Self-Adjusting Monitor Stand

ECE 445 Design Document

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Table of Contents

1. Introduction.................................................................................................................. 3
   1.1. Problem and Solution Overview........................................................................ 3
   1.2. Visual Aid............................................................................................................. 3
   1.3. High Level Requirements................................................................................... 4
2. Design.......................................................................................................................... 4
   2.1. Block Diagram...................................................................................................... 4
   2.2. Physical Design................................................................................................... 5
   2.3. Power Subsystem.................................................................................................. 6
   2.4. Location Detection Subsystem...........................................................................?
   2.5. Processing and Motor Control...........................................................................?
   2.6. Wired Remote Control.......................................................................................?
   2.7. Mechanical Components.................................................................................?
   2.8. Tolerance Analysis.............................................................................................?
3. Cost and Schedule......................................................................................................?
   3.1. Cost Analysis.......................................................................................................?
   3.2. Schedule.............................................................................................................?
4. Ethics and Safety.........................................................................................................?
5. References....................................................................................................................?
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 well adjustable, and it would be 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, only exacerbating 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 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**

- **Detection and Adjustment:** If the “adjust” button is pressed, the monitor stand should pan and tilt the monitor so that it is centered on the user within 10 degrees both vertically and horizontally. See Figure 2.

![Figure 2. Depiction of desired accuracy in the vertical direction.](image)

- **Vertical Positioning:** 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.

- **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.

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 use input provided by the location detection subsystem and the remote module to drive the motors. The location detection subsystem, as the name suggests, determines 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 drives the motors appropriately.
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. The initial testing of the design is based on a 18”x16” monitor, however, the design will be applicable to a variety of monitor sizes.
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.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verification</th>
</tr>
</thead>
</table>
| 1. Must convert 120 VAC to 12 V±1 V and 5 V±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 and ensure the measurement remains between 4 V and 6 V.  
c) Prove the 12 V rail using a |
digital multimeter and ensure the measurement remains between 11 V and 13 V.

2. The 5 V rail should have a 6 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. Voltage variance should remain within specification listed above.
   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.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Image processing must occur at 15 FPS to ensure accurate face detection without excessively heavy computation [2].</td>
<td>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. c) The minimum framerate should be recorded in the notebook.</td>
</tr>
<tr>
<td>2. The calculated ray from the camera to the detected facial position should be within 10 degrees of the actual ray from</td>
<td>2. a) The image processing algorithm should include reporting on the target position (vector coordinates).</td>
</tr>
</tbody>
</table>
camera to user.

| b) 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.  
| c) The maximum deviation of the calculated position from the actual position should be recorded in the notebook. |

### 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. This is a necessary step because the microcontroller cannot be powered by a voltage exceeding 3.6 V.

Signals from the user are sent to the microcontroller, which then communicates with the motor drivers. If the microcontroller receives a signal to move the monitor up or down, it communicates that information to the motor driver. The appropriate motor driver uses this signal to control the linear motor. If the microcontroller receives a signal to adjust the monitor angle, it first accesses data from the CV processor to determine the position of the user relative to the center of the monitor and to determine how far the monitor must pan and tilt. Encoders on the motors send feedback to the microcontroller whenever there is movement to ensure that the monitor is adjusted appropriately.

![Circuit schematic](image)

**Figure 5:** Circuit schematic for the conversion of the 5 V source to 3.3 V (VDD).
Figure 6: Circuit schematic of one half-bridge motor driver.

Table 3: Processing and motor control subsystem requirements and verification.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verification</th>
</tr>
</thead>
</table>
| 1. Must convert the voltage from the 5 V rail to 3.3 V ± 0.2 V to be used by the microcontroller. | 1. a) Connect the pin 4 on the LDO to a 5 V source.  
b) Probe pin 5 on the LDO using a digital multimeter and ensure the measurement remains between 3.1 V and 3.5 V. |
| 2. The microcontroller must not miss encoder steps at normal operational speeds between 2 RPM and 10 RPM. | 2. a)                                                                                                   |
| 3. The motor drivers must supply 3 A without exceeding 140°C.                | 3. a) Use an electronic load to simulate the motors and input a square wave (V_{pp} = 10 V) using an oscilloscope.  
b) Using a digital multimeter, probe the output of the half-bridge driver configuration to measure the current.  
c) While the motor is operating in Test 1, measure the temperature of the assembly using an infrared thermometer. |
d) Ensure the temperature never rises above 140°C.

