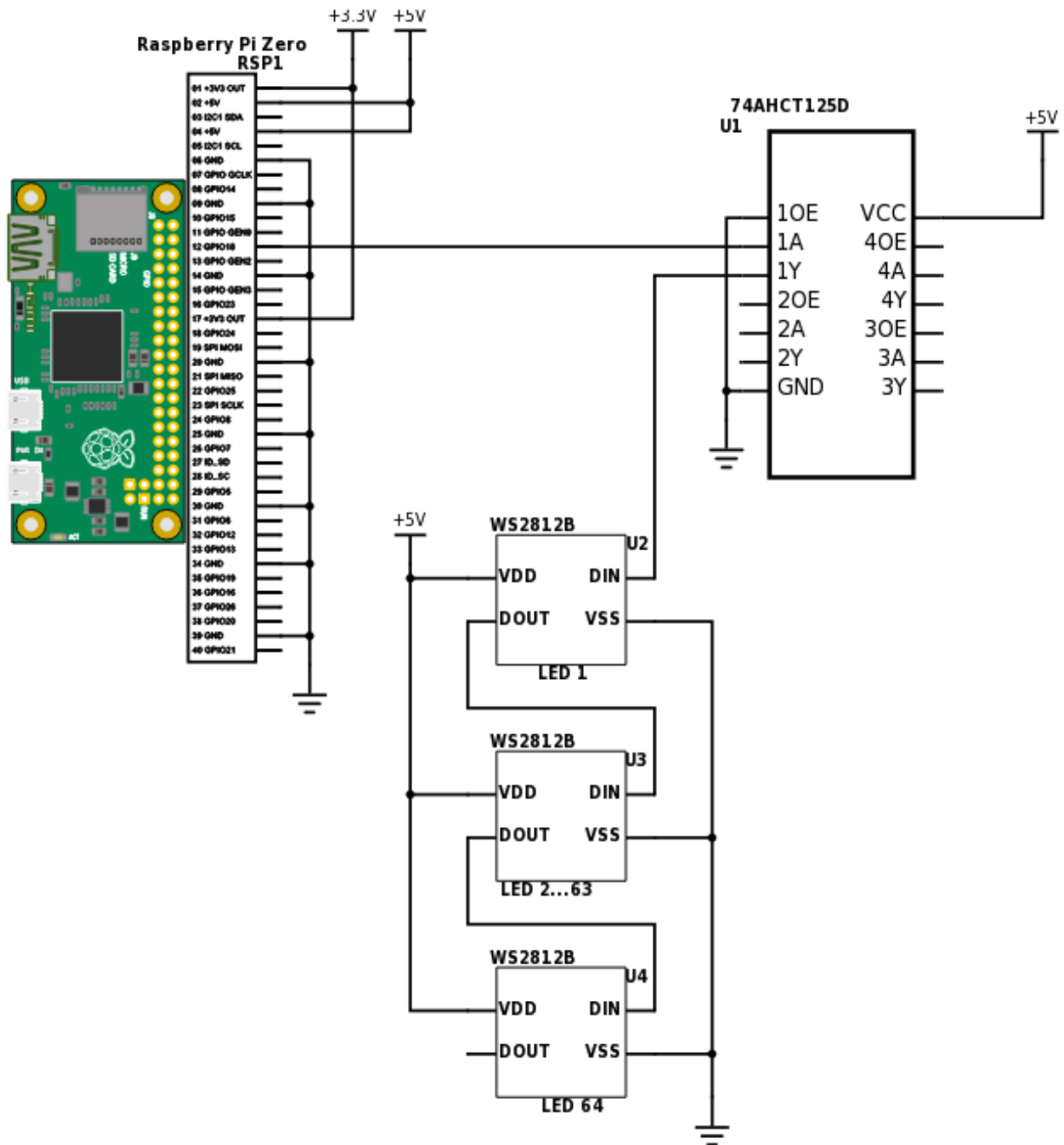
Fig. 6. LED Connections to the Level Converter and Raspberry Pi Zero

A user has posted a Raspberry Pi Driver for the WS2812B[24]. This driver uses the Raspberry Pi's PWM to drive the LEDs through the PWM GPIO Pin 18. The driver is written in C and has a library to write Python scripts with. The "Test Python Script" will consist of setting the LEDs to maximum brightness, and setting each LED's color to white (turning all bits of each LED to 1). By pushing each LED to maximum brightness at a white color, we insure that the LEDs are not faulty. Additionally, this library provides very

high-level control of the LEDs, so we do not need to worry about duty cycles and signal inputs to the LED Matrix. As seen in our LED Control Algorithm in Fig. 10, we are able to simply set values to variables to set brightness of individual LEDs and to set RGB Values of individual LEDs. We find this library to make the LEDs a very simple configuration.

