Automatic Light Switch

Sangsun Lee, Andrew Kim, Ruize Sun
ECE 445
Team 71
TA: Eric Tang
2/27/2025

I. Introduction

A. Problem

Many buildings and rooms still use traditional, non-smart light switches, requiring individuals to manually slide the knob up and down, to adjust the light level of the light bulb. Upgrading these switches to smart ones typically involves removing the existing switch and installing a smart light switch in its place. However, for people living in rented rooms or apartments, this option may not be feasible, as they do not own the property and are often restricted from making permanent changes to the electrical fixtures.

This limitation creates a challenge for renters or those in temporary living arrangements who want the convenience and energy-saving benefits of smart lighting systems without violating lease agreements or incurring high installation costs. Moreover, current solutions for retrofitting smart functionality are either limited in functionality, expensive, or complicated to install, making them inaccessible to the average tenant. As a result, there is a growing need for innovative, non-invasive solutions that enable smart functionality without requiring structural modifications to existing light switches or electrical wiring.

B. Solution

Many renters and homeowners want smart lighting solutions but face obstacles such as complicated wiring, permanent modifications, or landlord restrictions. Traditional smart switches often require electrical rewiring, making them inaccessible to those without technical expertise.

*1) **Product Functions**:* This smart switch is designed to mount over an existing dimmable light switch without any wiring modifications. It allows users to:

- Manually control their lights as they would with a traditional switch.
- Adjust brightness levels from 0 (off) to 5 (brightest) using voice commands.
- Remotely control lights through a dedicated mobile app with an intuitive brightness slider.
- Seamlessly integrate with Wi-Fi, enabling wireless operation without additional hubs.

*2) **Consumer Benefits**:*

- **Easy Installation** – No tools or rewiring required, making it renter-friendly.
- **Convenience** – Adjust lights with voice commands or through the app from anywhere.
- **Customization** – Precise brightness control for different moods and activities.
- **Accessibility** – Ideal for users with mobility limitations, as lights can be controlled remotely.

*3) **Key Features**:*

- No-wiring, no-drill design that fits over standard dimmable switches.
- Voice assistant compatibility for hands-free operation.
- Wi-Fi enabled mobile app with a smooth brightness slider.

This smart switch offers a hassle-free way to modernize lighting control, making smart home upgrades accessible to everyone.

C. Visual Aid

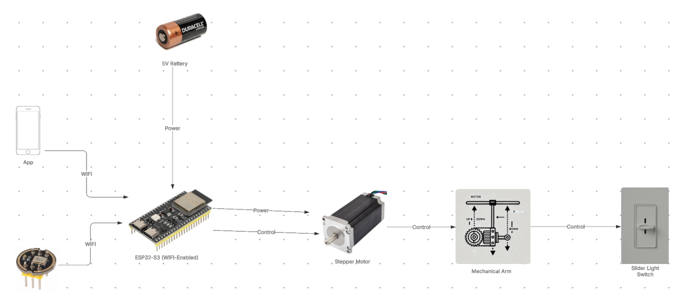

Fig. 1. Visual Aid of the Automatic Light Switch

For our project, we will make an automatic light switch that will mount over existing light switch with capabilities of voice control and app control. Figure 1 shows a visual aid of the automatic light switch.

The 5 volt battery will power the ESP32-S3, which in turn power the stepper motor. The INMP 441 will act as the external microphone and be used to accurately recognize the sound of numbers and transfer that signal to the ESP32-S3 through WIFI. The app will also communicate with the ESP32-S3 through WIFI. With the signals the ESP32-S3 receives from the app and the INMP 441, it controls the stepper motor to move a certain degree up and down, which the stepper motor moves the mechanical arm, which in return moves the slider light switch.

D. High-level Requirement List

To consider our project successful, it must meet the following requirements:

- The voice module must accurately recognize and respond to spoken numbers between 1 and 3, adjusting the light brightness to the corresponding level with precise control, ensuring that users can easily set their desired light intensity via voice command.
- The smart switch must execute app or voice commands within 2 seconds, providing near-instantaneous adjustments to the light level, ensuring a seamless and responsive user experience without noticeable delays.
- The smart switch must maintain a stable and uninterrupted connection with the mobile app over a Wi-Fi range of at least 100 feet (30 meters) indoors, allowing users to conveniently control their lights from any room in the house, even through walls or obstacles.

