ECE 445

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Project Proposal

An Auto-Hand Chasing Lamp With Hand Gesture Control

Team 49
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1. Introduction

1.1 Problem

In industrial and technical workspaces, especially those requiring precision tasks like large-scale soldering, lighting plays a pivotal role in determining the efficiency and quality of work. A common issue faced by professionals in these environments is the inadequate illumination of the workspace, primarily due to shadows cast by the workers' hands and tools. This problem is not trivial; it directly impacts the accuracy and precision required in soldering tasks, where the smallest detail can determine the success of the operation. The presence of shadows and poor lighting conditions can lead to significant visual discomfort and strain, reducing work efficiency and potentially compromising the quality of the final product. Studies in ergonomics and occupational health consistently highlight the critical need for proper workplace lighting to ensure safety, comfort, and performance.

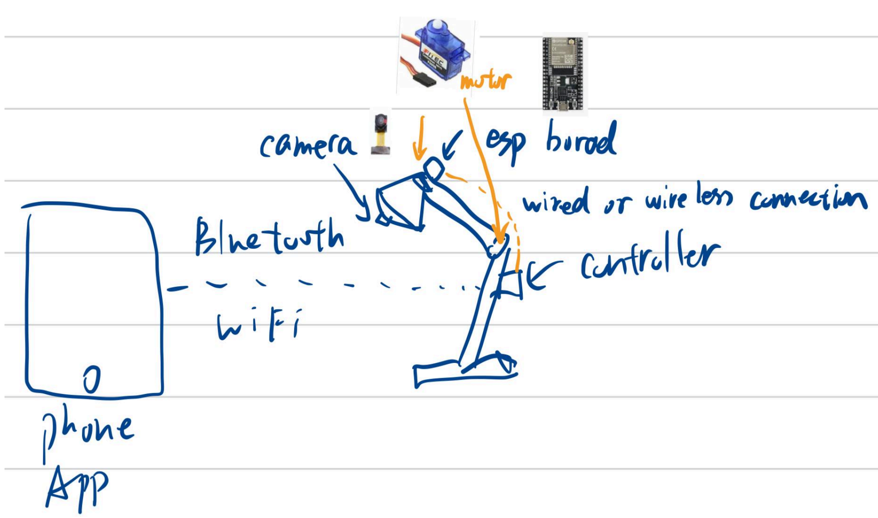
The challenge of maintaining optimal lighting conditions is exacerbated by the varying nature of industrial tasks and the changing light requirements they entail. Traditional desk lamps offer limited flexibility, often requiring manual adjustment to provide adequate illumination. This constant need to adjust lighting can interrupt the workflow, particularly in scenarios demanding sustained concentration and precision. Moreover, the one-size-fits-all approach to lighting fails to account for individual preferences and the specific requirements of different tasks, such as the need for cooler or warmer light temperatures to enhance visibility or reduce eye strain. The absence of an intuitive and adaptive lighting solution highlights a significant gap in the current market, underscoring the necessity for a smart desk lamp capable of autonomously adjusting its brightness and color temperature in response to varying external light conditions and user needs.

1.2 Solution

To address the challenges posed by inadequate workspace lighting in precision tasks, our team proposes an innovative solution: a smart desk lamp designed to revolutionize the lighting experience in industrial settings. At a high level, our solution focuses on enhancing work efficiency and comfort through dynamic lighting adjustment, driven by advanced artificial intelligence (AI) and mechanical engineering. The cornerstone of our design is a desk lamp equipped with the capability to autonomously track the user's hand movements, thereby eliminating the common issue of shadows obscuring the work area. This is achieved through a sophisticated combination of a camera, several servo motors, and a flexible mechanical arm embedded with AI technologies, all of which work in tandem to reposition the lamp in real-time, ensuring optimal illumination of the workspace.

