ECE445 Project:
Ambient Light Detection and Auto Dimming Smart Switch

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1. Introduction

Problem: Most light switches are binary switches and do not have brightness control. There are dimmer switches that allow the user to control brightness, but they do not automatically adjust if the ambient light changes. Users may need to adjust the light if they are in the same room for a long period of time. There are existing smart no-neutral switches, and lights that detect ambient light (like the BenQ e-Reading Desk Lamp), but there are no existing solutions that combine the two.

Solution: We plan to create a smart switch that can be connected to any existing light switch (including switches lacking neutral connections) and intelligently control lights. Sensors on the switch will be able to detect the ambient light and adjust the brightness of the lights to maintain a constant room brightness.

Visual Aid:

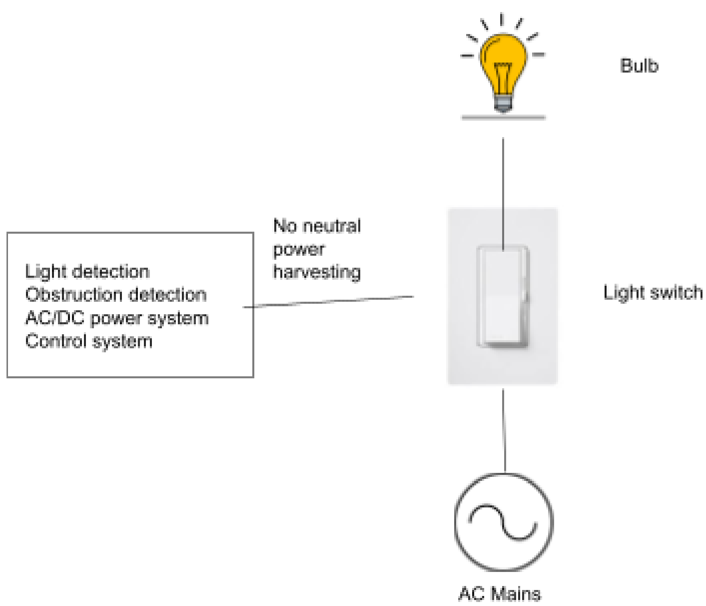

Figure 1: Visual Aid

High-level requirements list:

- Be able to connect to any existing light fixtures and switch. No neutral wire will be required.
- Maintain a constant light level for the room at desired brightness.

- Prevent unintended fluctuations in light from temporary obstructions in front of the switch.
- Have an override switch that allows for absolute control of the lights.