A high level requirement states that the lamp will output an effective 100 lumens through the LEDs. This is extremely hard to verify and is out-of-scope for our Design, as it requires specific, expensive tools to determine. We are able to calculate an approximate amount of lumens that the LED matrix will output, using this formula:

$$\Phi_{v(lm)} = \frac{I_{v(mcd)}\, x\, \left(2\pi\left(1 - cos(\frac{\theta}{2})\right)\right)}{1000}$$

$\Phi_{v(lm)} =$ Luminous Flux (lumens)

$I_{v(mcd)} =$ Luminous Intensity (millicandela)

$\theta =$ Apex Angle (degrees)

Using this equation and the datasheet on the WS2812B[9], the assumption that the effective luminous intensity is the luminous intensity of the strong component[25], and the apex angle is 120°[26], we obtain a minimum lumens-per-LED of:

$$\Phi_{v(lm)} = \frac{660\, x\, \left(2\pi\left(1 - cos(\frac{120[?][?]}{2})\right)\right)}{1000} = 2.07345\, lumens$$

And given that we have an LED matrix of 64 LEDs,

$$\Phi_{total} = \Phi_{v(lm)} * 64 = 132.7008\, lumens$$

is the minimum amount of lumens we expect out of the LED matrix. We note that the matrix has a fairly low amount of lumens compared to commercial bulbs, but since the matrix has a smaller apex(viewing) angle, we expect that the focused light intensity will provide enough for daily use. Should this not be enough, SK6812 would be a replacement set of LEDs that we would use, which output roughly three times the amount of luminous intensity[26]. The Raspberry Pi driver also works for these LEDs, but require a little tweaking of the driver.

2.4.3 Servo Motors

2.4.3.1 Functional Overview

The Servo modules we use are HITEC HS 322HD servos which are used to swivel and turn different parts of the robotic lamp. We will be using 3 servo motors for 3 joints which we'll use to control the motion of the lamp. One servo will be used to swivel the lamp head left and right in the xy-plane. Another one will be used to create the up down yz-plane motion for the lamp head. The third one will be used in the middle joint (in the neck of the lamp) to control the up down motion of the lamp itself. These motors

have an operating voltage range of 4.8V-6V and can produce upto 3kg/cm-3.7kg/cm [11]. The servo motors have an analog signal rate of 30 signal inputs per second. The motors will be connected to the PWM Driver[12] which receives duty cycle input from the pins of the raspberry pi using a 3 way connector cable [13][14]. We must make sure that the temperature of the servo motors does not exceed temperature ratings during prolonged use [15].

2.4.3.2 Requirements and Verifications

| Requirements	Verification

1. The torque requirement for the servo is at least a maximum of 3kg-cm. This implies that the servo can lift/control the load of the head of the lamp (50g), the head module(150g) and the load of the upper neck (1kg) of the lamp.	1.
	  a. Connect the servo module to the power input(4.8V-6V)
	  b. Attach drive gear to the servo end of the motor
	  c. Measure resistance between 2 of the 3 motor leads and make sure they're consistent with the manufacturer's spec sheet
	  d. Use a strobe tachometer to measure no-load speed and current
	  e. Attach your motor to another known spec motor and back drive the motor.
	  f. Take an oscilloscope and look at the waveform between any 2 of the 3 motor leads. Measure the peak voltage and record the speed at the time of the measurement.
	  g. Calculate the peak voltage divided by the speed (in rads/sec), then you get a back-emf constant in Volts/(rad/sec) which is equivalent to your torque constant in Nm/A.
	  h. Estimate torque and current draw from your no-load current and your torque constant.

2. Temperature of the servo motors does not exceed 60°C in persistent(>2 minute) duty cycle changes.	2.
	  a. Connect servo motors to GPIO pins of Raspberry Pi SoC
	  b. Create duty cycle PWM signal using the testing pwm module provided by us.
	  c. Use IR thermometer to measure the temperature of the motor casing.
	  d. Collect and analyse temperature readings through the testing program run.

