

Self-Adjusting Monitor Stand

ECE 445 Design Document

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Spring 2022

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1. Introduction

1.1. Problem and Solution Overview

Certain monitor technologies today have fairly tight viewing angles, and viewing a computer screen from more than 30-45 degrees off the normal will often introduce visual artifacts that make it difficult to read [1]. However, most consumer monitor stands are not easily adjustable, and it is time consuming to constantly tweak the position to match every possible viewing angle.

Additionally, many workplace environments require the use of privacy screens, which are designed to limit the field of view as much as possible, which exacerbates the problem. We aim to break this tradeoff between greater privacy and ease of use.

To improve a monitor that both provides privacy within a public setting as well as user viewing ease, we plan to implement a monitor stand that automatically adjusts the screen to the user's position. This is illustrated in Figure 1. This monitor stand has both automatic and manual components. For the automatic components, the user's position is detected by a camera, and the monitor adjusts its location to an angle. The height of the monitor is also adjustable to the user's preference by using a linear actuator.

For the manual component, the user can press buttons on the attached remote. The horizontal pan is physically adjusted through a gear that is between the mounting box and the actuator, while the vertical tilt is attached to the monitor. The motors involved in these adjustments include encoders to facilitate proper closed loop control. The height adjustment is purely based on the user's input. The viewing angle, or the pan and tilt, is determined by the user's location when a command is given to adjust the screen.

1.2. Visual Aid

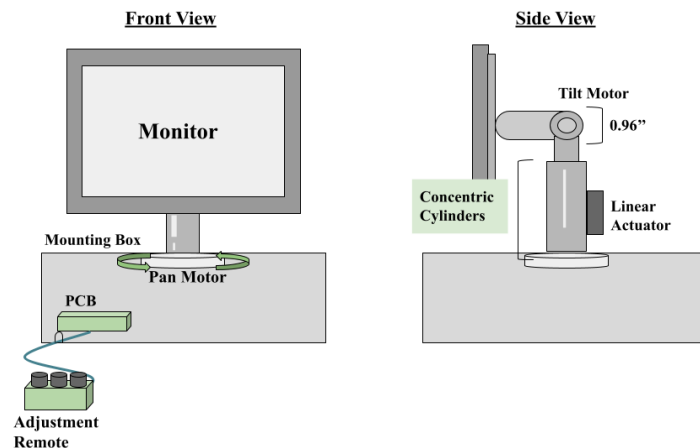


Figure 1. Simple sketch of the monitor stand and remote.

1.3. High-level Requirements

- **Adjustment to User Input:** If the “adjust” button is pressed, the monitor stand should automatically pan and tilt the monitor so that it is centered on the user within 10 degrees both vertically and horizontally. See Figure 2. If the “up” or “down” button is pressed, the system should raise or lower the monitor until the button is released, or the linear actuator reaches the maximum or minimum height, at a minimum rate of 2 cm/s.

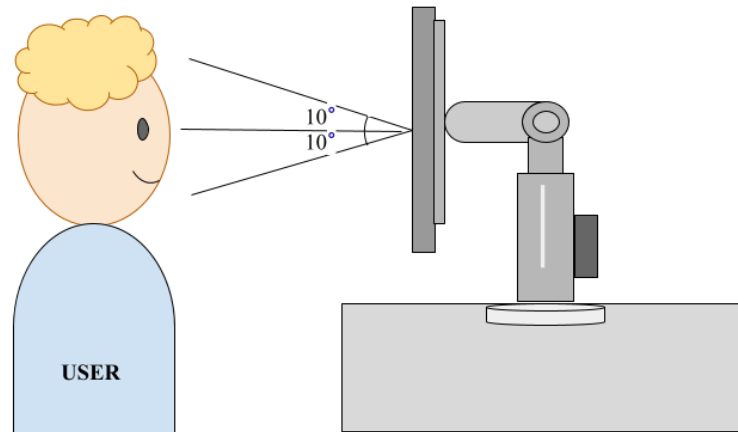


Figure 2. Depiction of desired accuracy in the vertical direction.

- **Face Detection:** The camera must be able to detect surroundings with a minimum of 15 FPS so the user is able to press the remote for monitor adjustment without pausing for the camera to process an accurate image of their current location. The detection system must also identify a face within the frame using Haar cascade face classification.
- **Reasonable Response Speed:** The system must adjust the angle of the monitor to be centered on the user (according to the first listed requirement) within 8 seconds. This time was chosen to ensure the system is capable of properly adjusting the monitor more quickly than the average time it would take a user to stand up, adjust the monitor by hand, check that it was adjusted to the desired angle, and readjust as needed.