2. Design

Block Diagram

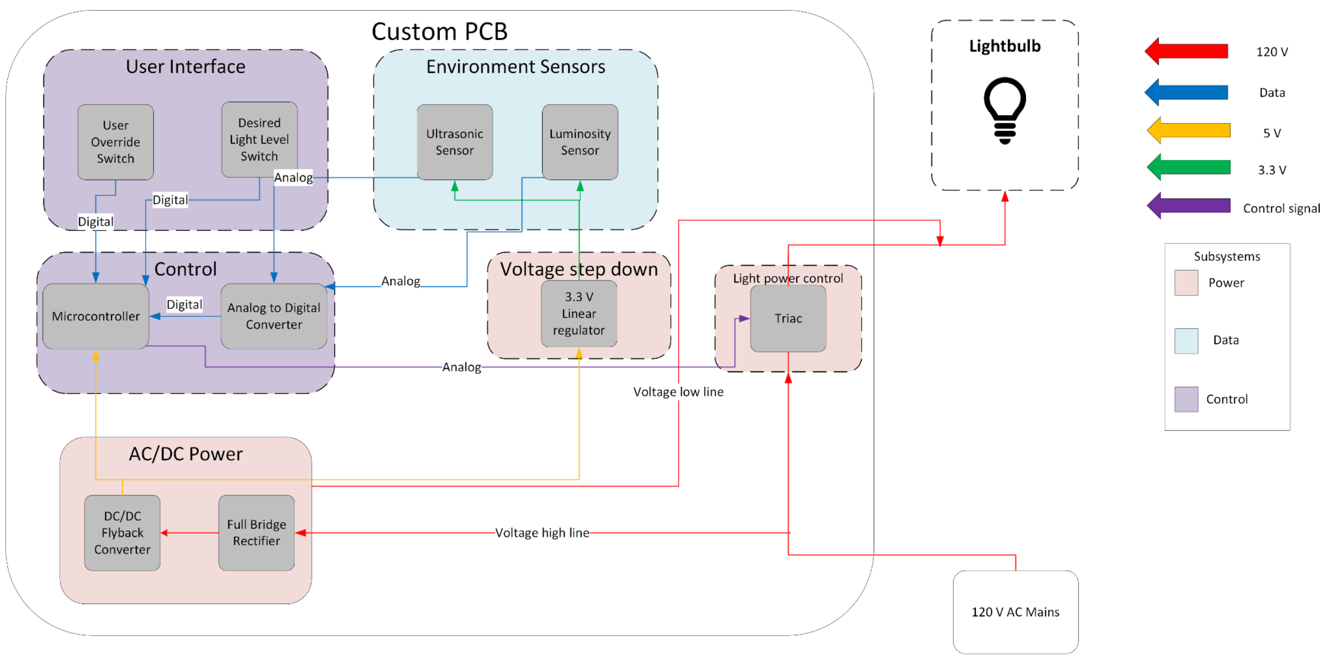

Figure 2: Block Diagram

Subsystem Overview

User Interface:

This system will give the user control over how they want the switch to operate. Based on the options selected here, the behavior of the control subsystem will change.

Desired Light Level Control

The user will be able to control the desired light level using a selector. This selection will send a signal to the microcontroller. Based on the desired light level and the existing ambient light, the microcontroller will vary the power level to the light bulbs.

Requirement 1: The user must have at least 3 light level options.

User Override Switch

The system will also be equipped with an override switch that allows the user to directly control the level of the lights, and bypass the ambient light control system. This will allow the user to turn off the ambient light control system.

Requirement 1: The override switch must make the switch behave like a normal ‘dumb’ switch.

Environment Subsystem:

This subsystem will detect the surrounding environment to provide data to the microcontroller. Based on this data, the microcontroller will be able to output control signals to allow the light to turn on and also adjust the power of the light.

Ultrasonic Sensor

This component is intended to prevent obstructions of the ambient light sensor from rapidly changing the light level. If an obstruction (like a person) is detected in front of the switch, a high signal will be output and the light control will pause and maintain the current light level until the obstruction is removed. After the obstruction is removed, the output will change back to a low signal and the circuit will resume monitoring the ambient light level and controlling the light level.

Requirement 1: The ultrasonic sensor must be able to accurately detect an object within 1 m.

Luminosity Sensor (Ambient Light Detection)

This subsystem will detect the existing ambient light and adjust the power to the overhead lighting to match the desired light level. The power level adjustment will be triac controlled to only pass a portion of the AC mains waveform to the lights.

Requirement 1: The luminosity sensors must be able to detect the full typical range of brightness of a room from dark to full brightness.

Power Subsystem:

Since we are designing a smart switch with no neutral connection, the smart switch has to obtain power and stay in standby mode. It will have a power harvesting circuit that allows a small amount of power to the lightbulb even when the switch is not turned on to complete the circuit. When the switch is turned on, enough power will be sent to the lightbulb to light it up. The power supply should be able to extract power from the open circuit over a wide voltage range.

In order to power the switch, we are sourcing power from the 120V 60Hz AC source existing in the wall circuit on the neutral side and providing isolated switching conversion in DC. The circuit design will consist of a triac optocoupler to control the power passing to the bulb, chopping up the waveform into the desired trigger angle with the optocoupler. [1] [2] From there, a zener diode will be paired with the input filtering needed to feed into a flyback converter to provide isolated DC/DC conversion to power the rest of the control circuits. [3] The decision of opting for a switching regulator over a linear regulator was made based on efficiency characteristics, and the isolation included in a flyback reduces the potential for a short.[4][5][6] This increases safety for the user.

Full Bridge Rectifier

This full bridge rectifier will take the AC mains waveform and output a DC waveform to be used in the DC/DC flyback converter. A capacitor will be used to reduce the ripple and smooth the waveform provided to the flyback converter.