2.4.3.3 Supporting Materials
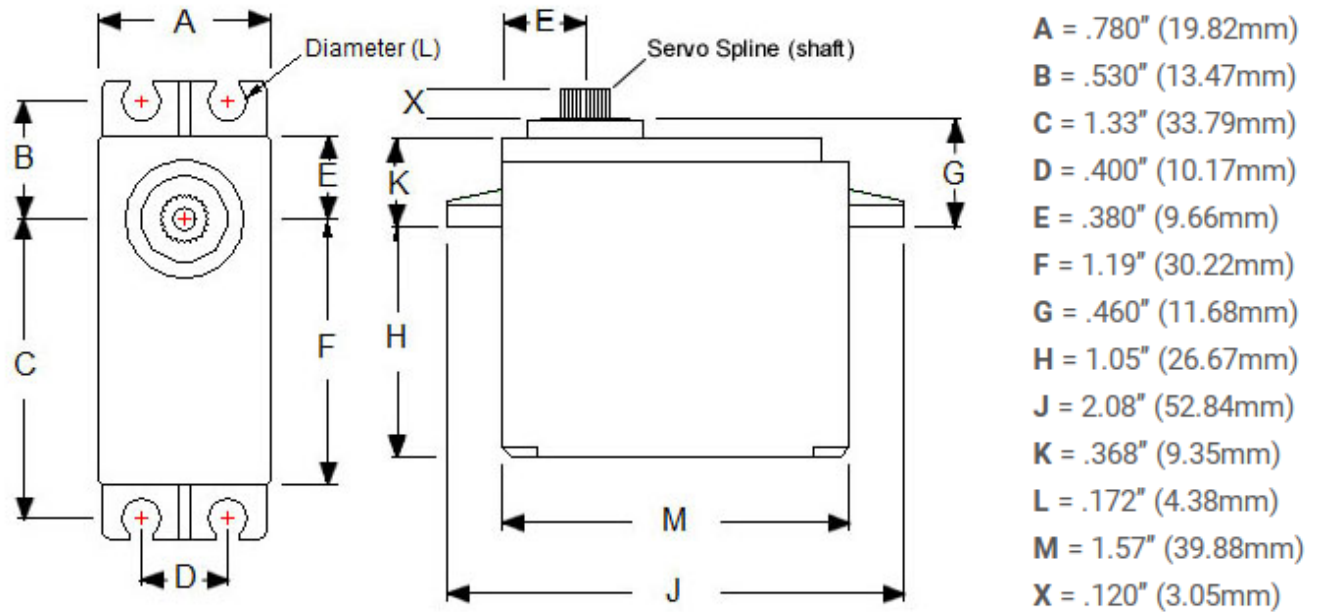
Fig. 7. HS-322HD Servo Motor[15]

The HS-322HD Standard Heavy Duty Servo utilizes Hitec's revolutionary Karbonite™ gear train which is four times stronger than the standard white nylon gears. Karbonite™ gears and Hitec's custom IC make the HS-322HD a great choice for an economical sport servo [17][18][19]. The servo motor was chosen specifically because of its small form factor (See Figure 7) and its high gear ratio which ensures that the motor does not require constant drive current to maintain torque and hold lamp elements in position.

Operating Voltage Range (Volts DC)	4.8V ~ 6.0V
Speed (Second @ 60°)	0.19 ~ 0.15
Maximum Torque Range kg. / cm.	3.0 ~ 3.7
Current Draw at Idle	7.7 mAh
No Load Operating Current Draw	180 mAh
Stall Current Draw	800 mAh
Dimensions (Metric)	40.0 x 20.0 x 36.5
Weight (Gram)	43.0

As we can see above, the torque range of the servo motor is high enough to be able to lift the weights we need to control or our contraption. We provide the motors a constant DC input of 5V which falls into

the voltage range for the motors. Note the we choose motor which had high enough torque that they would be able to maintain their state even in stall state. The motors are small enough to fit in the different hinges of the lamp without increases the weight of the total contraction by much.

2.5 Power Module

The power module provides proper voltage to the Control and I/O Modules through conversions from 12V AC. A Kill-Switch turns off all power from the whole system.

2.5.1 Power Routing Circuit

2.5.1.1 Functional Overview

The power routing circuit is a module of the project which is going to be used to control the power supply to other elements of the circuit. We get a 12V DC volt current from the AC/DC converter. This current goes through an override switch for the rest of the circuit. The output of the switch is connected to linear voltage regulators, which power the motors and the rest of the circuit while stepping down the voltage from 12V to 5V. [20].
The routing circuit also has a kill-switch(S1) to turn off the whole system if the user wants to turn off the monitoring from the camera module due to privacy concerns.

2.5.1.2 Requirements and Verifications

| Requirements	Verification

1. Ensure that override switch turns the voltage off the level shifter and PWM driver when the switch is turned off	1.
	
	  a. Connect functional generator to power routing circuit module
	  b. Measure output voltage at the output of the linear voltage regulator with switch in ON position. The output should be 5V.
	  c. Measure output voltage at the output of the linear voltage regulator with switch in OFF position. The output should be 0V.
	  d. Confirm observation through repetition.

2. Ensure linear regulators work with the voltage conversion of 12V DC to 5V DC which maintaining the current to at least 2.54A	2.
	