II. Design

A. Block Diagram

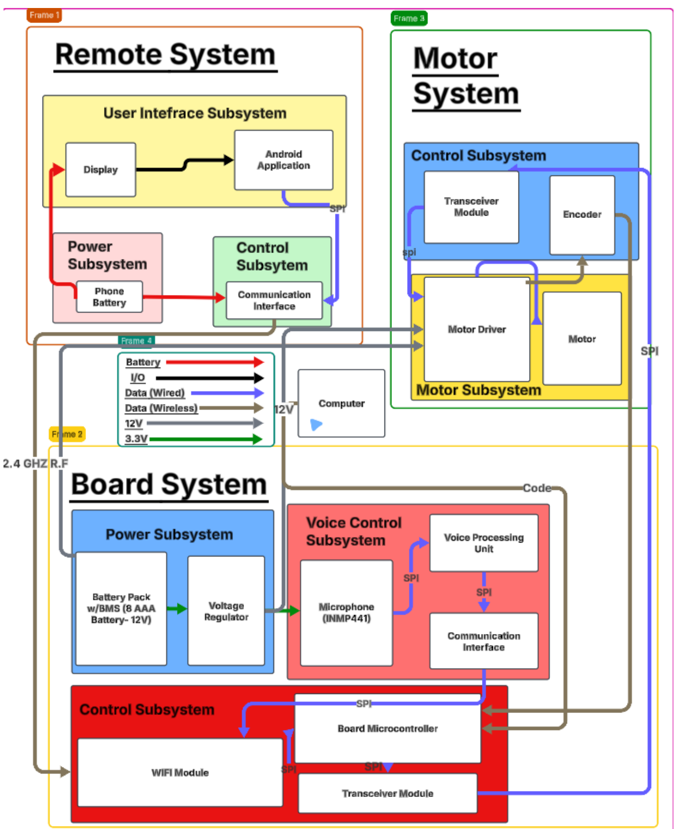

Fig. 2. Block Diagram of the Automatic Light Switch

Remote System- Create an application using Android Studio and connect to the ESP32 micro controller to send signals and activate the light switch.

Board System- Send user voice command to the ESP32-S3, with the help of INMP441 and digital signal processing. Provide the power supply for ESP32 and Motor Driver Module of the Motor System. Allows long-distance connection between the Remote System and the Board System, with the help of ESP32-S3's wifi module.

Motor System- The battery pack will power the motor driver, and the ESP32-S3 will send the intended signals to the Transceiver Module of the Motor System, which will rotate the motor to it intended movement.

B. Functional Overview & Block Diagram Requirements

*1) **Remote System**:* The application will be developed on Android Studio emulator using the programming languages Java and/or Kotlin. The application will consist of a slider that adjusts the intensity of the light for the users. The application will require access to an internet connection and will send signals to the WIFI module of ESP32. The application will connect to the HTTP server on ESP32 and send/receive signals through HTTP requests/responses.

- **User Interface Subsystem** – The Display is powered up by the Phone battery of the Power Subsystem and the Android Application has a I/O interaction with the Display. The Android Application of the User Interface Subsystem sends signal (SPI) to the Transceiver module of the Control Subsystem.
- **Power Subsystem** – The battery of the phone will power up the Display of the User Interface Subsystem and the Transceiver module of the Control Subsystem.
- **Control Subsystem** – The Communication Interface will communicate with the WIFI Module of the Board System through UART.

Figure 3 shows a UI Design and Software Design.

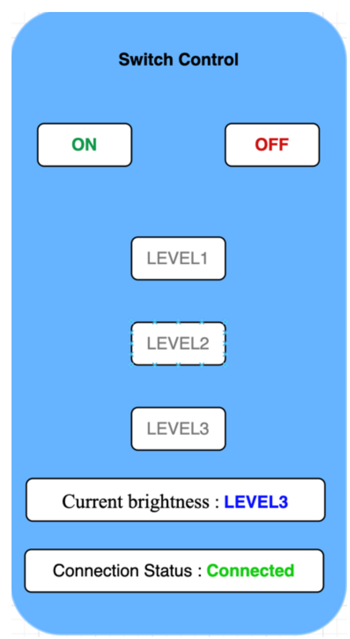

Fig. 3. UI Design of the App

This APP is mainly used to control the light brightness level and switch status.