Requirement 1: Ripple factor must be lower than the usual value of 0.483.

DC/DC Flyback Converter

The flyback converter will get input power from the full bridge rectifier and output a 5V signal. This 5V signal will be the basis for all the DC electronics included on the PCB. Due to the nature of the no neutral circuit, the converter must be able to function over a wide voltage range and maintain the 5V output.

Requirement 1: Must provide a 5V ±10% output signal to the microcontroller and linear regulator.
Requirement 2: Must function over 5V-120V input voltage range.

Light Power Control

Conduction to the light will be managed by a triac. When the triac receives a pulse from the microcontroller, the triac will begin conducting and the light will turn on.

Voltage step down

A linear regulator will be used to step down the 5V from the flyback converter to 3.3V. This portion of the subsystem will provide power to the environment sensor subsystem.

Control Subsystem

This subsystem will provide the control for the light. By taking in data from the sensors and user interface controls, the microcontroller will vary the power that the light receives. The microcontroller will intake data from the sensors using an analog to digital converter.

Microcontroller
The microcontroller is responsible for handling the inputs from the User Interface and Environment subsystem and controlling the power to the light. It will first set the operation mode based on the user override switch and whether obstruction is detected by the ultrasonic sensor. If the override switch is on, the system operates as a simple switch. If not but there is an obstruction, the system will hold the current light power level until the obstruction clears. In normal operation, the microcontroller will utilize inputs of the luminosity sensor and the desired light level switch to run a control loop that adjusts the power sent to the light to approach the desired light level received by the luminosity sensor. The light control will continue to adjust to reach the desired level unless it reaches a limit by the minimum or maximum power levels available to the light.

Requirement 1: Must be able to communicate with the analog to digital converter over a wired connection.
Requirement 2: Must allow the triac to conduct to allow for power siphoning, while ensuring the light stays off.

Analog to Digital Converter
The analog to digital converter will convert the analog signals output by the sensors and convert them to a digital signal that can be read by the microcontroller. The ADC will take the signal from the luminosity and ultrasonic sensors simultaneously and output data to the microcontroller to be used in control.

Requirement 1: Must be able to simultaneously process the signals from the luminosity and ultrasonic sensors.
Requirement 2: Must be able to communicate with the microcontroller over a wired connection.

Tolerance Analysis

The most significant potential risk would most likely be in our power conversion circuitry. When designing with the transformer, the winding ratio and duty ratio $Duty_{max}$ must be carefully selected to be consistent with desired flyback voltage. In addition, in order to operate in PWM continuous mode, we must identify the critical point to avoid discontinuous modes. This can be done by calculating the overload protection point where the maximum load current I_{omax} should be 1.2x the output current.

$$I_{spk} = \frac{2 \cdot I_{omax}}{1 - Duty_{max}}$$

$$L_s \prec \frac{(V_{out} + V_F)(1 - Duty)^2}{2 \cdot I_{omax} \cdot f_{swmax}}$$

When selecting the actual transformer core size, it is based upon the output power. With the area of the transformer core A_e, the primary windings turns N_p must be set so that the magnetic flux density B_{sat} falls within the tolerance range as specified by the manufacturer to avoid magnetic saturation. [7]

$$N_p \succ \frac{V_{in} \cdot t_{on}}{A_e \cdot B_{sat}} = \sqrt{\frac{L_p}{A_L}}$$

Ethics and Safety

IEEE code of ethics section I.1 specifies to hold safety in the highest regard [8]. The primary safety/ethics issue with our project is the usage of AC mains voltage. If not treated very carefully, this could lead to electric shock or possibly death. It is also very important that attached documentation notes the dangers of working with AC mains voltage. Ensuring that the user turns off the breaker for the circuit before replacing the switch will prevent a user from being shocked while installing this smart switch. Minimization of excess heat and high quality wiring is paramount to the safety of our device. If the components of our circuit were to heat up too much, there could be an electrical fire.

Outside of the safety risk of using AC mains voltage, we do not foresee any other ethical concerns. Our project will not store any data from the user, and no data will leave the self-contained system.

References

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