

Robot Desk Lamp with User Interaction

Project Proposal

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1. Introduction

1.1 Problem

Desk lamps are used for reading, studying, electronics work, drawing, and other tasks that require localized illumination. The illuminated region often changes as the user moves between a notebook, keyboard, circuit board, or other work area. Conventional adjustable lamps solve this by requiring the user to grasp the lamp head or arm and reposition it manually. That interaction is inconvenient when the user's hands are occupied and can interrupt the task itself.

Lighting quality is also relevant to comfort and safety at a workstation. A field study of adjustable LED task lighting reported improvements in visual comfort, posture, and musculoskeletal comfort when users were able to adjust the task light [1]. OSHA guidance for computer workstations likewise recommends positioning task lighting so that it does not create reflected glare on a display, because glare can contribute to eye strain and fatigue [2]. These observations motivate a lamp that can be repositioned easily and repeatedly to suit the current task.

The project also raises ethical considerations related to accessibility, user safety, and privacy. The hands-free interaction method is intended to make lamp adjustment easier for users who may have difficulty repeatedly repositioning a conventional lamp. Because the system uses a camera and powered robotic motion, the design must avoid unnecessary collection of user data and must reduce risks from unintended movement, pinch points, and excessive joint loading.

1.2 Solution

Our solution is a camera-controlled robotic desk lamp with a 3–4 degree-of-freedom articulated arm. The user provides input through hand gestures observed by a camera. The camera sends image frames to a Raspberry Pi 5, which performs the vision processing required to interpret the user's gesture and determine the requested lamp movement.

The Raspberry Pi communicates the resulting control information to a 3.3 V microcontroller through UART. The microcontroller performs the motion-control calculations and communicates over I2C with a dedicated PWM servo driver. The servo driver then provides PWM control signals to the 3–4 servos that actuate the robotic arm. Power is supplied from a single external 12 V DC adapter. Separate conversion paths generate a 5 V rail for the Raspberry Pi, a 6 V rail for the servos, and a 3.3 V rail for the microcontroller and logic circuitry. The LED lamp is supplied from the 12 V rail through its lamp driver. Separating the high-current servo supply from the logic rails reduces the effect of servo current transients on the processor and microcontroller supplies.

1.3 Visual Aid

Figure 1 provides a pictorial overview of the proposed hardware architecture. It shows the 12 V DC adapter supplying the Raspberry Pi 5, microcontroller, servo-powered robot arm, and LED lamp; the camera connected to the Raspberry Pi for vision processing; UART communication between the Raspberry Pi and microcontroller; and PWM control from the microcontroller to the robot arm and lamp.