2. Design

2.1. Block Diagram

The block diagram for this project is depicted in Figure 3. The main subsystems of the design are the power subsystem, the processing and motor control subsystem, the location detection subsystem, the remote module, and the mechanical subsystem. The power subsystem is responsible for providing the appropriate voltages to various components in the design from a 120 VAC input. The processing and motor control subsystem uses input provided by the location detection subsystem and the remote module to drive the motors. The location detection subsystem takes an input of the position of the user relative to the monitor and sends that data to the microcontroller in the processing subsystem. The mechanical subsystem consists of the motors in the design and physically moves the monitor stand. The final subsystem, the remote module, sends a signal to the processing subsystem based on the user's input, which in turn triggers the corresponding motor drivers.

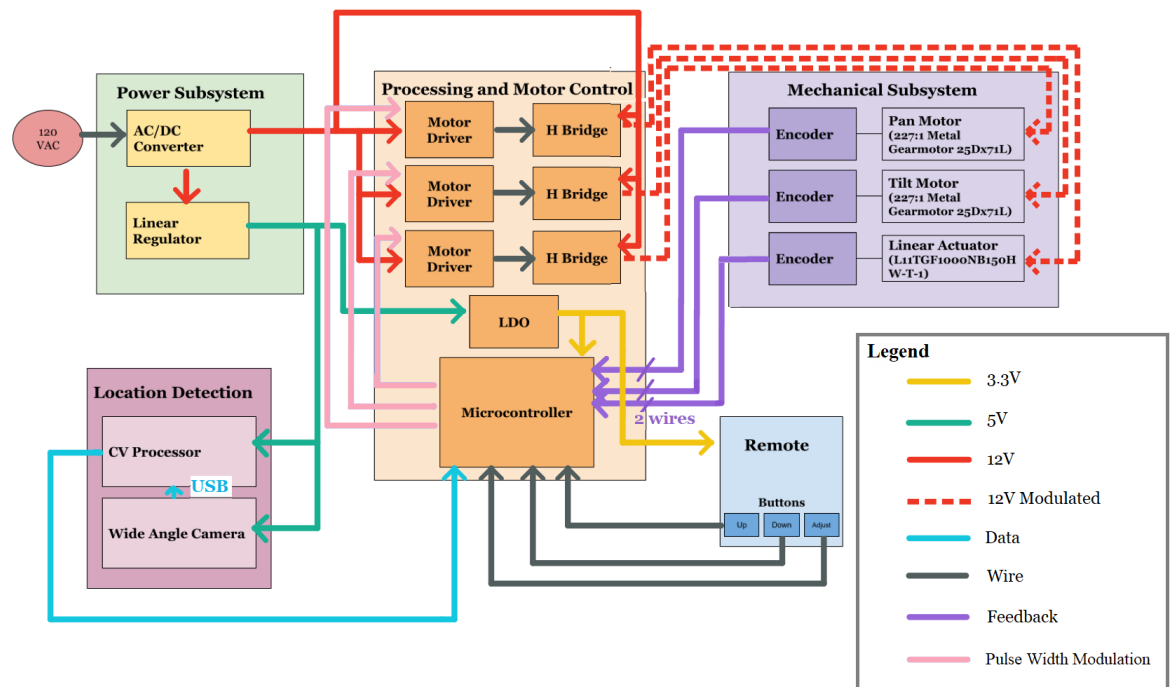


Figure 3. High-level block diagram of the monitor stand and remote.

2.2. Physical Design:

The physical design of the monitor stand is depicted in Figure 4. Three degrees of motion are accomplished by using a rotating motor at the base to pan the monitor, a rotating motor with a short moment arm near the monitor to tilt it upwards and downwards, and a linear actuator to adjust the height of the monitor. The entire stand rests on an aluminum box as a base. This box also houses the primary PCB and subsequent subsystems. Although not depicted, the remote module is connected to the main PCB by a 3-ft cable that extends from the base to where the user is seated. The initial testing of the design is based on a 16"x13.5" monitor, however, the design will be applicable to a variety of monitor sizes.