- ON button: turns the light on, possibly returning it to the last set brightness level.
- OFF button: turns the light off, completely extinguishing it.
- LEVEL1: Low brightness (suitable for nighttime, energy-saving mode)
- LEVEL2: Medium brightness (conventional lighting)
- LEVEL3: High brightness (reading, work lighting)

Users can click different LEVEL buttons to adjust the brightness of the light.

Current Position tells the user the current light brightness level, for example, ”LEVEL3” means the light is at the highest brightness.

Current Status displays the connection status of the device (STA mode): ESP32 is connected to WIFI, and the APP communicates with ESP32 through the local IP address. [2]

The APP controls the ESP32 by sending HTTP requests. ESP32 runs a web server that listens for commands from the APP

- APP presses the ON button → sends HTTP request → ESP32 receives the request → the motor pushes the switch to the “ON” position → APP displays “Light is on”
- APP presses the OFF button → sends HTTP request → ESP32 receives the request → the motor pushes the switch to the ”off” position → APP displays ”Light is off”
- APP presses LEVEL1 → Send HTTP request → ESP32 receives the request → motor moves to LEVEL1 (low brightness) → APP displays “Current brightness: LEVEL1”
- APP presses LEVEL2 → Send HTTP request → ESP32 receives the request → motor moves to LEVEL1 (low brightness) → APP displays “Current brightness: LEVEL2”
- APP presses LEVEL3 → Send HTTP request → ESP32 receives the request → motor moves to LEVEL1 (low brightness) → APP displays “Current brightness: LEVEL3”
- APP sends HTTP request → ESP32 returns status (brightness level + connection status) → APP parses JSON data → displays “Current brightness: LEVEL3” + “Connection: Connected”

*2) **Board Control Subsystem**:* The Board Control Subsystem is responsible for receiving transmission from the APP, Voice control Subsystem and Rotary Encoder. Based on these inputs, the Board Control Subsystem will command the motor driver to control the motor. The Board Control Subsystem will receive the feedback from the encoder to determine when the motor should stop. The Board Control Subsystem is made up of ESP32 MCU that interfaces with the motor driver via PWM and with the APP via SPI. For more information about the software design on the MCU, please refer to the Section Remote System. [2]

To ensure the Board Control Subsystem is fulfilling its responsibilities for receiving the transmission from the APP, Rotary Encoder, and Voice Control Subsystem, and commanding the DC motor driver, a requirements & verification table can be found below.

Requirements	**Verification**
The MCU needs to be able to output a PWM signal to control the Motor Driver, and MCU should also know When should stop output PWM signal	Use an oscilloscope to measure the PWM output signal and the frequency is stable above 10kHz. And observe if the motor can stop when it reaches the desired angle. This information comes from the A/B phase signal of the incremental encoder. And print encoder count value
MCU needs to send a direction signal (DIR) through the GPIO port to control the forward and reverse rotation of the motor.	Connect the Motor Driver and observe whether the motor direction change matches the MCU control signal.

TABLE I
BOARD CONTROL SUBSYSTEM - REQUIREMENTS AND VERIFICATION

*3) **Board Power Subsystem**:* The Board Power Subsystem is responsible for Powering all the components on the board like motor driver, MCU, Voice control module. And the voltage regulator module will adjust the input voltage which satisfies the different power requirement for each electronic component. To ensure the Board Power Subsystem is fulfilling its responsibilities for powering each component, a requirements & verification table can be found below.

Requirements	**Verification**
The power subsystem needs to provide stable 3.3V (ESP32) (Rotary Encoder) and 12V (Motor Driver)	Use a multimeter to measure the power supply terminals of ESP32, Motor Driver, Rotary Encoder to ensure that the voltage is within the ±5% error range. [2]
The power supply needs to have reverse polarity protection	Add a diode to avoid damage to electronic components caused by reverse power connection
The power output ripple should be lower than 50mV (3.3V) / 100mV (12V) to avoid affecting the MCU and encoder.	Use an oscilloscope to measure the power ripple to ensure that the ripple voltage is within the required range.