	  a. Connect functional generator to power routing circuit module
	  b. Measure output voltage and current, before and after linear regulator using oscilloscope with switch in ON position. The current should be at least 2.54A at 5V within 3% error.
	  c. Confirm observation through repetition.
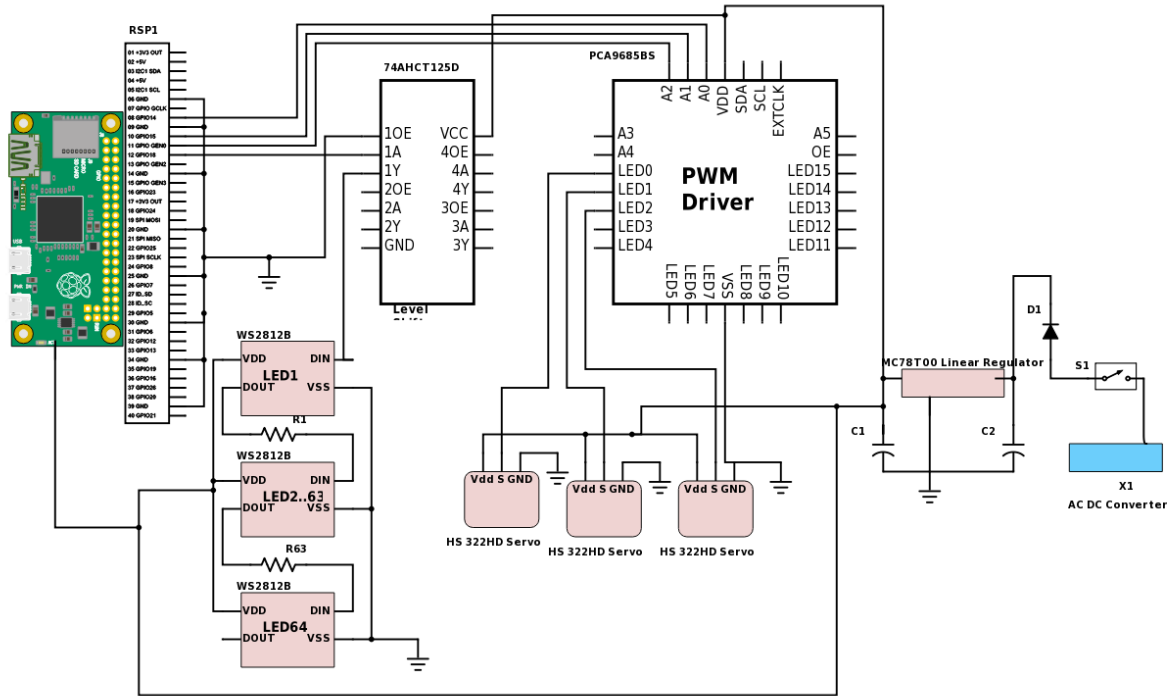
Fig. 8. Power Routing Circuit Schematic

2.5.1.3 Supporting Materials

The circuit takes 12V of DC input voltages, and outputs a constant 5V. The range of input voltages in linear voltage regulators is required to be greater than the output voltage, plus some margin. The diode(MC78T05CT) in the circuit is used to prevent damage in case the polarity of the input voltage is reversed. The capacitors(0.33μF) are used to filter out AC noise from the input.

Diode: 1N4148WXTPMSCT-ND
Voltage Regulator: MC78T05CT

2.5.2 AC/DC Converter

2.5.2.1 Functional Overview

Since the components of the circuit require DC power supply, we're going to use this module to convert AC power which we get from the wall socket into the DC power required for the components[20].

2.5.2.2 Requirements and Verifications

Requirements	Verification

1. Ensure that AC/DC voltage converted signal is consistent(± 0.15V) and accurate (intended voltage output of 12V) at least 2A.	1.
	   a. Connect AC/DC voltage convertor to wall socket to receive 110V AC input
	   b. Use multimeter to measure output DC voltage and ensure consistency and accuracy of 12V within 3% error.
	   c. Test with resistors(5Ω, 100Ω, 500Ω, 5kΩ independently) and measure current across the resistors.
	   d. Ensure the current measured is 2.4A, 0.12A, 24mA and 2.4mA respectively within 3% error.

2.5.2.3 Supporting Materials

Input Voltage	110V
AC Frequency	60Hz
Output Voltage	12V DC
Weight	1lb

3. Software Flow

[START]
Camera Module takes image, sends to SoC

SoC removes background using Gaussian Mixture-based Background/Forground Segmentation Algorithm