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.

![Remote Control](image)

**Figure 7:** Circuit schematic of the remote module.

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The remote must send a signal to the microcontroller in the processing unit via a 3-ft cable.</td>
<td>1. a) A DMM should be used to verify the signal at the PCB is detectable by the microcontroller. 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. c) The average voltage at the</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Requirements</th>
<th>Verification</th>
</tr>
</thead>
</table>
| 1. The linear actuator assembly must have a minimum of 6 inches of travel. | 1.  a) 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 [3]. | 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

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The pan motor assembly must be capable of traveling 45 degrees in either direction when measured from the center position.</td>
<td>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 point as the initial line to mark out 45° to the left and right. 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. 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. e) Repeat Step d), this time rotating the motor to the right.</td>
</tr>
<tr>
<td>2. The surface temperature of the assembly must not exceed 115°F [3].</td>
<td>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.</td>
</tr>
</tbody>
</table>

- **Tilt**

Similar to the pan mechanical subsystem, there is also a subsystem to allow the monitor to tilt. This is accomplished using a 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

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The tilt motor assembly must have 15 degrees of travel upward and downward when measured from the center position.</td>
<td>1.</td>
</tr>
</tbody>
</table>
| 2. The surface temperature of the assembly must not exceed 115°F [3].       | 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.                                                |

#### 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 [4].

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 [4]. 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 just even 200 features with a 95% accuracy [5].

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.

Total Team Labor = 3($38.32/hr x 2.5 x 100 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.

Total Machine Shop Cost = $50/hr x 18 hrs = $900.

Parts:

Table 8: Cost breakdown of the required components.

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Quantity</th>
<th>Price per Unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>???</td>
<td>AC/DC Converter</td>
<td>???</td>
<td>1</td>
<td>???</td>
<td>???</td>
</tr>
<tr>
<td>Part Number</td>
<td>Description</td>
<td>Supplier</td>
<td>Quantity</td>
<td>Cost 1</td>
<td>Cost 2</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------</td>
<td>-------------------</td>
<td>----------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>926-LP2986AIMX33NOPB</td>
<td>LDO Voltage Regulators</td>
<td>Texas Instruments</td>
<td>1</td>
<td>$2.28</td>
<td>$2.28</td>
</tr>
<tr>
<td>STM32GO61C8T6</td>
<td>Mainstream Arm Cortex-M0+ 32-bit MCU</td>
<td>STMicroelectronics</td>
<td>1</td>
<td>$4.05</td>
<td>$4.05</td>
</tr>
<tr>
<td>490-TB007-508-02BE</td>
<td>Fixed Terminal Blocks 2</td>
<td>CUI Devices</td>
<td>5</td>
<td>$0.85</td>
<td>$4.25</td>
</tr>
<tr>
<td>NCP51530BDR2G</td>
<td>Half Bridge Driver</td>
<td>onsemi</td>
<td>6</td>
<td>$2.03</td>
<td>$12.18</td>
</tr>
<tr>
<td>IRFZ24NPBF</td>
<td>N-Channel MOSFET</td>
<td>Infineon Technologies</td>
<td>12</td>
<td>$0.65</td>
<td>$7.84</td>
</tr>
<tr>
<td>1655-1354-1-ND</td>
<td>Diode Schottky 45V 15A</td>
<td>SMC Diode Solutions</td>
<td>12</td>
<td>$0.80</td>
<td>$9.60</td>
</tr>
<tr>
<td>4869</td>
<td>227:1 Gearmotor 25Dx71L with encoder</td>
<td>Pololu</td>
<td>2</td>
<td>$34.95</td>
<td>$69.90</td>
</tr>
<tr>
<td>L11TGF1000NB150HW-T-1</td>
<td>8-inch Linear Actuator Motor</td>
<td>ECO LLC</td>
<td>1</td>
<td>$41.99</td>
<td>$41.99</td>
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<tr>
<td>G143452239825</td>
<td>ODROID-XU4</td>
<td>HardKernel</td>
<td>1</td>
<td>$53.00</td>
<td>$53.00</td>
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<tr>
<td>Tecknet C016 720P Web Camera</td>
<td>USB Camera</td>
<td>iNassen</td>
<td>1</td>
<td>$26.99</td>
<td>$26.99</td>
</tr>
<tr>
<td>???</td>
<td>ISP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sum of Costs** = Total Labor Cost + Machine Shop Cost + Cost of Parts