TABLE II
BOARD POWER SUBSYSTEM - REQUIREMENTS AND VERIFICATION

*4) **Board Voice Control Subsystem**:* The Board Voice Control Subsystem is responsible for capturing voice input from the user via a microphone. Using an onboard speech recognition module to an external processor for recognition. The Board Voice Control Subsystem will interface with MCU via SPI. Interpreting voice commands to adjust the motor position by sending appropriate signals to the motor driver. For example, Level 3 -¿ the motor will move to position 3. Finally, confirming successful command execution through LED indicators. To ensure the Board Voice Subsystem is fulfilling its responsibilities for capturing voice input, a requirements & verification table can be found below.

Requirements	Verification
The subsystem capture voice commands using a microphone with clear audio input	Test microphone sensitivity in different noise conditions and verify audio quality using an oscilloscope or spectrum analyzer
The subsystem process voice commands and recognize 5 predefined switch levels (e.g., ”Level 1” to ”Level 3”)	Test voice recognition accuracy using 5 different user voices, ensuring at least 95% recognition accuracy [1]
The voice control module shall send recognized commands to the MCU via SPI	Check data transmission with logic analyzer to confirm commands are correctly sent to the MCU

TABLE III
BOARD VOICE CONTROL SUBSYSTEM - REQUIREMENTS AND VERIFICATION

*5) **Motor Control Subsystem**:* The Motor Control Subsystem is responsible for sending the feedback information to MCU about how many angles that the motor has rotated, and MCU can response base on this information. The MCU will keep generating PWM signal to motor driver until the angle reaches the desired position.

To ensure the Board Control Subsystem is fulfilling its responsibilities for sending the accurate information, a requirements & verification table can be found below.

Requirements	Verification
The encoder shall provide real-time position feedback to the MCU.	Rotate the motor manually and verify encoder output using an oscilloscope or MCU serial print.
The encoder outputs quadrature signals (A/B phase shift of 90°) for direction detection.	Use an oscilloscope to confirm A/B signals are 90° out of phase.
The encoder sends position data to the MCU within 1ms response time to ensure real-time control.	Measure the latency between movement and MCU response using timestamp logging. [3]

TABLE IV
MOTOR CONTROL SUBSYSTEM - REQUIREMENTS AND VERIFICATION

*6) **Motor Subsystem**:* The Motor Subsystem is responsible for pushing the switch up and down. The motor driver controls the rotation direction of the motor and how many angles needed to rotate based on the PWM signals from MCU. The MCU will keep generating PWM signal to motor driver until the angle reaches the desired position. To ensure the Motor Subsystem is fulfilling its responsibilities for pushing the switch up and down, a requirements & verification table can be found below.

Requirements	Verification
The motor shall support 5 distinct levels of movement, corresponding to switch positions	Command the motor to each level and measure displacement accuracy with a caliper or encoder feedback
The motor shall achieve an angular precision of ±1° to ensure accurate switch control	Compare actual motor rotation angle (via encoder) with the expected angle for multiple test cases [3], [4]
The motor shall support bidirectional movement (up/down switch adjustment)	Apply forward and reverse PWM signals and verify correct movement

TABLE V
MOTOR SUBSYSTEM - REQUIREMENTS AND VERIFICATION

*7) **Tolerance Analysis**:* In this project, sliding switch mechanism in this project requires precise displacement control to ensure accurate selection of the 5 predefined levels. The displacement accuracy is influenced by the encoder resolution. The primary sources of tolerance affecting displacement accuracy is Encoder Resolution (PPR). Encoder Angular Resolution = PPR/360

Linear Displacement Resolution = (displacement per 180 degree * Encoder Angular Resolution)/180

When the linear displacement resolution is greater than the accuracy required by the system, it will become a source of error because the system can only move according to this minimum step size and cannot achieve a smaller displacement adjustment, resulting in a deviation between the actual position and the target position.

For PPR = 100, linear displacement resolution is 1mm. But if our requirement is less than or equal to 0.1 mm, so the minimum unit of each displacement is 1 mm, which means that the gear position may not be accurately aligned, resulting in position error. For PPR = 1000, linear displacement resolution is 0.1mm. If our requirement is less than or equal to 0.1 mm, this resolution can achieve our objective.