SoC extracts contours using OpenCV's canny filter

SoC finds Convex Hull and Defects using OpenCV

SoC uses OpenCV to determines Position and Location for Palm and Fingers

Action requires more training and verification

Incomprehensible Image/no hand movement or positioning detected
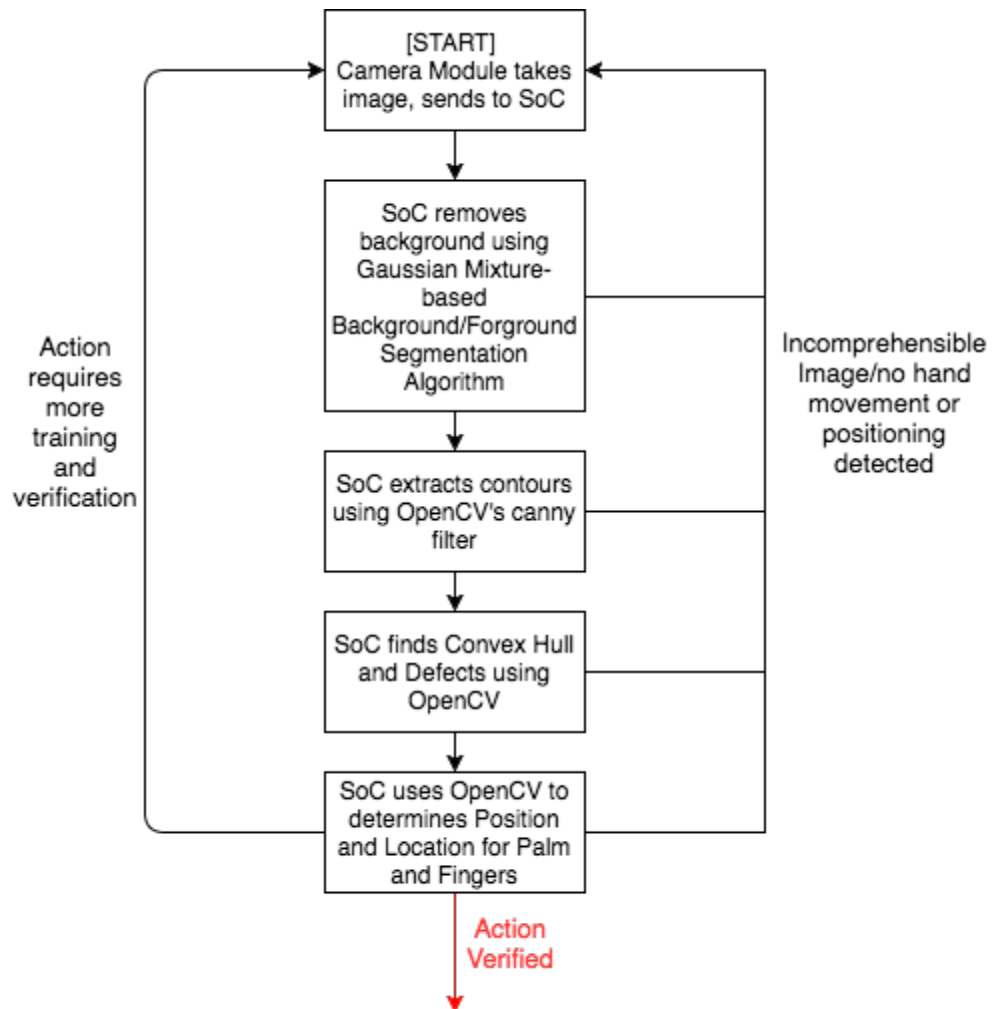
Action Verified