= $22,992 + $900 + $_____ = $___.

### 3.2. Schedule

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

<table>
<thead>
<tr>
<th>Week</th>
<th>Anna</th>
<th>Jake</th>
<th>Iris</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/28</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/7</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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” [6] 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” [7]. 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 [6, 7]. 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” [6]. 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.
References


[?] Mamadou Diallo, “Bootstrap Circuitry Selection for Half-Bridge Configurations,” *Texas
Introduction

1. Design

1. Block Diagram:

2. Physical Design (if applicable):
   A physical diagram of the project indicating things such as mechanical dimensions or placement of sensors and actuators. The physical diagram should also be accompanied by a brief one paragraph description.

3. [SUBSYSTEM NAME]
   For each subsystem in your block diagram, you should include a highly detailed and quantitative block description. Each description must include a statement indicating how the block contributes to the overall design dictated by the high-level requirements. Any and all design decisions must be clearly justified. Any interfaces with other blocks must be defined clearly and quantitatively.
   Include any relevant supporting figures and data in order to clearly illustrate and justify the design. Typically a well justified block design will include some or all of the following items: Circuit schematics, simulations, calculations, measurements, flow charts, mechanical diagrams (e.g. CAD drawings, only necessary for mechanical components).
   You must include a Requirements and Verifications table. Please see the R&V page for guidance on writing requirements and verification procedures.

4. Tolerance Analysis: Through discussions with your TA, identify the block or interface critical to the success of your project that poses the most challenging requirement. Analyze it mathematically and show that it can be feasibly implemented and meet its requirements. See the Tolerance Analysis guide for further guidance.

2. Cost and Schedule

1. Cost Analysis: Include a cost analysis of the project by following the outline below. Include a list of any non-standard parts, lab equipment, shop services, etc., which will be needed with an estimated cost for each.
   - Labor: (For each partner in the project)
     Assume a reasonable salary
     ($/hour) x 2.5 x hours to complete = TOTAL
     Then total labor for all partners. It's a good idea to do some research into what a graduate from ECE at Illinois might typically make.
   - Parts: Include a table listing all parts (description, manufacturer, part #, quantity and cost) and quoted machine shop labor hours that will be needed to complete
the project.

- Sum of costs into a grand total

2. **Schedule:**
   Include a time-table showing when each step in the expected sequence of design and construction work will be completed (general, by week), and how the tasks will be shared between the team members. (i.e. Select architecture, Design this, Design that, Buy parts, Assemble this, Assemble that, Prepare mock-up, Integrate prototype, Refine prototype, Test integrated system).

3. **Discussion of Ethics and Safety:**

   1. Expand upon the ethical and safety issues raised in your proposal to ensure they are comprehensive. Add any ethical and safety concerns that arose since your proposal.
   2. Document procedures to mitigate the safety concerns of your project. For example, include a lab safety document for batteries, human/animal interfaces, aerial devices, high-power, chemicals, etc. Justify that your design decisions sufficiently protect both users and developers from unsafe conditions caused by your project.

   Projects dealing with flying vehicles, high voltage, or other high risk factors, will be required to produce a Safety Manual and demonstrate compliance with the safety manual at the time of demo.

4. **Citations:**

   Any material obtained from websites, books, journal articles, or other sources not originally generated by the project team **must be appropriately attributed with properly cited sources** in a standardized style such as IEEE, ACM, APA, or MLA.