ECE 445

Spring 2024

Design Document

An Auto-Hand Chasing Lamp With Hand Gesture Control

Team 49
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1. Introduction

Problem:

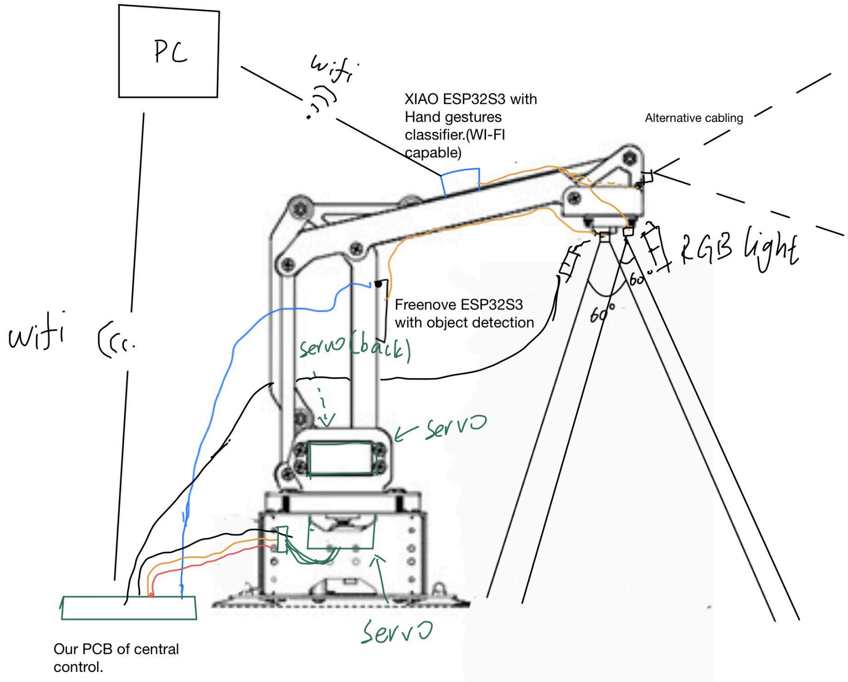
In industrial workspaces, inadequate lighting, especially from shadows, hinders precision tasks like soldering, impacting work quality and efficiency. Traditional lighting lacks flexibility and fails to meet specific task needs, leading to a demand for a smart, adaptable desk lamp.

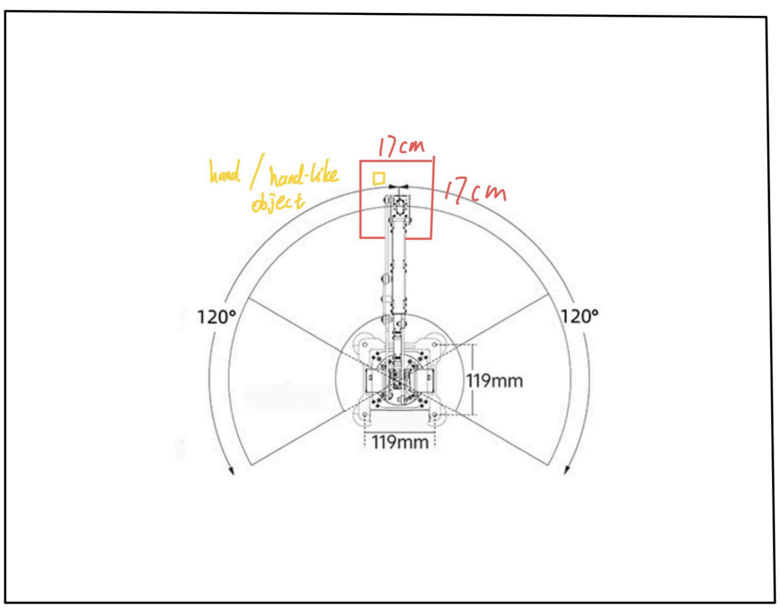
Solution:

Our design is a desk lamp equipped with the capability to autonomously track the user's hand/handlike object movements, thereby eliminating the common issue of shadows obscuring the work area. This is achieved through a combination of a camera, several servo motors, and a flexible mechanical arm, all of which work in tandem to reposition the lamp in real-time

The system utilizes gesture recognition technology, powered by an ESP32 module, to interpret hand gestures. This allows users to control the lamp's functionalities—ranging from adjusting brightness and color temperature to switching the lamp on and off. Furthermore, the lamp is capable of executing more advanced commands, such as controlling the RGB matrix to generate light to create atmosphere.