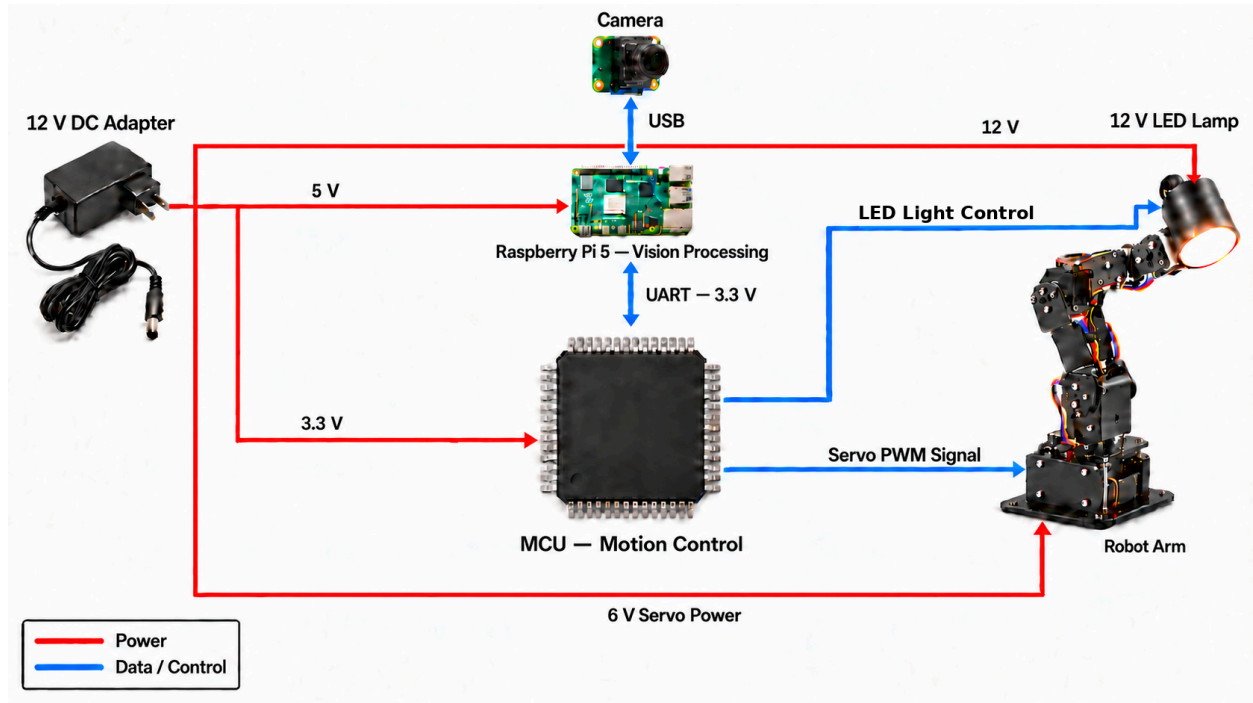


Figure 1. Pictorial overview of the proposed robotic desk lamp hardware and signal connections.

1.4 High-Level Requirements

- The robotic lamp shall successfully reposition its lamp head toward a user-specified target direction in at least 80% of test trials conducted within the defined desk workspace and the response time should be within 15s.
- The vision and interaction subsystem shall correctly interpret the user's intended gesture or target direction then finish the corresponding action in at least 80% of test trials under defined operating conditions.
- The complete system shall operate the Raspberry Pi 5, microcontroller, LED lamp, and all 3–4 servo motors simultaneously for at least 6 minutes without processor reset, MCU reset, or loss of servo control, while the 5 V, 6 V, and 3.3 V supply rails remain within $\pm 5\%$ of their nominal values.

2. Design

2.1 Block Diagram

The system is divided into five functional subsystems: external power and regulation, control and interaction, microcontroller and motion control, servo actuation and robot-arm mechanics, and lamp illumination. Figure 2 shows the current block diagram. The design intentionally separates high-current servo power from the processor and logic rails while preserving a common control path from user gesture to camera, Raspberry Pi 5, microcontroller, PWM driver, and robot arm.