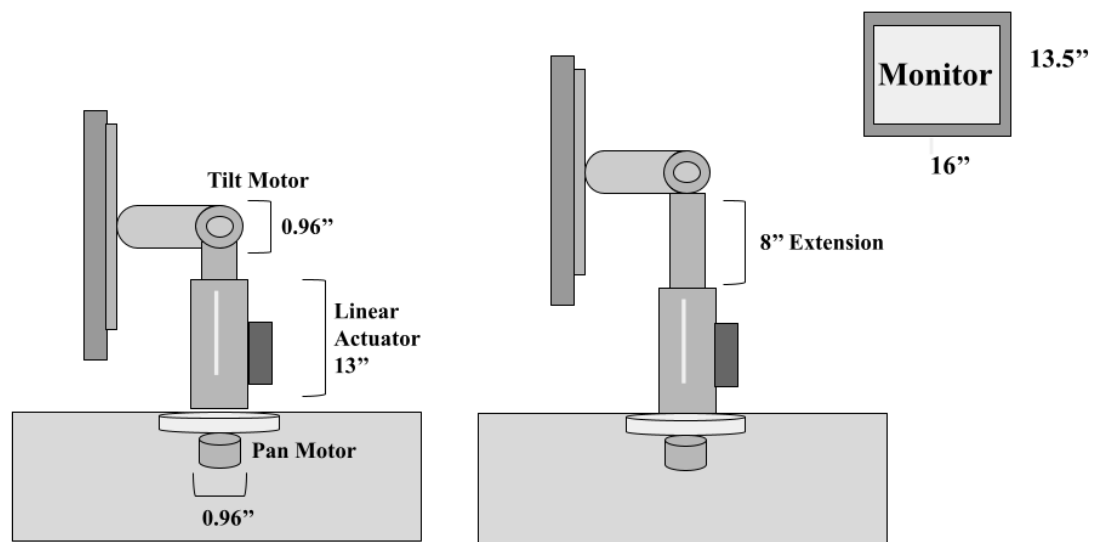


Figure 4: Sketch of the physical design including the placement of motors.

2.3. Power Subsystem

The entire project is powered using a wall adapter, which introduces the need for this subsystem. The power subsystem converts the input from AC to DC so that the various components in our device are appropriately powered. This subsystem also creates a 12 V and a 5 V power rail to accommodate the different voltage requirements of each component. An AC/DC converter takes the 120 VAC input and converts it to a DC 12 V output. The resulting 12 V is then used to create the 5 V rail via a buck converter.

In the design, the 5 V rail powers the camera, the CV processor, and is stepped down to power the microcontroller. The CV processor draws about 4 A, and the microcontroller and camera combined draw less than 1 A. The 12 V rail powers the motors, which each draw a maximum of 1.8 A, and is the basis for the 5 V

rail. Therefore, the 5 V rail must be able to support at least 5 A and the 12 V rail must be able to support 10 A.

Table 1: Power subsystem requirements and verification.

Requirements	Verification
1. Must convert 120 VAC to 12 V \pm 1 V and 5 V \pm 1 V power rails.	1. a) Connect the subsystem to a 120 VAC voltage source from the wall. b) Probe the 5 V rail using a digital multimeter (DMM) and ensure the measurement remains between 4 V and 6 V. c) Probe the 12 V rail using a DMM and ensure the measurement remains between 11 V and 13 V.
2. The 5 V rail should have a 5 A capacity, and the 12 V rail should have a 10 A capacity.	2. a) Use electronic load testing equipment to verify current requirements. b) Load should be placed on each rail and run for 10 minutes to ensure stability. While the load test is occurring, a DMM should be used to measure the voltages of both the 12V and 5V rails. These rails should not deviate from their designed voltages by more than the design specification (\pm 1V). c) The maximum voltage deviation from nominal should be recorded in the notebook.

2.4. Location Detection Subsystem

A core aspect of this project is the ability to detect the user and use that location to adjust the monitor. The location detection subsystem consists of a USB camera and a computer vision (CV) processor. We have decided to use an Odroid XU4 to serve as the processor in this project. Both main components in this subsystem are powered using the 5 V rail. The camera connects to the processor by USB, and the processor sends data to the microcontroller in the processing and motor control subsystem using the I2C protocol.

Table 2: Location detection subsystem requirements and verification.