1.3 Visual Aid





1.4 High-level requirements list:

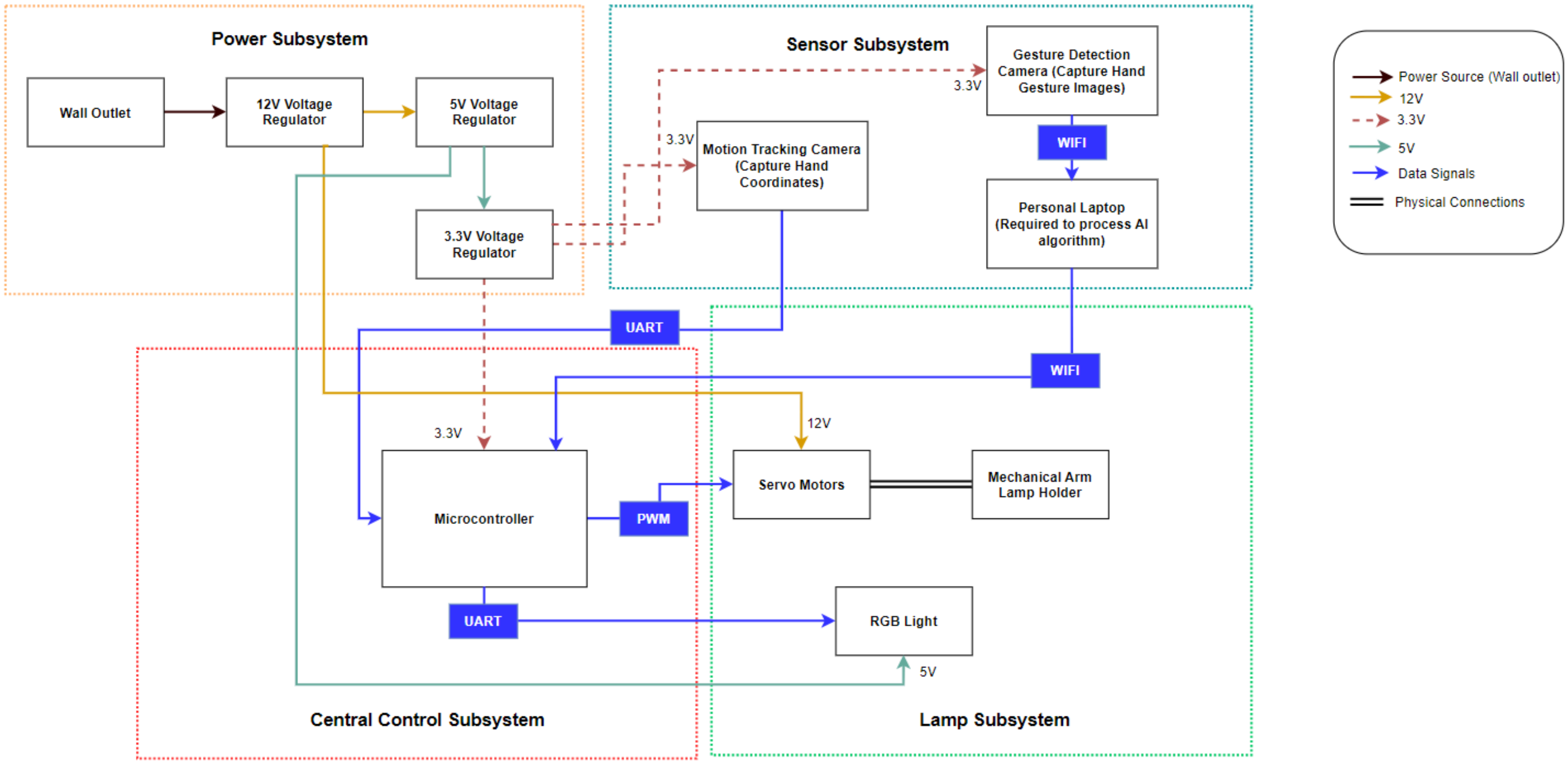
i. **Autonomous Tracking Accuracy:** The smart desk lamp can accurately detect and follow a human hand's movement when a hand is placed at least 15cm away from the camera. The lamp should differentiate human hands from objects and not move when a pen is placed in front of the camera.