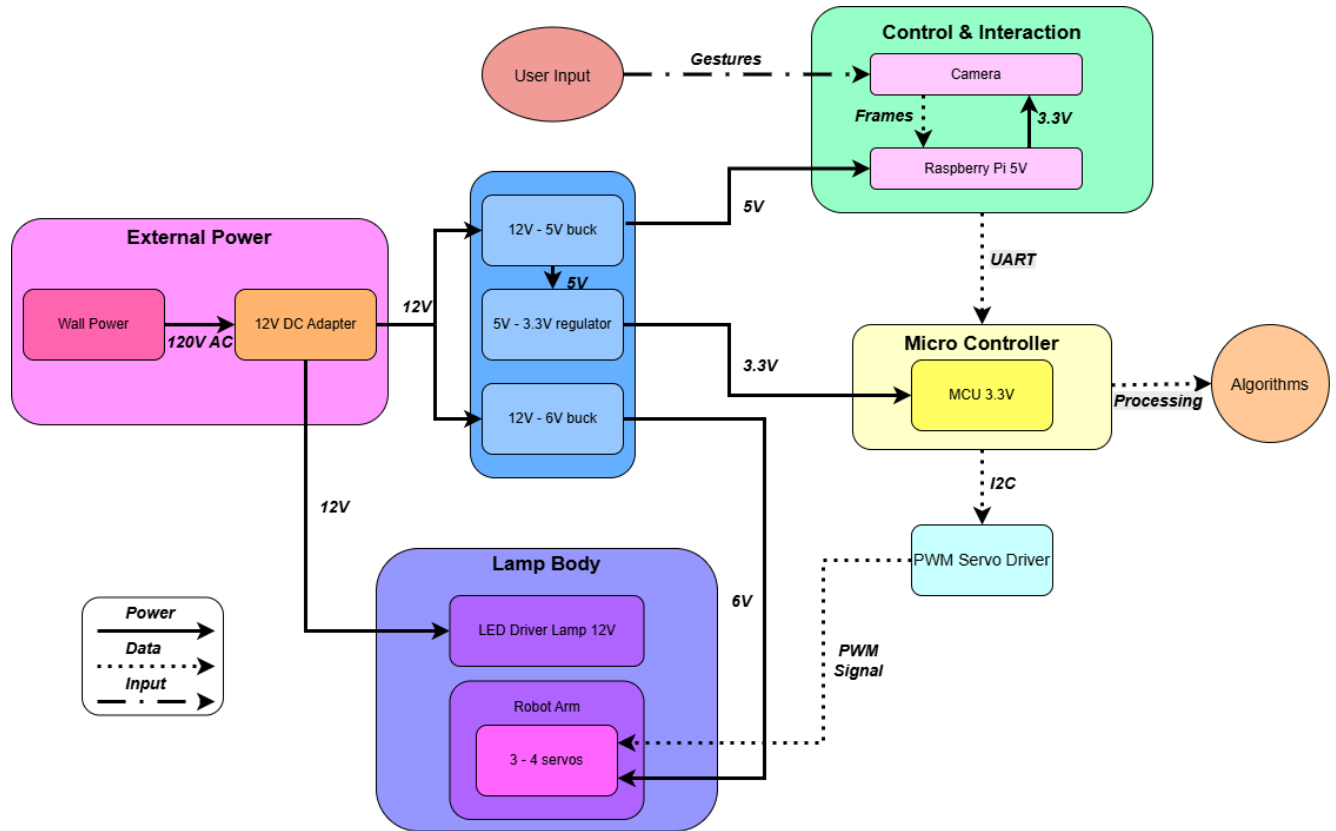


Figure 2. Current block diagram of the robotic desk lamp system, including power, processing, communication, and actuation interfaces.

2.2 Subsystem Overview

The external power subsystem converts wall power to 12 V DC and distributes that source to the lamp and the three regulated logic/actuation rails. A 12 V-to-5 V buck converter powers the Raspberry Pi 5, a 12 V-to-6 V buck converter powers the servos, and a 5 V-to-3.3 V regulator powers the microcontroller and associated logic. The 12 V rail also feeds the LED lamp driver directly.

The control and interaction subsystem contains the camera and Raspberry Pi 5. The camera observes the user's hand gesture and provides image frames to the Raspberry Pi. The Raspberry Pi performs the vision processing needed to identify the user's intended command and sends the resulting target information to the microcontroller over UART.

The microcontroller and motion-control subsystem receives target information from the Raspberry Pi at 3.3 V logic levels and converts that target into commands for the arm. The microcontroller communicates with the dedicated PWM servo driver through I2C. The PWM driver then produces the servo-control waveforms required by the robot arm.

The servo actuation and robot-arm subsystem contains 3–4 servo motors powered by the regulated 6 V rail. These servos form the articulated arm that physically changes the position and orientation of the lamp head. This subsystem converts the electrical PWM commands into mechanical joint motion and is directly responsible for meeting the lamp-repositioning requirement.

The lamp illumination subsystem contains the 12 V LED driver and lamp mounted on the robot arm. It remains electrically separate from the servo-control signals and must remain illuminated while the arm is repositioned.

2.3 Subsystem Requirements

Power Subsystem

The power subsystem supports the system-reliability high-level requirement by providing stable supply rails to every electrical load. Its input is 12 V DC from the external adapter. Its outputs are 5 V to the Raspberry Pi 5, 6 V to the servos, 3.3 V to the microcontroller and logic, and 12 V to the LED lamp driver.