Requirements	Verification
<p>1. Image processing must occur at 15 FPS to ensure accurate face detection without excessively heavy computation [2].</p>	<p>1. a) The image processing algorithm should be developed with an integrated FPS tracker. b) The system should be run in various lighting and facial conditions, while recording the framerate. Lighting conditions:</p> <ul style="list-style-type: none"> - Normal lighting measure in a lit workspace. - Low light in the same workspace, but with the light turned off. - High light in the workspace with an additional bright lamp directed at the face. <p>Facial Conditions:</p> <ul style="list-style-type: none"> - Neutral expression looking into the camera - Neutral expression turned slightly away from the camera. - Contorted facial expressions (e.g. angry) looking into the camera - Each of the above conditions are measured for different skin tones and ethnicities. <p>c) The minimum framerate should be recorded in the notebook.</p>
<p>2. The calculated ray from the camera to the detected facial position should be within 10 degrees of the actual ray from camera to user.</p>	<p>2. a) The image processing algorithm should include reporting on the target position (vector coordinates). b) Define the true camera-face</p>

	<p>vector by measuring the distance from the camera to the user's face (x_1) and measuring the distance that the face is horizontally from the center of the camera (x_2). The angle between the camera-face vector and a ray normal to the monitor can be calculated as $\theta = \sin^{-1}(x_2/x_1)$.</p> <p>c) The system should be run in a variety of lighting conditions and environments, and the true camera-face vector should be compared against the calculated.</p> <p>d) The maximum deviation of the calculated position from the actual position should be recorded in the notebook.</p>
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2.5. Processing and Motor Control

This subsystem uses information from the user and the camera to control the vertical, pan, and tilt motors. The main components in this subsystem are the microcontroller and MOSFET motor drivers. The microcontroller is powered using a low-dropout regulator (LDO), which regulates the 5 V from the power subsystem to 3.3 V as depicted in Figure 5. This is a necessary step because the microcontroller cannot be powered by a voltage exceeding 3.6 V.

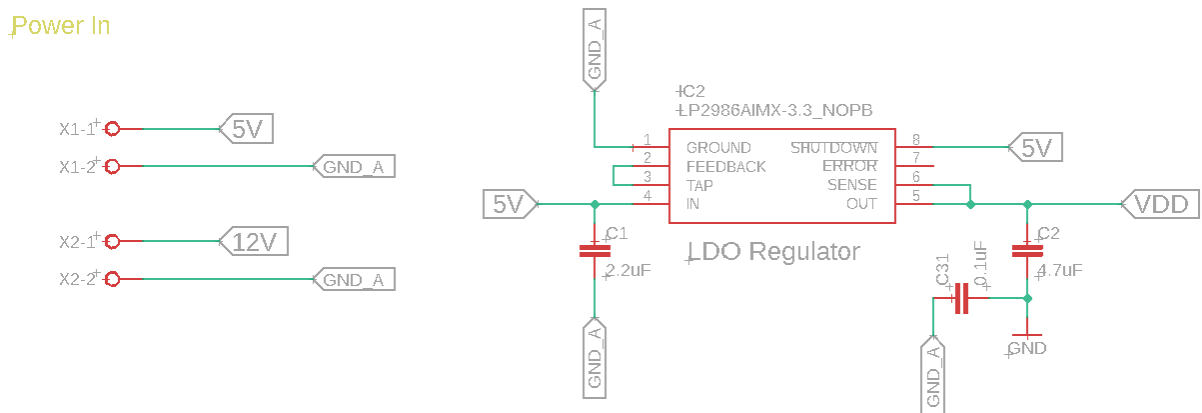


Figure 5: Circuit schematic for the conversion of the 5 V source to 3.3 V (VDD).

The DC rotary motors must be capable of operating in both directions to

	<p>then attempt to return it to the original position as closely as possible. Measure the encoder's reported new position.</p> <p>c) The average position drift should be recorded in the notebook.</p>
<p>3. The motor drivers must supply 3 A without exceeding 140°C.</p>	<p>3. a) Use an electronic load to simulate the motors and input a square wave ($V_{pp} = 10\text{ V}$) using a function generator</p> <p>b) Using a DMM, probe the output of the half-bridge driver configuration to measure the current.</p> <p>c) While the motor is operating in Test 1, measure the temperature of the assembly using an infrared thermometer.</p> <p>d) Ensure the temperature never rises above 140°C.</p>

2.6. Wired Remote Control

The user interface for this system is a wired remote with three buttons: an “up” button, a “down” button, and an “adjust” button. When a button is pressed, a signal is sent to the microcontroller in the processing and motor control subsystem. The monitor stand responds accordingly by moving up, down, or adjusting the angle of the screen with respect to the user. For vertical adjustment, the buttons must be held down until the monitor is at the desired position. For the angle adjustment, the “adjust” button should be pressed once. The buttons are powered using 3.3 V, which is accomplished by stepping down the voltage from the 5 V rail.