ii. **Gesture Recognition Responsiveness:** The user can show the following hand gestures to control the light:
   1. Palm or fist to open or close the RGB light
   2. Control the movement of the Server by hand gestures
   3. A pinching motion to activate and deactivate tracking mode
   4. Other interesting features.

iii. **Light Adjustment Range:** The lamp can change between 2 brightness and 2 colors when different hand gestures are captured through the camera.

2. Design

2.1 Block Diagram



Auto-Hand Chasing Lamp's Block Diagram

2.2 Subsystem Overview

2.2.1 Sensor Subsystem

The sensor subsystem is divided into two systems, the first is the object detection system, we will use this to capture images in ESP32S3Cam, run the pre-trained object detection AI locally in ESP32S3, and pass the offset to the central control system. Eventually, the model may be trained using the model hand rather than the real hand according to various limitations.

In addition, the gesture system will use another ESP32S3cam for image capture. If the accuracy of the training model is too low, the picture will be transmitted to the computer through WIFI, and the command will be sent to the central control system after the picture is processed on the computer.

2.2.2 Central Control Subsystem

This system contains a microcontroller that integrates the ESP32 module and necessary I/O modules. It needs to process the input data from the sensor system like the offset of the servo and the data into the RGB light. It can also communicate remotely with a computer to control specific programs through WIFI. The lamp subsystem will receive outputs from the microcontroller and change mechanical arm movement and light bulb activities based on the detected hand gestures. Detectable gestures will include fists and raising, directions of thumbs, and other interesting gestures. The gestures will be able to turn on/off, increase/decrease brightness, and increase/decrease light temperature and other features.

2.2.3 Lamp Subsystem

The lamp subsystem makes up the physical lamp that will be used to track the user's hand/ hand-like object movement. It contains two key parts, which are a mechanical arm lamp holder and a light bulb. Three servo motors and a linear potentiometer are used to control the rotation and location of the lamp. The lighting bulb should be adjustable in terms of color temperature and brightness through instructions from the central control system.

2.2.4 Power Subsystem

The power subsystem provides the power needed for the sensors, microcontroller, and lamp system. We use a 12V voltage adapter to power the core lamp system. A separate 3.3V voltage adapter will be used to power smaller components including the camera sensor and microcontroller. The power needs to be sufficient to support the three servo motors in moving the physical-mechanical arms, and a wall outlet would be used as the primary energy source.

2.3 Subsystem Requirements

2.3.1 Sensor Subsystem

In the sensor subsystem, we will employ a camera sensor, specifically the ESP32S3-CAM, which is capable of capturing images accurately. The hand gesture tracking and hand movement tracking will be conducted directly on the ESP32S3-CAM, leveraging its onboard processing capabilities to facilitate local model deployment. This approach is aimed at maximizing efficiency and minimizing latency by processing data directly on the device. However, should the accuracy or speed of gesture recognition not meet our requirements when processed locally on the ESP32S3-CAM, we may consider offloading the gesture recognition tasks to a computer for processing. This ensures a flexible approach to achieving the desired performance levels while exploring the potential for local processing.