- The 5 V, 6 V, and 3.3 V rails shall remain within $\pm 5\%$ of nominal during simultaneous operation: 4.75–5.25 V, 5.70–6.30 V, and 3.135–3.465 V, respectively.
- The 5 V rail shall be capable of supplying at least 5 A to the Raspberry Pi 5. The 6 V rail shall have a continuous-current rating of at least 1.2 times the sum of the selected servos' maximum current ratings. The 3.3 V rail shall have a continuous-current rating of at least 1.2 times the maximum current required by the microcontroller and associated logic.
- The complete power system shall support simultaneous operation of the Raspberry Pi 5, microcontroller, lamp, and all servos for at least 6 minutes without a processor reset, MCU reset, or loss of servo control.

Control and Interaction Subsystem

This subsystem supports the gesture-recognition high-level requirement by converting the user's hand motion into a digital target command. The camera supplies image frames to the Raspberry Pi 5, and the Raspberry Pi sends the recognized command to the microcontroller through 3.3 V UART.

- The camera-processing pipeline shall process at least 10 frames per second during normal operation.
- The subsystem shall correctly interpret the intended gesture or target direction in at least 80% of test trials under the defined test conditions.
- Recognized commands shall be transmitted to the microcontroller over UART at 115200 baud.

Microcontroller and Motion-Control Subsystem

This subsystem connects perception to actuation and therefore contributes to both the lamp-repositioning and system-reliability high-level requirements. The microcontroller receives target commands from the Raspberry Pi and sends joint-control data to the PWM servo driver.

- The microcontroller shall operate from the 3.3 V rail within 3.135–3.465 V.
- The Raspberry Pi-to-microcontroller UART interface shall operate at 115200 baud, and the microcontroller-to-PWM-driver I2C interface shall operate at 400 kHz or lower if required by the selected PWM driver.
- The controller and PWM driver shall support all 3–4 servo channels and shall not command any joint beyond the calibrated mechanical limits.

Servo Actuation and Robot-Arm Subsystem

This subsystem directly satisfies the lamp-repositioning high-level requirement by converting PWM commands into coordinated joint motion. The servos are powered by the 6 V rail and receive individual PWM control signals from the servo driver.

- All arm servos shall operate from 5.70–6.30 V and shall receive the PWM frequency and pulse-width range specified by the selected servo datasheet.
- For each joint, the selected servo shall have a rated torque of at least 1.5 times the calculated worst-case static gravitational torque for that joint.
- The arm shall successfully reposition the lamp head toward the user-specified target direction in at least 80% of workspace test trials while remaining within its calibrated joint limits.

Lamp Illumination Subsystem

This subsystem provides the useful lighting output while the arm changes orientation. It is powered from the 12 V rail through the LED driver and is mechanically mounted to the robot arm.

- The lamp driver shall receive 12 V DC within $\pm 5\%$ of nominal, or 11.4–12.6 V.
- The LED lamp shall remain illuminated during arm motion and throughout the 6-minute simultaneous-operation test.
- Lamp wiring shall include sufficient routing and strain relief to permit the full calibrated range of every arm joint without pulling on a connector or obstructing motion.

2.4 Tolerance Analysis

A major implementation risk is keeping the 6 V servo power rail stable when several motors move at the same time. Servo motors can draw a large amount of current during startup or under load, so the 6 V supply and wiring must be able to provide enough current without allowing the voltage to drop too far.

To reduce this risk, the servos are powered from a dedicated 6 V rail instead of sharing the Raspberry Pi or microcontroller supply. The rail is required to remain between 5.70 V and 6.30 V during operation. The 6 V converter will be selected with additional current capacity above the combined maximum current of all 3–4 servos, and the wiring and connectors will be chosen to minimize voltage drop.

During testing, all servos will be moved simultaneously while the 6 V rail is measured. If the voltage falls outside the allowed range or the control electronics reset, a higher-current converter, lower-resistance wiring, or additional power filtering will be used. This test will verify that the power subsystem can support worst-case arm motion without causing instability in the rest of the system.