The circuit schematic of the remote module is depicted in Figure 8. The buttons are powered by a 3.3 V source to ensure that the signal received by the microcontroller is high enough to be measured as a logic 1 without exceeding the maximum set by the source voltage of the microcontroller. The signals from the three buttons are transmitted through an RJ-11 connector to the microcontroller in the processing and motor control subsystem via a 3-ft cable.

Remote Control

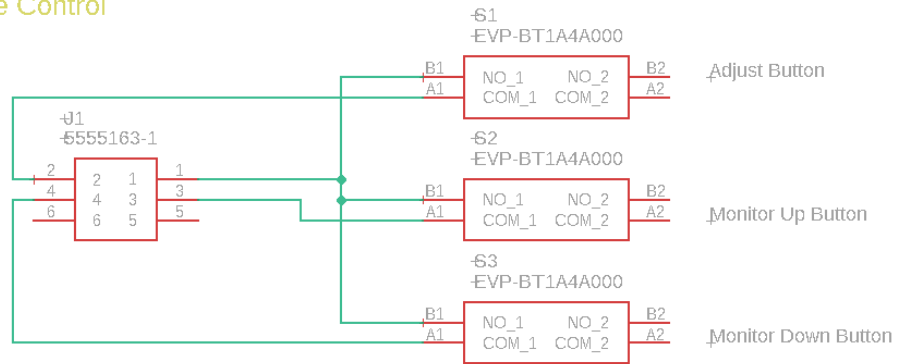


Figure 8: Circuit schematic of the remote module.

Table 4: Wired remote control module requirements and verification.

Requirements	Verification
1. The remote must send a signal to the microcontroller in the processing unit via a 3-ft cable.	<p>1. a) A DMM should be used to verify the signal at the PCB is detectable by the microcontroller.</p> <p>b) The voltage received by the microcontroller should be above the minimum logic 1 level ($0.7 * V_{DD}$ or 2.31 V). This will be measured with the DMM under various operating conditions.</p> <p>c) The average voltage at the microcontroller should be measured and recorded in the notebook.</p>

2.7. Mechanical Components

• Vertical

In order to physically move the monitor, a vertical mechanical subsystem is required. This unit consists of a linear actuator and an encoder. Based on the signal from the motor driver, the linear actuator adjusts the monitor height. The encoder provides feedback to the microcontroller to keep track of how much movement has occurred.

Table 5: Vertical mechanics requirements and verification.

Requirements	Verification
1. The linear actuator assembly must have a minimum of 6 inches of travel while supporting a load of 15 lbs.	1. a) Place a 15 lb load to simulate a monitor on the stand. A ruler should be used to measure travel length. b) A fixed point on the linear actuator mechanism should be chosen, and the system driven to its lower and upper end stops. The difference between the height of this point at these lower and upper stops should be calculated. c) This travel distance should be recorded in the notebook.
2. The surface temperature of the assembly must not exceed 115°F [5].	2. a) While the motor is operating in Test 1, measure the temperature of the assembly using an infrared thermometer. b) Ensure the temperature never rises above 115°F.

- **Pan**

There is also a subsystem to allow the monitor to pan. This is accomplished using a rotating platform that allows the monitor to turn to the right or left. The microcontroller sends a signal to the motor driver, which sends a signal to the pan motor. This motor is a 12 V DC motor with a reduction gearing attached. This actuates a worm drive system to turn the monitor. The encoder provides feedback on how much the motor has turned so that the monitor stops when it is centered on the user within 10 degrees.