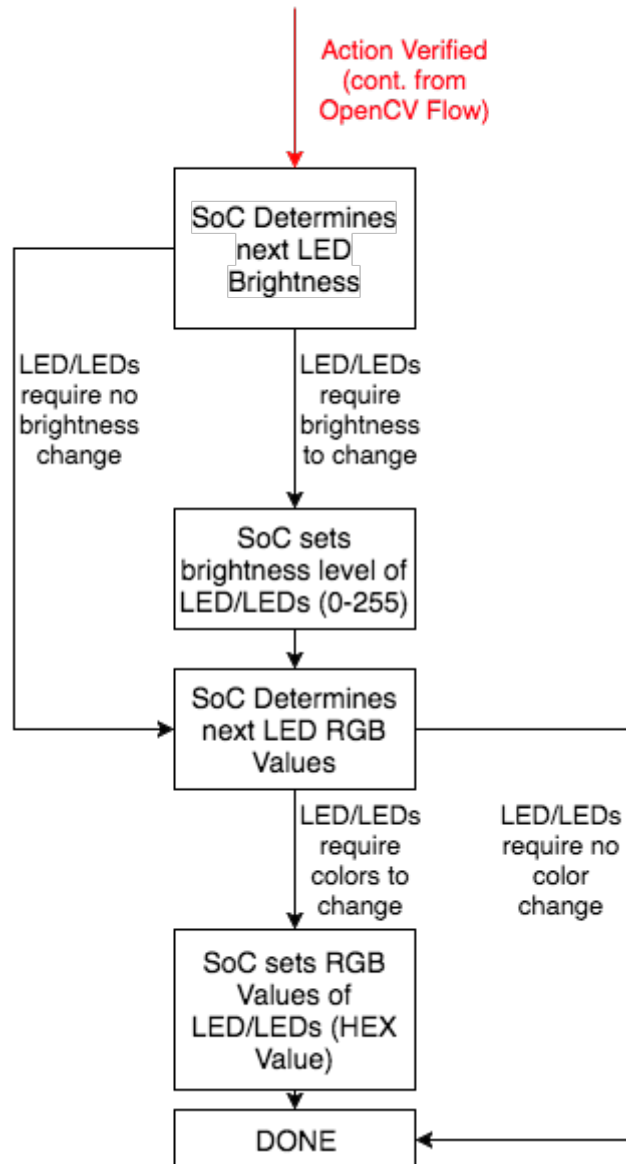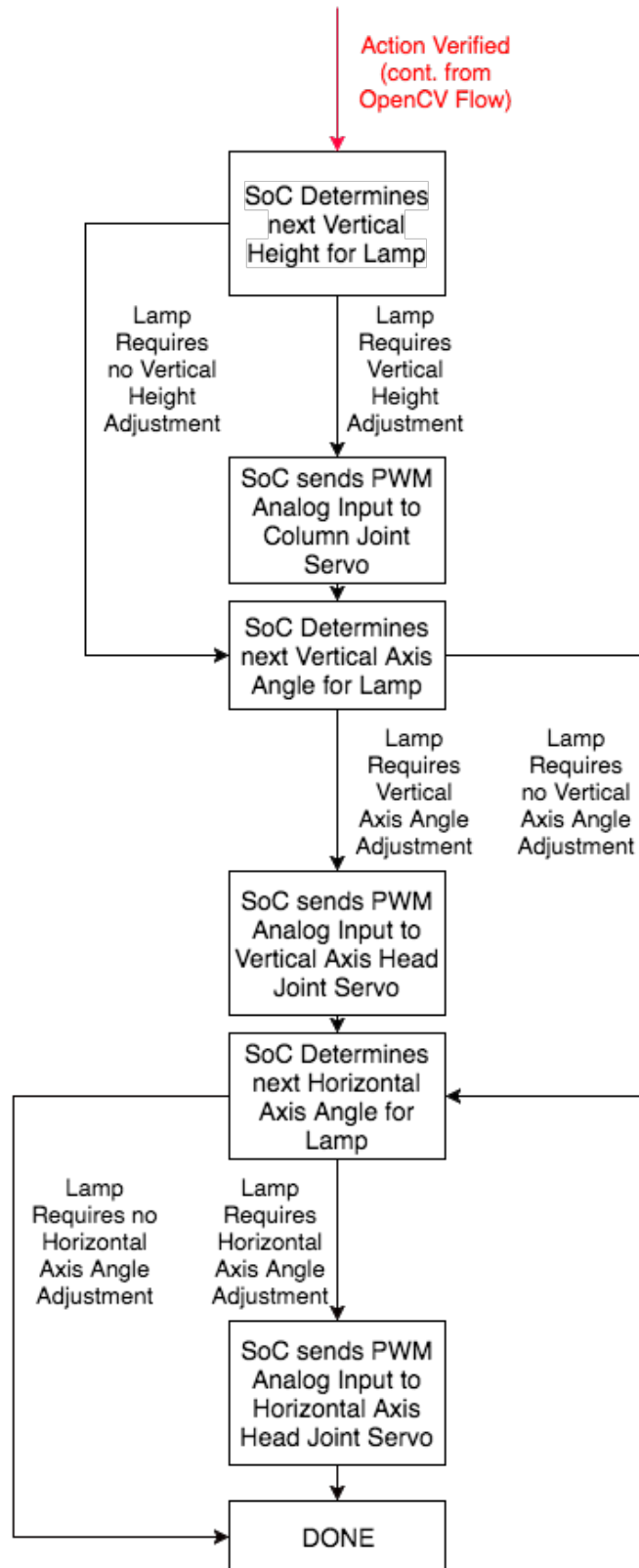**Fig. 9. OpenCV Image Processing Algorithm**

Fig. 10. LED Control Algorithm

Fig. 11. Servo Control Algorithm

4. Costs

Development costs are based on a $45/hour salary, working 8 hours a week for 3 people. We believe that to be production-ready there are a lot of added features that are out-of-scope for this course, but can be implemented, so only 50% of our final design is appropriated in the labor.

$$3*\frac{\$35}{1\,hour}*\frac{8\,hours}{1\,week}*\frac{15\,weeks}{}*2.5*2=\$63,000$$

The machine shop will be helping to place the servo motors within our pre-bought lamp. The cost are as follows:

$$\frac{\$50}{1\,hour}*\frac{10\,hours}{}=\$500$$

Part	Cost (prototype)	Cost (bulk,100 pieces)
Raspberry Pi Zero	$20.00	$5.00
Camera Module OV5467	$16.99	$6.84
8x8 LED Matrix WS2812B	$15.62	$4.30
Level-Shifter 74AHCT125	$1.50	$1.20
Architect Lamp	$22.00	$5.94
Voltage Regulator **MC78T05CT**	$0.56	$0.44
Servo motors x 3 HITEC HS 322HD	$43.35	$43.45
AC/DC Converter Sunforce GM1200	$22.04	$11.5
10Ω Resistors	$0.40	$0.10
Diodes 1N4148WXTPMSCT-ND	$0.14	$0.08
Capacitor (0.33μF)	$0.20	$0.12
PCA9685 PWM Driver	$14.95	$11.96
Switch TRD13D10WL	$1.00	$0.89