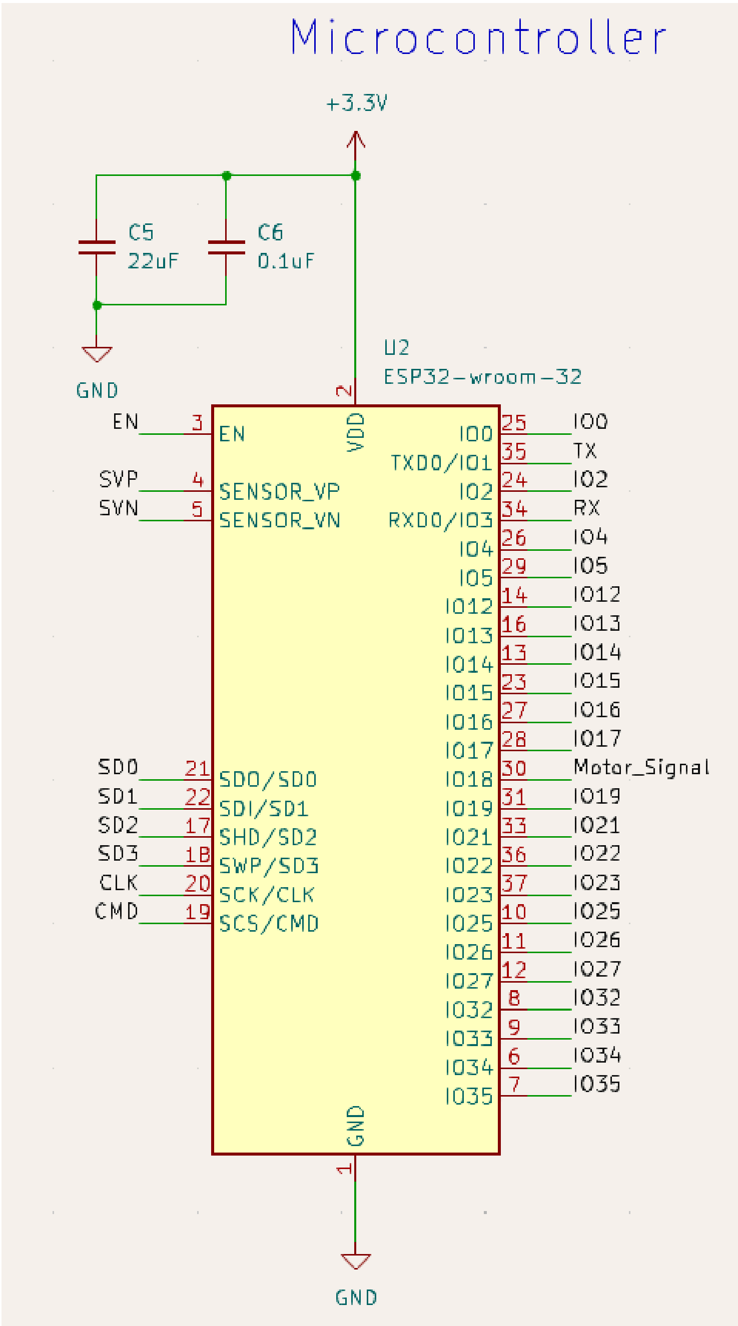
Hand Tracking

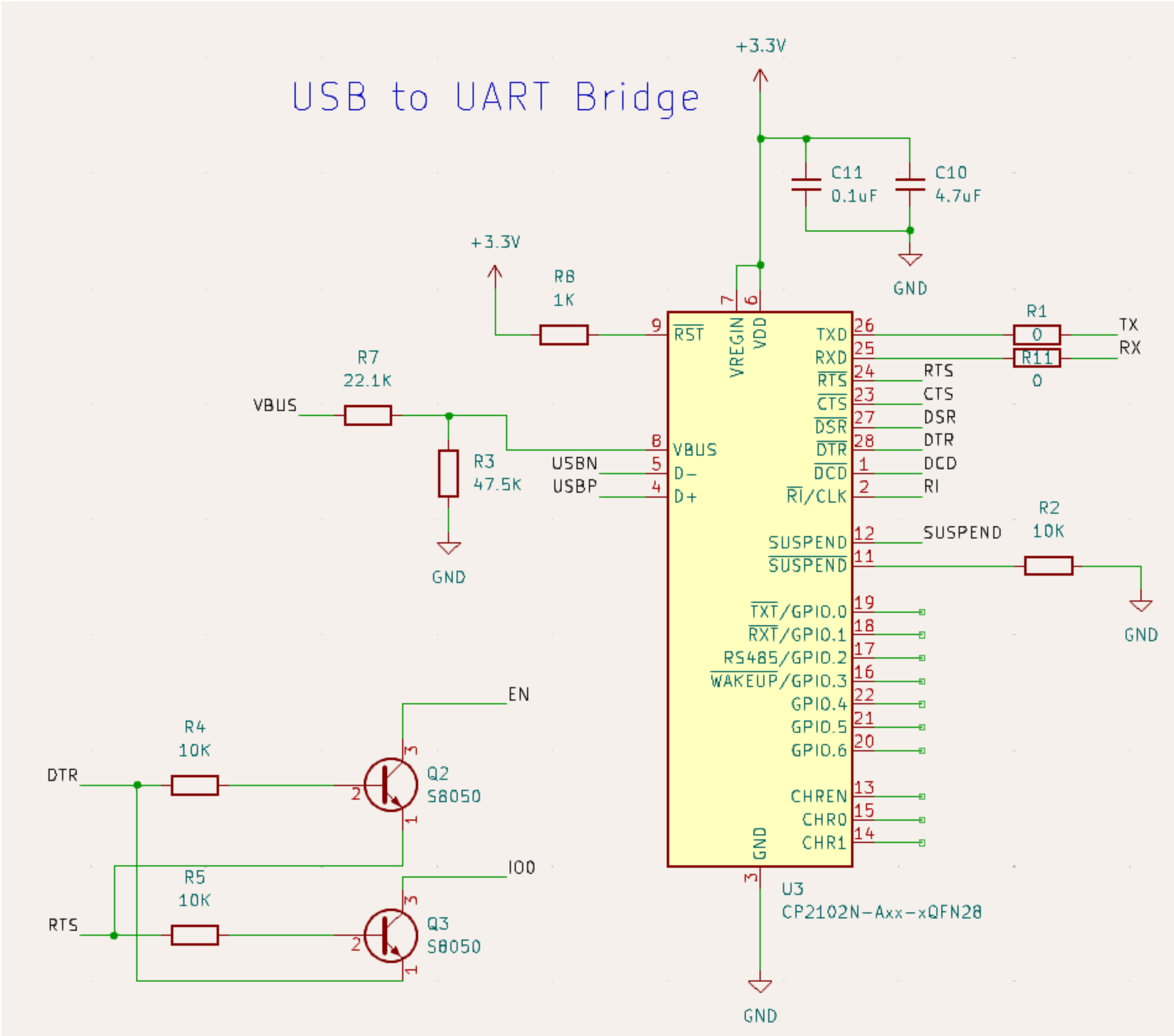
After training the model, the Sensor Subsystem calculates the offset based on the center coordinates of the picture (48,48) and the positioning coordinates of the model output, and outputs this offset to the center control, which calculates the Angle to be adjusted and passes it to the servo.

Requirement	Verification
1. Able to capture the image when the sensor is powered on by 5V +/- 5%	● Set up both camera sensors on Arduino IDE and connect them to a 5V power source ● Use an oscilloscope on the camera power input to verify that the power input is within the range 5V +/- 5% ● Check on a personal laptop if Arduino IDE can receive images from the ESP32 sensor
2. Able to conduct model training for the tracking object	● Conduct a model test on ESP32S3, the processing time for each frame should be less than 200ms.
3. Able to accurately count stretched-out fingers within the range of 0-5	● Use the gesture detection camera to take 20 hand images with stretched-out fingers ranging from 0 - 5. ● Check all trained images' properties to verify if the images are correctly tagged with finger numbers within the range of 0 - 5
4. Able to identify hand coordinates to enable hand movement tracking	● Set up the motion tracking camera to start taking 96 x 96 pixels pictures ● Set the center coordinate to 48 x 48 pixels to compute offsets with the new coordinate of hands ● Move one's hand in front of the camera to observe if the camera can move in the same direction as the hand's movement

2.3.2 Central Control Subsystem

A selected microcontroller, ESP-WROOM-32 Microcontroller, will be able to process captured images from the ESP32 sensor and connect with the lamp system to determine mechanical arm movement and lamp lighting.





Microcontroller and USB to UART Bridge's Schematic

The microcontroller's outputs will be connected to the lamp subsystems. A linear potentiometer and three servo motors will be used to move mechanical arms based on signals received from the ESP32 microcontroller.