Delving into the specifics, the lamp utilizes AI-based gesture recognition technology, powered by an ESP32 module, to interpret simple to complex hand gestures. This allows users to effortlessly control the lamp's functionalities—ranging from adjusting brightness and color temperature to switching the lamp on and off—without the need to physically interact with the device. Furthermore, the lamp is capable of executing more advanced commands, such as controlling external devices like computers to perform actions including playing music or adjusting volume, thereby enhancing the user's control over their workspace environment. To complement its primary features, the lamp includes a customizable notification system that uses subtle changes in color temperature to alert users about important tasks or reminders, aiding in productivity and focus. Through this multifaceted approach, our smart desk lamp not only solves the problem of inadequate lighting but also introduces a level of interaction and functionality that transcends traditional lighting solutions, marking a significant leap forward in workspace lighting technology.

1.3 Visual Aid

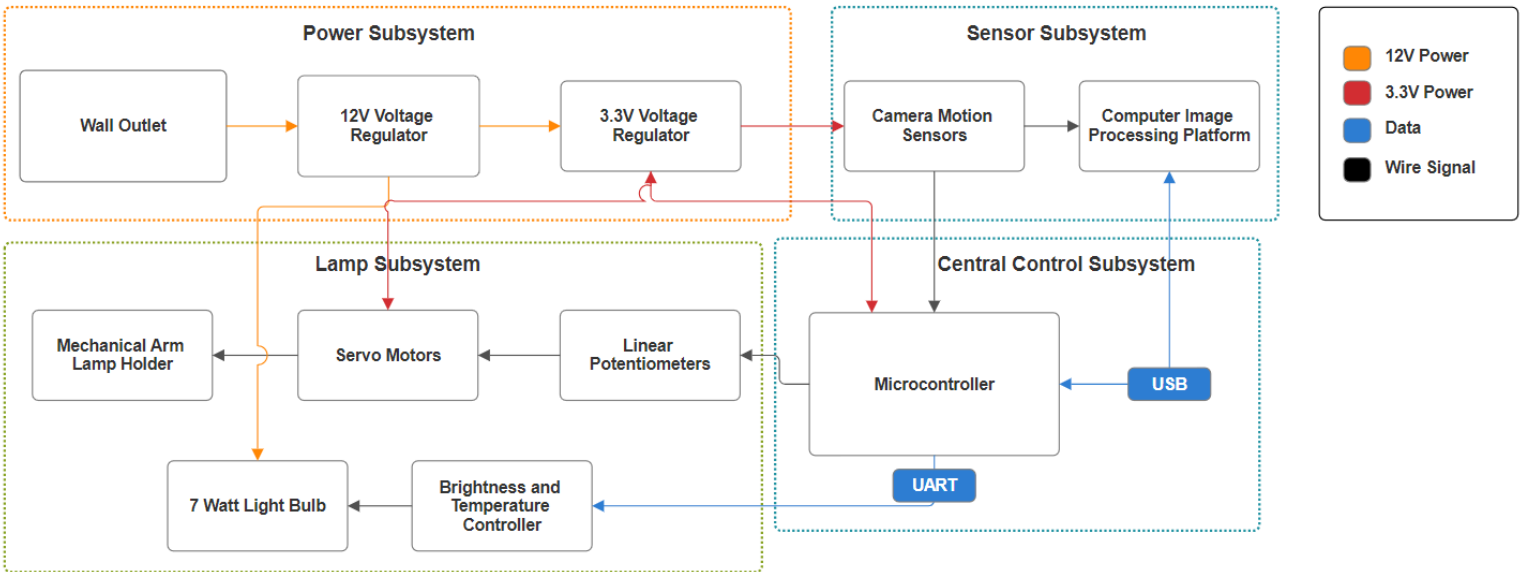


1.4 High-level requirements list:

i. **Autonomous Tracking Accuracy:** The smart desk lamp must possess the ability to track the user's hand movements with a minimum accuracy of 95%, ensuring that the work area is consistently well-illuminated without manual adjustment of the lamp's position.
ii. **Gesture Recognition Responsiveness:** The system must be able to interpret and respond to predefined hand gestures within a timeframe of no more than two seconds from the moment of gesture completion, allowing for intuitive and efficient control of the lamp's functions.
iii. **Light Adjustment Range:** The lamp must be capable of adjusting its brightness from a minimum of 100 lumens to a maximum of at least 1000 lumens and its color temperature from 2700K (warm light) to 6500K (daylight), to accommodate various lighting conditions and user preferences.