Table 6: Pan mechanics requirements and verification

Requirements	Verification
1. The pan motor assembly must be capable of traveling 45° in either direction when measured from the center position.	1. a) Using a ruler, draw a straight line out from the front of the motor assembly base. b) Align a protractor with the 90° marking on top of the line drawn in Step a). Draw rays originating from the same

	<p>point as the initial line to mark out 45° to the left and right.</p> <p>c) With the monitor mount and pan motor in the center position, mark a position of the rotating assembly that is in line with the center line.</p> <p>d) Drive the motor to rotate to the left. Check that the mark made in Step c) is now aligned with or past the leftmost 45° line. Return the assembly to the center position.</p> <p>e) Repeat Step d), this time rotating the motor to the right.</p>
2. The surface temperature of the assembly must not exceed 115°F [5].	<p>2. a) While the motor is operating in Test 1, measure the temperature of the assembly using an infrared thermometer.</p> <p>b) Ensure the temperature never rises above 115°F.</p>

- **Tilt**

Similar to the pan mechanical subsystem, there is also a subsystem to allow the monitor to tilt. This is accomplished using a rotating motor that tilts the monitor screen up or down. The microcontroller sends a signal to the motor driver, which sends a signal to the tilt motor. This motor is a 12 V DC motor with a reduction gearing attached. The motor drives another worm gearing to tilt the monitor. A worm drive system ensures that gravity cannot backdrive the motor easily. The encoder provides feedback on how much the motor has tilted the monitor to ensure it is centered on the user within 10 degrees.

Table 7: Tilt mechanics requirements and verification

Requirements	Verification
1. The tilt motor assembly must have 15° of travel upward and downward when measured from the center position.	<p>1. a) Start the monitor perpendicular to the mounting box.</p> <p>b) Set up a stable vertical clamp with a protractor whose flat edge aligns with the edge of the monitor.</p>

	<p>c) Have the tilt motor go to maximum downwards position and measure the new angle with the stable protractor.</p> <p>d) Repeat for maximum upwards position.</p>
<p>2. The surface temperature of the assembly must not exceed 115°F [5].</p>	<p>2. a) While the motor is operating in Test 1, measure the temperature of the assembly using an infrared thermometer.</p> <p>b) Ensure the temperature never rises above 115°F.</p>

2.8. Tolerance Analysis

One of the most challenging and important aspects of our project is the ability to detect the location of a person in front of the monitor using a camera and computer vision. The ability to train and efficiently recognize the human face from a video input affects almost every aspect of our design because the horizontal pan and vertical movement is automatic based on where the user is.

First, we use Haar features instead of having the convolutional neural net learn which features to look for. Haar features are better for recognizing edges, as long as the user's face is not obscured. This allows us to create a classifier with a smaller dataset.

Haar features split up the window into various sections. The pixels in these sections are added, and the difference between them is calculated. Summing all the pixels in a window can be inefficient. If we use integral images, which set the value of the pixel at (x,y) to the sum of the pixels above and to the left of it, the sum of all the pixels in a given window can be calculated in $O(1)$ time, rather than $O(n)$, where n represents the window area [6].

However, the number of Haar features can be quite large depending on the size of the window. If we analyzed the image with a 24x24 window, there would be 160,000+ possible Haar features. We use the "Adaboost" boosting technique in order to find which features are the best to use [6]. This algorithm works by repeatedly changing the weights of the Haar features until a minimum error rate is met, with a final classifier of the weighted sum of the weak classifiers. This can allow us to use as few as 200 features with a 95% accuracy [7].

Finally, when analyzing the image, much of it is background instead of the user.

Instead of passing all 200 features in a single window, we first check if the window is a face through a cascade classifier that groups features into stages. If it does not pass all the stages, the region is classified as a “non facial region,” and it is not analyzed again.

These techniques allow for fast, robust face detection within our camera’s field of view. Various other techniques can be applied to improve the positive detection rate for differing backgrounds and situations. By tailoring our algorithm to solve any significant new problems encountered, we are confident that the Location Detection subsystem functions as intended.

3. Cost and Schedule

3.1. Cost Analysis

Labor:

In this project, the cost of labor can be attributed to that of the team and the Machine Shop.

The average annual salary for an electrical engineering graduate of the University of Illinois at Urbana-Champaign (UIUC) was \$79,714 as of the 2018-19 academic year [8]. Assuming a 40 hour work week for 52 weeks in a year, this salary can be converted to an hourly rate of around \$38.32/hr. This project will take approximately 100 hours to complete.

$$\text{Total Team Labor} = 3(\$38.32/\text{hr} \times 2.5 \times 100 \text{ hrs}) = \$22,992 .$$

Labor and material rates for engineering machine shops at UIUC range from \$35/hr to \$60/hr depending on the department [9, 10, 11]. Therefore, a reasonable rate assumption of \$50/hr can be made. This project will take approximately 18 hours for the Machine Shop.

$$\text{Total Machine Shop Cost} = \$50/\text{hr} \times 18 \text{ hrs} = \$900.$$

Parts:

Table 8: Cost breakdown of the required components.