Total	$158.75	$91.82

Total cost of building the prototype: **$63,658.75**

5. Schedule

Week	Task	Delegation
2/20	Create Block Diagrams and physical design parts for mock design review document and design document	Dhruv
	Create camera and LED module as well as ethical and safety issues sections for mock and final design document	James
	Work on microprocessor, introduction and citation sections of the mock and final design document	Saksham
2/27	Order hardware parts for the project and assemble lamp hardware and base	Dhruv
	Develop control software for LEDs	James
	Develop OpenCV code to record and analyse images from web cam interface	Saksham
3/6	Attach servos and finalize position of hardware components	Dhruv
	Add GPIO signal output to control software	James
	Add feature extraction and detection	Saksham
3/13	Test hardware components and movement of lamp	Dhruv
	Test control to all IO signals from the SoC	James
	Test basic contour mapping and object detection using webcam	Saksham
3/20	Solder together the power routing module. Ensure documentation and individual progress reports are upto date	Dhruv
	Create control module which controls servos from routing module and SoC. Ensure documentation and individual progress reports are upto date	James
	Integrate gesture recognition with control module with James. Ensure documentation and individual progress reports are upto date	Saksham
3/27	Combine GPIO outputs with Servo and other parts	Dhruv
	Write code to handle servo motors and functions of interaction	James
	Combine gesture recognition code with SoC camera module	Saksham

4/3	Create function flow for behavior of robotic lamp	Dhruv
	Write function control for LEDs output structure	James
	Test gesture recognition from OpenCV and optimize for device	Saksham
4/10	Add interaction behavior to the servo motors as a reaction to gesture input	Dhruv
	Test gesture recognition quality and LED output quality	James
	Create interesting routines for robotic lamp	Saksham
4/17	Test power circuit and connect to the base of the lamp and other circuits	Dhruv
	Connect I/O module to the head of lamp	James
	Connect Controller module to the lamp and connect with the I/O module	Saksham
4/24	Finish up lab report for power module and servo motor part	Dhruv
	Finish up lab report for LED module and Camera part	James
	Finish up lab report for control module and computer vision software part	Saksham

6. Tolerance Analysis

6.1 PWM Driver

The PWM Driver is used to provide a PWM signal to the motors without putting the extra computation on the SoC. The Raspberry Pi also has only one PWM enabled GPIO Pin (GPIO18) which gets used in creating the signal for the LED grid. The PWM Driver has an operating voltage of 2.3-5.5V which is supplied by the power routing circuit module. The power routing circuit module provides a constant 5V output from voltage regulator which is in the tolerance limits for the circuit. A precision error of $10\mu s$ in the duty cycle can change up to 90° of position in the servo motors; therefore it's important to maintain high precision through the use of such a PWM driver, as opposed to a software one.

6.2 Power Routing Circuit

The power routing circuit consists of a linear voltage regulator which uses a voltage regulator(MC78T05CT) and decoupling capacitors($0.33\mu F$) to filter out the AC current. The voltage regulator has a tolerance of $\pm4\%$[29] and the capacitors come with a tolerance of 20%. These are still within the operating limits of the motors, LED and Raspberry Pi Zero. We also added a diode (1N4148WXTPMSCT-ND) to make sure the output coming from the 12V AC/DC Converter is within the

operating limits(5V-18V)[29] of the voltage regulator and to also ensure the correct polarity of the AC/DC converter.

7. Ethics and Safety

There are a lot of ethical issues and safety issues that will come up with a mechanical, robotic lamp. To highlight one of the most severe issues of this decade - privacy. We want to keep the lamp functioning as robotic rather than "smart". As it states in IEEE Ethic #8: "to treat fairly all persons and to not engage in acts of discrimination..." [22]. As spying on cameras have been a bigger problem for personal privacy, we want to prevent engagement in personal and discriminatory acts that may be possible by spying through the lamp's camera. We acknowledged this in our choice of parts, and in particular the Raspberry Pi Zero SoC, which has no networking capabilities built in. This "closed loops" robotic lamp will not have any communication to any signals or inputs from outside the lamp's circuitry, preventing any harm that can be done from attacking personal privacy through the camera.

We also want to emphasize and put efforts towards safety and preventing physical harm, an important IEEE Ethic, #9: "to avoid injuring others, their property…" [22]. As much effort as could to prevent mechanical and electrical malfunction of a robotic lamp, we are implementing a kill switch to immediately disable power to the control and I/O modules (until being turned back on). We will also provide guidelines on the area that the lamp may move, so users will be informed of potential injury or destruction if something were to get in the vicinity of the lamp. This most important includes the degree and range of movement the lamp may move. Additionally, since the lamp will be tracking the user's motions through the use of arm and hand, algorithms for image processing using OpenCV so that the lamp will never touch the hand for any reason.

Additionally, since we will be working with many pre-built parts such as servos, an LED matrix, and a SoC, we will abide IEEE Ethic #6: "to undertake technological tasks for others only if qualified by training or experience…" [20]. We will not take apart these parts and tamper with them unless we have read the documentation, safety guidelines, and all other paperwork regarding these parts. We will follow instructions on how to properly use these parts.