Therefore, improving the encoder PPR can reduce quantization errors and allow the system to reach the target position more accurately.

C. Cost and Schedule

The total cost of this project is shown in the the table below. Hourly wages will be $40/hr$, found using average expected salary for ECE graduates at UIUC. There are 3 in our group and we expect to work around 6 hrs a week, so doing the math.

$$LaborCost = 3 * 40/hr * 6hrs * 10weeks = 7,200$$

See Figure 5 for Schedule Table.

This concludes our Cost and Schedule.

D. Discussion of Ethnics and Safety

Our project consists of three main ethics and safety concerns, according to the IEEE Code of Ethics.

Privacy and Data Security

Description	Provider	Part #	Quantity	Cost ($)
0.1 µF -20%, +80% 25V Ceramic Capacitor Y5V (F) 0805 (2012 Metric)	ECE Electronics Service Shop	CL21F104ZAANNNC	10	Via ECE Supply Store
10 µF ±20% 50V Ceramic Capacitor X5R 0805 (2012 Metric)	ECE Electronics Service Shop	GRM21BR61H106ME43L	5	Via ECE Supply Store
Linear Voltage Regulator IC Positive Fixed 1 Output 1A TO-252-3	ECE Electronics Service Shop	AZ1117CD-3.3TRG1	1	Via ECE Supply Store
Linear Voltage Regulator IC Positive Fixed 1 Output 600mA SOT-25	ECE Electronics Service Shop	AP2112K-3.3TRG1	1	Via ECE Supply Store
USB - micro B USB 2.0 Receptacle Connector 5 Position Surface Mount, Right Angle; Through Hole	ECE Electronics Service Shop	10118194-0001LF	1	Via ECE Supply Store
Bluetooth, WiFi 802.11b/g/n, Bluetooth v5.0 Transceiver Module 2.4GHz PCB Trace Surface Mount	ECE Electronics Service Shop	ESP32-S3-WROOM-1-N16	1	Via ECE Supply Store
1 kOhms ±5% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Automotive AEC-Q200 Thick Film	ECE Electronics Service Shop	RMCF0805JT1K00	5	Via ECE Supply Store
10 kOhms ±5% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Automotive AEC-Q200 Thick Film	ECE Electronics Service Shop	RMCF0805JG10K0	5	Via ECE Supply Store
100 kOhms ±5% 0.125W, 1/8W Chip Resistor 0805 (2012 Metric) Automotive AEC-Q200 Thick Film	ECE Electronics Service Shop	RMCF0805JT100K	5	Via ECE Supply Store
0 Ohms Jumper Chip Resistor 0805 (2012 Metric) Automotive AEC-Q200 Thick Film	ECE Electronics Service Shop	RMCF0805ZT0R00	5	Via ECE Supply Store
Red 638nm LED Indication - Discrete 1.8V 1206 (3216 Metric)	ECE Electronics Service Shop	LTST-C150CKT	3	Via ECE Supply Store
Diode 40 V 5A Surface Mount DO-214AC (SMA)	ECE Electronics Service Shop	CDBA540-HF	3	Via ECE Supply Store
N-Channel 30 V 5.3A (Ta) 1.3W (Ta) Surface Mount Micro3™/SOT-23	ECE Electronics Service Shop	IRLML0030TRPBF	5	Via ECE Supply Store
Bipolar (BJT) Transistor NPN 25 V 1.5 A 100MHz 300 mW Surface Mount SOT-23-3	ECE Electronics Service Shop	SS8050-G	5	Via ECE Supply Store
Rotary Encoder 24PPR	ECE SUPPLY CENTER	150340901	1	6.91
5 Position MTA156 Header	ECE SUPPLY CENTER	560117770	1	0.72
H-Bridge Motor Driver for DC Motors- 8DIP -2.5V-12V 800mA L9110H	ECE SUPPLY CENTER	110300681	1	2.56
AA Battery	ECE SUPPLY CENTER	620109000	8	0.65
Quad AA Battery Holder	ECE SUPPLY CENTER	620108501	2	3.04
EV_INMP441-FX	Amazon	1428-1043-ND	4	1.56
Total Parts Cost				27.71
Labor Cost				7200
Total Cost				7227.71