Part Number	Description	Manufacturer	Quantity	Price/ Unit	Cost
LM200-10B12-C	AC/DC Converter	Mornsun America, LLC	1	\$24.06	\$24.06
200217	5A Voltage Regulator	DROK	1	\$9.99	\$9.99
VA-139-52	3A Voltage Regulator	Valefod	6	\$1.83	\$10.99
926-LP2986AIMX33NOPB	LDO Voltage Regulators	Texas Instruments	1	\$2.28	\$2.28
STM32GO61C8T6	Mainstream Arm Cortex-M0+ 32-bit MCU	STMicroelectronics	1	\$4.05	\$4.05
490-TB007-508-02 BE	Fixed Terminal Blocks 2	CUI Devices	5	\$0.85	\$4.25
NCP51530BDR2G	Half Bridge	onsemi	6	\$2.03	\$12.18

	Driver				
IRFZ24NPBF	N-Channel MOSFET	Infineon Technologies	12	\$0.65	\$7.84
1655-1354-1-ND	Diode Schottky 45V 15A	SMC Diode Solutions	12	\$0.80	\$9.60
4869	227:1 Gearmotor 25Dx71L with encoder	Pololu	2	\$34.95	\$69.90
L11TGF1000NB15 0HW-T-1	8-inch Linear Actuator Motor	ECO LLC	1	\$41.99	\$41.99
G143452239825	ODROID-XU4	HardKernel	1	\$53.00	\$53.00
Tecknet C016 720P Web Camera	USB Camera	iNassen	1	\$26.99	\$26.99
			Total	\$277.12	

Sum of Costs = Total Labor Cost + Machine Shop Cost + Cost of Parts
= \$22,992 + \$900 + **\$277.12** = **\$24,169.12**.

3.2. Schedule

Table 9: Proposed weekly schedule and division of labor to complete the project.

Week	Anna	Jake	Iris
2/28	Finish PCB design	Finish PCB design	Finish PCB design
3/7	Research face-detection algorithms	Research and code half-bridge control	Research face-detection algorithms
3/14	BREAK	BREAK	BREAK
3/21	Continue research and come up with test cases for face detection and start soldering	Work on communication between camera and CV processor and start soldering	Continue research and begin coding face detection and start soldering
3/28	Finish soldering and start debugging the power subsystem	Finish soldering and start debugging the power subsystem	Finish soldering and start debugging the power subsystem
4/4	Test and debug the remote module	Debug the motor control	Debug the location detection subsystem

4/11	Finish any remaining debugging	Finish any remaining debugging	Finish any remaining debugging
4/18	Mock Demo	Mock Demo	Mock Demo
4/25	Address any issues and finalize project for Demo	Address any issues and finalize project for Demo	Address any issues and finalize project for Demo
5/2	Work on Final Report	Work on Final Report	Work on Final Report

4. Ethics and Safety

One of the major ethical concerns in our system is the potential for privacy invasion. The monitor stand uses a camera to identify where the user is sitting and processes the image data to determine how the monitor should be moved. Section I.1 of the IEEE Code states that we must “protect the privacy of others” [12] and Section 1.6 of the ACM Code of Ethics states that “an essential aim...is to minimize negative consequences of computing, including threats to health, safety, personal security, and privacy” [13]. To ensure the privacy of the user is protected, the camera image is only accessed internally by the processor when necessary. There is no long-term storage of any image data, and the images are not used for any purpose other than calculating the necessary monitor adjustments.

Another ethical consideration related to the detection of the user. A common issue in detection and facial recognition is the disparity of detection between races and skin tones. It is our responsibility to treat everyone fairly and avoid engaging in any kind of discrimination based on color or race [12, 13]. We shall do our best to address this problem by selecting training datasets that contain faces of various races and skin tones.

Additionally, there are safety considerations that must be made regarding the system. The IEEE Code of Ethics states in Section I.1 that we must “hold paramount the safety, health, and welfare of the public” [12]. Section II.9 also states that we must consider how our system could injure others or their property. In our proposed design, we are limiting the speed at which the monitor moves to prevent damage, and we are addressing user safety concerns by requiring that the surface temperature of the device remain below 115°F and by controlling the current through the motor. The linear actuator also includes electromechanical endstops to prevent motor stalls when the end of travel is reached.

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