Requirement	Verification
1. Able to communicate data through PWM, and UART protocols	• Set up and program the ESP-WROOM-32 Microcontroller through Arduino IDE • Connect ADALM2000 between the

	ports used to transfer PWM and UART data to verify if signals are sent to sensor and lamp subsystems
2. Communicate with the mechanical arm to follow human hands with a delay < 0.5s	● Set up and assemble the complete control, lamp, sensor, and power systems ● Initiate hand movement in front of ESP32 Cam ● Use the timer app on your mobile phone to ensure the reaction speed delay of mechanical arm tracking is below 0.5s
3. Communicate with the light controller to switch on/off and adjust brightness with a delay < 0.5s	● Set up and assemble the complete control, lamp, sensor, and power systems ● Stretch out one finger (turn on light gesture) in front of ESP32 Cam ● Use the timer app on your mobile phone to ensure the light switching delay is below 0.5s

2.3.3 Lamp Subsystem

The lamp system ensures the movement of the light bulb and controllable lighting. The lamp uses a mechanical arm to move the light bulb to track hand movement. Three HTS35h servo motors are used to control the lamp movement. A programmable RGB light strip is used for lighting. By taking inputs from the Microcontroller, the RGB light will select light mode and adjust brightness based on the user’s hand gestures.

Requirement	Verification
1. Servo motors can move the mechanical arm when powered on by 12V +/- 5%	● Set up servo motors and mechanical arms and connect servo motors to a 3.3V power source ● Activate HTS35H motors and observe

	if mechanical arms can be moved by motors
2. Mechanical arm can move in x and y directions	● Set up servo motors and mechanical arms and connect servo motors to a 3.3V power source ● Activate the servo motors and observe if the mechanical arm can move in the corresponding x and y directions
3. RGB Light strip can adjust brightness and temperature when powered on by 5V +/- 5%	● Assemble the complete power, sensor, central control, and lamp subsystems and connect an RGB light strip to a 5V power source ● Stretch out 2-3 fingers in front of ESP32 Cam to verify if the light strip can increase/decrease brightness through dimming ● Stretch out 4-5 fingers in front of ESP32 Cam to verify if the light strip can change color temperature

2.3.4 Power Subsystem

The power system supports the energy needed for the lamp, sensor, and central control subsystems. A wall outlet will be the primary energy source. Extra 12V, 5V, and 3.3V voltage adapters are used to power up separate components in the design.

Requirement	Verification
1. Wall outlet supports up to 2A current draw	● Use breadboard and resistors to build a test load that could draw 2A current ● Connect the wall outlet to the test load and use a multimeter in between the test load to verify if it can read from 0A to 2A correctly
2. Primary voltage regulator enables 12V +/- 5% voltage output	● Connect a 12V voltage regulator to a wall outlet ● Use an oscilloscope on the voltage regulator output to verify if it supports 12V +/- 5% output

2. Primary voltage regulator enables 5V +/- 5% voltage output	● Connect a 5V voltage regulator to a wall outlet ● Use an oscilloscope on the voltage regulator output to verify if it supports 5V +/- 5% output
3. Secondary voltage regulator enables 3.3V +/- 5% voltage output	● Connect a 3.3V voltage regulator to a wall outlet ● Use an oscilloscope on the voltage regulator output to verify if it supports 3.3V +/- 5% output

2.4 Tolerance Analysis

In our design, we will be utilizing the ESP32 controller, which has a minimum load requirement of 0.5A. Additionally, we will also be using several FS90R motors to control the robotic arm, with a stall current of 800mA. If the FS90R can't do the task we need correctly, we'll use the SF3218MG, a motor with 20kg of high torque that will meet our needs.

$$\tau = F \cdot r \cdot \sin\theta$$

Referring to the torque formula, the entire lamp would weigh at most 2kg. Assuming a rotation radius of 20cm and an angle of 270 degrees. We calculate that the minimum torque required to move the lamp would be $\tau = 9.81*2*0.2*\sin(90) = 3.5$ N-M. SF3218MG motor could support torque greater than 5 N-M and is expected to meet our needs.

We have also planned to use a power supply capable of providing 2A of current, so we can safely utilize this power source. Furthermore, we need to ensure that the cameras' field of view (FOV) can capture as much of the scene as possible to avoid losing track. For the ESP32-CAM, we are using the OV2640, which offers around 65 degrees of FOV, sufficient to capture adequate scene information. Additionally, the maximum resolution can reach 1622x1200. When used separately from a computer, the ESP32-S3 is capable of shooting at 400 × 300 pixels and running relatively small AI models at the same time. This gives us enough computing power and pixels to find the hand bones.