Safety is one of the most important priorities of this robotic lamp, as stated in IEEE Ethic #1: "to accept responsibility in making decisions consistent with the safety, health, and welfare of the public…"[22]. While we work with many electrical components such as the LEDs, we are aware that these parts will have many limiting factors. This includes particular Voltage and Current regulations. For example, datasheets regarding our LED Matrix[10] provides regulations on max voltage input into the LEDs, as well as working temperatures. Failure to follow regulations such as these will result in blowing out LEDs, or potentially worse. We will abide by each component's standards, and implement Voltage and Current regulators where necessary.

We are and continue to pay attention to safety precautions we will have to make regarding the servos. In our Requirements and Verifications for our Servos, we are making sure not to exceed torque

maximums and temperature maximums. This prevents the lamp from moving excessively, and from potential burning or fires.

We took into careful consideration our mechanical design in regards to safety. A lamp rotating and moving at high speeds can cause serious damage or injury, so maintaining a velocity and force that is non-threatening is very important to abiding and enforce IEEE Ethics #9 [22]. Our lamp and servo motor design prevents wide ranges of motions of the lamp. The lamp columns are only able to move vertically, and the lamp head is only able to move rotationally. We wanted to prevent the lamp from spinning back and forth and having a wide horizontal range of motion, so by only allowing vertical movement for the columns and rotational movement of the lamp head, we limit the area that needs to be avoided for full lamp functionality.

We also wanted to have a careful look at the force that the lamp is able to output from any point on the lamp at max velocities. The datasheet on the HS-322HD servo motor indicated a No-load speed of 60° in 0.19 seconds (4.8V) and a Stall torque of 3.0 kg/cm [16]. A Torque/Speed Curve for a motor helps us to determine that the relationship is linear:
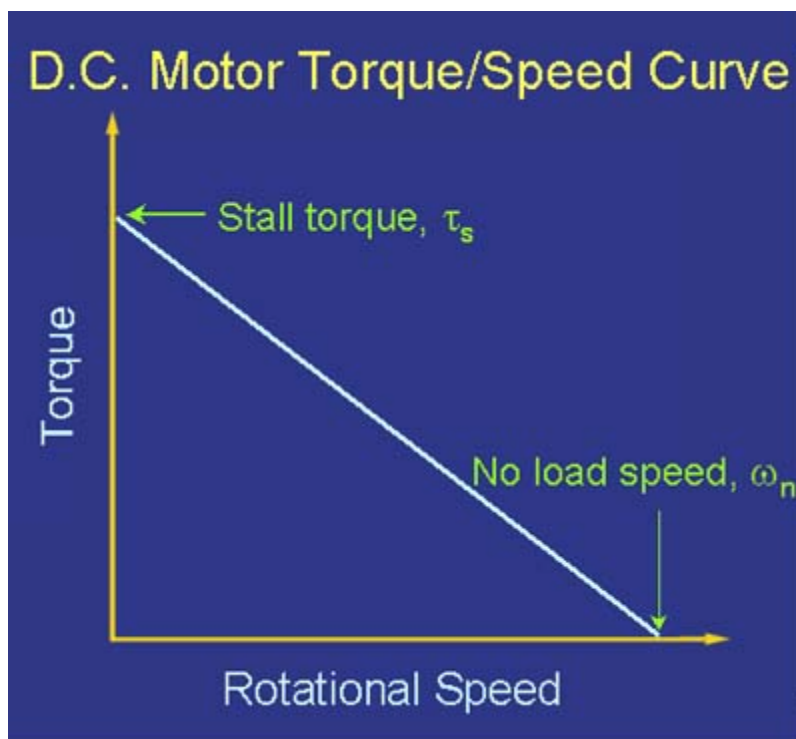

Fig. 12. D.C. Motor Torque/Speed Curve [30]

With this information, as well as the no load speed and stall torque of the HS-322HD, we were able to calculate the relationship between load torque and angular velocity:

$$\tau = 3 - 0.544\omega$$

τ= Torque (kg/cm)
ω= Angular Velocity (rads/second)

Using a lamp head weight of 75 grams at a radius of 2 inches (5.08cm), we calculate that the angular velocity for the lamp head is 4.81434 rads/second. Knowing that the lamp takes more than a second to make a full rotation, as well as the fact that it weighs less than a baseball (145 grams), we deem the lamp head as unable to cause harm. Looking at the lamp columns, we calculate a weight of 400 grams at a radius of 5 inches, we calculate that the angular velocity for the lamp head is 1.84 rads/second. This means the servo makes a full rotation in more than 3 seconds. This is even slower than the lamp head, and due to it's vertical motion, we believe that this is not a great enough force for harm as well. After future careful testing, if these angular velocities seem too high for commercial use, additional torque can be added to make the servo motors run slower.

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