3. Ethics, Safety, and Societal Impact

The project presents ethical and safety concerns because it combines a camera with a powered robotic mechanism. These concerns apply both during development and during normal use, so the design must protect privacy, prevent unintended motion, and avoid overstating the reliability of the system.

3.1 Ethical Responsibilities

The IEEE Code of Ethics emphasizes public safety, privacy, and honest statements about technical capabilities, while the ACM Code of Ethics emphasizes avoiding harm and respecting privacy [3], [4]. The camera will therefore be used only to recognize the predefined hand gestures needed to control the lamp. Image frames will be processed locally on the Raspberry Pi and will not be stored or transmitted; only the resulting control command will be sent to the microcontroller. The system will not identify individual users or create biometric templates. This also avoids the type of hand- or face-geometry data regulated by the Illinois Biometric Information Privacy Act [9]. Gesture-recognition accuracy will be reported from measured test results rather than assumed performance.

Accidental or intentional misuse is also considered. A camera-equipped device could be repurposed for surveillance, and a robotic arm could be commanded to move toward a person rather than toward the intended workspace. To reduce these risks, the project will not provide remote network control of the arm, will enforce calibrated joint limits in software, and will allow motion to be stopped by removing system power.

3.2 Safety and Regulatory Considerations

The main physical hazards are electrical faults and mechanical pinch points. The system uses an external 12 V DC adapter and lower-voltage 6 V, 5 V, and 3.3 V rails. Wiring will be insulated and strain-relieved, and the power path will be sized for the maximum expected current so that conductors and converters are not overloaded. For the moving arm, joint travel will be limited to the calibrated workspace and the mechanism will be arranged so that users do not need to place their hands between moving links. OSHA machine-guarding requirements identify pinch points and moving parts as hazards that should be guarded or otherwise kept inaccessible; these requirements provide a relevant safety benchmark for the prototype [5].

Development will also follow ECE 445 laboratory policy, including completion of required safety training and the rule that students do not work alone in the lab [6]. For the lamp and electronics, IEC 60598-1 provides general luminaire safety requirements, while IEC 62368-1 uses a hazard-based approach for electronic and information-technology equipment [7], [8]. The prototype is not being presented as a certified commercial product, but these standards guide choices such as using a protected external

power adapter, insulating conductors, providing mechanical strain relief, and limiting user exposure to electrical and mechanical hazards.

3.3 Societal Impact

The intended benefit is easier lamp positioning, particularly when a user's hands are occupied or when repeated manual repositioning is difficult. The camera-based interface also creates a privacy responsibility, which is addressed by local processing and by not retaining images. Economically, the robotic arm and camera add hardware compared with a conventional desk lamp, so the design uses readily available components rather than custom hardware where possible. Environmentally, the design uses an LED light source and localized task lighting, while the added electronics and servos increase material and energy use. The gesture set will be simple and explicitly defined so that operation does not depend on culturally specific signs, allowing the interaction method to remain understandable across different users.

4. Extended Goals

The following goals extend beyond the baseline system described above. They are optional stretch objectives to be pursued only after the core requirements in Section 1.4 and Section 2 are met, and are not required for project completion.

4.1 Expanding to 5–6 DOF for full-range motion

If time and mechanical design permit, the arm will be extended from the baseline 3–4 DOF to 5–6 DOF (e.g., adding wrist roll and/or a second elbow joint) to remove the workspace dead zones inherent to the lower-DOF configuration and allow the lamp head to reach a broader range of orientations, including positions that require avoiding the arm's own singular configurations.

4.2 Adding a phone-based Bluetooth control or voice-control module

As a supplementary interaction channel alongside the primary gesture-based control, we will explore adding either a BLE virtual-joystick interface on a smartphone or a basic voice-command module, giving the user an alternative way to reposition the lamp when the camera-based interaction is unavailable or impractical (e.g., poor lighting, occlusion).

4.3 Conducting a user interaction experience study.

If the above goals are completed with time remaining, we will run a small user study (e.g., a short task-based session with a handful of participants) comparing perceived ease of use, response

satisfaction, and task interruption across the available interaction modes, to assess whether the system meets its intended usability goal beyond the quantitative success-rate metrics already defined in Section 1.4.

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