3 Cost Analysis

The cost analysis for this project is primarily divided into two main components: labor costs and parts costs. We have estimated the hourly wage for each project partner at $56, based on market research for graduates from Electrical and Computer Engineering (ECE) at the University of Illinois. Below is a detailed cost analysis:

3.1 Labour Costs

- The assumed hourly wage for each partner is $56.
- The total hours each person should use for the project is 20 hours/person, And we assume to finish the project in 8 weeks.
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- The formula for total labor cost is: `56 x 2.5 x 20 x 3 x 8 = 67200`.

3.2 Parts Cost

The following table lists all the parts required for the project, including description, manufacturer, part number, quantity, and cost, along with estimated machine shop labor hours needed to complete the project.

Item	Manufacture	Part Number	Quantity	Unit Price(USD)	Total Price(USD)
ESP32-S3-CAM	Freenove	-	1	20	20
HTS-35H	Hiwonder	-	3	23	69
Robot Arm kit	Hiwonder	-	1	50	50
ESP32-S3-CAM	XIAO	-	1	23	23
ESP-WROOM-32	Espressif	N16CT-ND	1	3	3
Power Jack Connector	CUI Devices	CP-037A-ND	1	0.59	0.59
5V Linear Regulator	Texas Instruments	LM1117DT-5.0	1	1.81	1.81
USB to UART Bridge	Silicone Labs	336-5889-ND	1	4.66	4.66
NPN Transistor	Onsemi	SS8050CBU-ND	2	0.41	0.82

3.3V Linear Regulator	Texas Instruments	LM1117DT-3.3	1	1.81	1.81
Single Diode	STMicroelectronics	497-6610-1-ND	1	0.38	0.38
47.5K Ohm Resistor	YAGEO	311-47.5KCRCT-ND	1	0.1	0.1
22.1 Ohm Resistor	YAGEO	311-22.1KCRCT-ND	1	0.1	0.1
TVS Diode	Onsemi	ESD9B5.0ST5G	3	0.17	0.51
Tacile Switch	C&K	401-1426-1-ND	2	0.57	1.14
22UF Capacitor	Samsung	1276-1100-1-ND	1	0.13	0.13
0 Ohm Resistor	ECE Supply Shop	-	2	0	0
1k Ohm Resistor	ECE Supply Shop	-	1	0	0
10k Ohm Resistor	ECE Supply Shop	-	4	0	0
0.1uF Capacitor	ECE Supply Shop	-	7	0	0
10 uF Capacitor	ECE Supply Shop	-	4	0	0
4.7 uF Capacitor	ECE Supply Shop	-	1	0	0
Micro USB-B Connector	ECE Supply Shop	-	1	0	0
3 Position Header Connector	ECE Supply Shop	-	1	0	0
18 Position Header Connector	ECE Supply Shop	-	2	0	0
Total					177.05

3.3 Grand total

The grand total will include the sum of the labor costs and the parts costs. The specific labor cost will need to be calculated based on the actual hours worked by each partner. The total parts cost is $177.05. All labor costs amounted to $67,200.At the same time, we also need to consider the expenditure of PCB board design completion. This will be updated after we decide on the design, tentatively set at $20. The total cost is therefore approximately 67,400.

2. Schedule:

Week 1 (Feb 22 - Feb 28): Initial Planning and Architecture

Task: Select architecture and finalize project scope.

Members Involved: Jincheng (Lead), Yiyan, Feiyang.

Deliverables: Project scope and architecture plan

Week 2 (Mar 1 - Mar 7): Detailed Design Phase

Task: Design sensor subsystem; Yiyan begins ESP32-CAM integration.

Members Involved: Feiyang (Lead on sensor design), Yiyan (ESP32-CAM), Jincheng.

Deliverables: Sensor subsystem design, initial ESP32-CAM setup.

Week 3 (Mar 8 - Mar 14): Control and Lamp Design

Task: Design central control subsystem; start lamp subsystem design.

Members Involved: Jincheng (Lead on central control), Feiyang (Lead on lamp design), Yiyan.