2. Design

2.1 Block Diagram



2.2 Subsystem Overview

2.2.1 Sensor Subsystem

The sensor system is used to detect hand movement and upload the image to a computer to perform image processing trainings. It uses a ESP32 camera sensor to capture image and upload the image to an image processing platform on personal computer. The sensor sends digital output to the microcontroller when hand movements are detected, and the image processing platform would distinguish certain hand gestures through data processing.

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 images captured by the camera, determine how much each motor in the mechanical arm should move to track the bulb and be sensitive to specific gestures to adjust various parameters of the bulb. It can also communicate remotely with a computer to control specific programs and execute a trained AI gesture model. The lamp subsystem will receive outputs from microcontroller and change mechanical arm movement and light bulb activities based on the detected hand gestures like fist and pinching .

2.2.3 Lamp Subsystem

The lamp subsystem makes up the physical lamp that will be used to track the user's hand movement. It's 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 separated 3.3V voltage adapter will be used to power smaller components including the camera sensor and microcontroller. The power need to 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

A sensor and an image processing platform will be used to in the sensor subsystem. The camera sensor, ESP32-CAM, can accurately capture image and communicate with a chosen image processing platform to track human hand movements. OpenCV or similar image processing tool will be used to distinguish human hands from other objects. This also ensures that we can identify certain hand gestures like pinching that are used to control the lamp.

- *Requirement 1:* Upload readable camera image that could be used for image processing
- *Requirement 2:* Able to capture image when sensor is powered on by 3.3V +/- 5%
- *Requirement 3:* Identify human hands with an accuracy > 90%
- *Requirement 4:* Able to accurately count stretched out fingers within the range 0-5

2.3.2 Central Control Subsystem

A selected microcontroller, ARM® Cortex®-M4 STM32F4 Microcontroller, will be able to process captured image from ESP32 sensor and connect with the lamp system to determine mechanical arm movement and lamp lighting.

- *Requirement 1:* Able to communicate data through USB and UART protocols
- *Requirement 2:* Communicate with the mechanical arm to follow human hands with a delay < 0.5s

- *Requirement 3:* Communicate with the light controller to switch on/off and adjust brightness with a delay < 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 in order to track hand movement. Three FS90R servo motors and a P0915N potentiometer are used to control the lamp movement. A 7 Watt light bulb such as Govee A19 with adjustable temperature and brightness will be used to control the lamp lighting. By taking inputs from the Microcontroller, the light controller will select light mode and adjust brightness based on the user's hand gestures.

- *Requirement 1:* Mechanical arm can move in x, y, and z directions
- *Requirement 2:* Servo motors are able to move the mechanical arm when powered on by 3.3V +/- 5%
- *Requirement 3:* Light bulb can adjust brightness and temperature when powered on by 12V +/- 5%

2.3.4 Power Subsystem

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

- *Requirement 1:* Wall outlet supports up to 2A current draw
- *Requirement 2:* Primary voltage regulator enables 12V +/- 5% voltage output
- *Requirement 3:* Secondary voltage regulator enables 3.3V +/- 5% voltage 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. We have 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, which can greatly assist in parsing skeletal points of the hand.

3. 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.

Safety and Regulations: We will steadfastly follow laboratory usage rules and avoid acting alone when developing mechanical parts as much as possible. Also, when using Wi-Fi and Bluetooth, we will ensure that the connection between users and our system is private and secure.

Reference

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