Fig. 4. Block Diagram of the Automatic Light Switch

Week	Dues	Task- Person
1	First Round PCBWay Orders Teamwork Evaulation Design Document	Finish designing the PCB on Kicad and submit it to TA- Sun, Ruize Finish Teamwork Evaluation- ALL Finish writing up the Design Document- ALL Buy the parts and start building the Breadboard- ALL
2	Breadboard Demo Second Round PCBWay Orders	Finish making the breadboard- Ruize, Andrew Make adjustments to the PCB- Sun, Ruize Continue on designing the app- Andrew
3	Spring Break	PCB and Breadboard revisions- Sun, Ruize After Breadboard Demo, get the necessary parts- Sun, Ruize
4	N/A	PCB Revisions- Sun, Ruize Start testing Speech Recognition- Andrew Start Assembling the project- ALL
5	Third Round PCBWay Orders Individual Progress Reports	Continue testing- ALL PCB Revision- ALL Turn in Individual Progress Reports- ALL
6	Fourth Round PCBWay orders	PCB Revisions- ALL Finish Assembling- ALL Continue Testing- ALL
7	Team Contract Assessment	Finish with Assembly- ALL Finish with PCB Revisions- ALL Finish Testing- ALL
8	Mock Demo	Fix Bugs- ALL
9	Final Demo Mock Presentation Extra Credit Video	Final Demo-ALL
10	Final Presentation Final Papers Lab Notebook Due	Turn in Final papers and Lab Notebook- ALL Final Presentations- ALL

Fig. 5. Schedule

- The application and microcontroller we are using require access to WiFi and Bluetooth, so there are security risks if the data transferred is misused .
- Voice control, if recorded, can collect and store sensitive data, which imposes security risks to users

Potentially violates IEEE Code of Ethics (Respect privacy.) and (Honor confidentiality.)[5]

We will avoid these issues by making sure we don't record the data from users and release the development process to the public to ensure that data transferred through WIFI and Bluetooth are not sent to third parties.

Reliability and Safety

- If our system malfunctions, safety issues can occur in specific locations, such as hospitals, staircases, or emergency exits

Potentially violates IEEE Code (Give comprehensive and thorough evaluations of computer systems and their impacts, including analysis of possible risks.) and (Ensure that the public good is the central concern during all professional computing work.) [5]

We will ensure reliability by testing voice control with various sounds, so that it doesn't malfunction in unwanted cases.

Misuse of Technology

- Unauthorized users having access to the light switch might turn the lights on/off without permission

Potentially violates IEE Code of Ethics (Avoid harm.) [5]

We will avoid this issue by allowing everyone to have access to the light switch, since voice recognition of specific users requires our system to record voices, and this goes against our first safety concern mentioned. This is not that big of an issue since using the light switch without permission does not lead to large safety concerns.

E. Citation

- INMP441 Omnidirectional Microphone with Bottom Port and I 2 S Digital Output GENERAL DESCRIPTION. https://invensense.tdk.com/wp-content/uploads/2015/02/INMP441.pdf
- ESP32-S3-WROOM-1-ESP32-S3-WROOM-1U Datasheet 2.4 GHz Wi-Fi (802.11 B/G/N) and Bluetooth ® 5 (LE) Module Built around ESP32-S3 Series of SoCs, Xtensa ® Dual-Core 32-Bit LX7 Microprocessor Flash up to 16 MB, PSRAM up to 8 MB 36 GPIOs, Rich Set of Peripherals On-Board PCB Antenna.https://www.alldatasheet.com/datasheet-pdf/pdf/1642038/ESPRESSIF/ESP32S3.html
- DPL12SV2424A21F3, Encoders DPL12S 24P 24DET 21F RD/GRN, https://www.mouser.com/datasheet/2/418/3/NGDS1-1773449-0G-716223.pdf
- "Adafruit L9110H H-Bridge Motor Driver for DC Motors - 8 DIP." 3DMakerWorld, Inc., 2025, 3dmakerworld.com/products/l9110h-h-bridge-motor-driver-for-dc-motors-8-dip. Accessed 7 Mar. 2025.
- IEEE. ""IEEE Code of Ethics"." (2016), [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html (visited on 02/08/2020).