Deliverables: Control and lamp subsystem designs.

Week 4 (Mar 15 - Mar 21): Parts Procurement and Testing

Task: Order and test individual components; finalize ESP32-CAM integration.

Members Involved: Yiyan (Lead on ESP32 and testing), Jincheng, Feiyang.

Deliverables: Components ordered, initial component tests, ESP32 integration.

Week 5 (Mar 22 - Mar 28): Assembly of Subsystems

Task: Assemble sensor and central control subsystems.

Members Involved: Feiyang (Lead on assembly), Jincheng, Yiyan.

Deliverables: Assembled sensor and control subsystems.

Week 6 (Mar 29 - Apr 4): Lamp Assembly and System Integration

Task: Assemble lamp subsystem and integrate with control system.

Members Involved: Jincheng (Lead on lamp assembly and integration), Feiyang, Yiyan.

Deliverables: Lamp assembly, integrated system.

Week 7 (Apr 5 - Apr 11): System Refinement and Demo Preparation

Task: Refine integrated system and prepare for mock demo.

Members Involved: Feiyang (Lead on refinement), Jincheng, Yiyan.

Deliverables: Refined system, prepared demo.

Week 8 (Apr 12 - Apr 15): Final Testing and Demo Execution

Task: Conduct final system testing and execute mock demo.

Members Involved: Yiyan (Lead on final testing), Jincheng, Feiyang.

Deliverables: Final testing completion, successful mock demo.

4 Ethics and Safety

In terms of ethics and morality, our team adheres to the IEEE Code of Ethics adopted by the IEEE Board of Directors in June 2020. We firmly believe that as members of UIUC, a world-renowned university, we need to hold ourselves to the highest academic and ethical standards. We hope to change the world with our technology. Therefore, when working in our team, we will take the following measures, including but not limited to:

1: Diligently Studying Technology and Actively Communicating with Guides (TAs, Professors): Within our team, we strive to learn as much technology as possible in this project, as well as how to successfully combine the knowledge we have learned into a viable project. We will seek various resources, including but not limited to the internet, videos, and books, and actively seek advice from professors with insights in this field. At the same time, we will also actively share and exchange experiences and insights within the group to help everyone gain sufficient knowledge and skills. In this task, we will learn about relatively cutting-edge fields such as web development, AI vision, firmware development, PCB research and development, and robotics. Perhaps our ability to delve deeply is temporarily limited, but at least we can explore these fields and gain insights. We will continue to learn and apply this knowledge in the future in academia or the industry.

2: Developing Comprehensive Feedback and Testing Plans: In our team, because there are many different areas of content, we will develop comprehensive testing plans for subsystems including robotic arms and AI, and timely feedback these test results to TAs while planning the next strategy.

3:Treating Everyone with Respect and Kindness and Ensuring These Codes Are Adhered To: To ensure good teamwork and communication, we have set up chat groups, a GitHub repository, and Google Drive space to share resources. We ensure all technical details can be tracked.

Laboratory Usage and Safety

Adherence to Laboratory Rules: Strictly following all laboratory rules and guidelines is essential for ensuring safety. This includes wearing appropriate personal protective equipment (PPE), such as safety goggles, gloves, and lab coats, when necessary.

Supervised Mechanical Work: When developing or working on mechanical parts, supervision or collaboration is crucial. Working alone on mechanical components can increase the risk of accidents, so we'll ensure that team members are present or that a lab supervisor is available for assistance.

Equipment Training: Before using any lab equipment, team members will receive proper training. This training will cover the operation of the equipment, safety procedures, and emergency protocols.

Digital Security

Secure Wi-Fi and Bluetooth Connections: Given the project's reliance on Wi-Fi and Bluetooth for communication, ensuring these connections are secure is vital. We will implement encryption protocols such as WPA2 for Wi-Fi and LE Secure Connections for Bluetooth to protect against unauthorized access.

Data Privacy: Protecting the privacy of users interacting with our system is paramount. We will design the system to collect only the necessary data, ensuring it is stored securely and that users are informed about how their data is used.

Reference

IEEE code of Ethics. IEEE. (n.d.-a). https://www.ieee.org/about/corporate/governance/p7-8.html