ECE 445

Senior Design Laboratory

Design Document

Illuminate

Multi-sensor Motion Detector for Reliable Lighting Control

Team No. 21

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1 Introduction

1.1 Problem

In offices, classrooms, and lecture halls worldwide, motion sensors are commonly used to automate lighting control. While convenient, these systems share a critical flaw: lights often switch off when people remain in the room but are relatively still, such as when typing, reading, or watching a presentation. This leads to frustration, disrupts productivity, and creates an inefficient work environment. The root of the issue lies in the reliance on Passive Infrared (PIR) sensors, which detect the infrared radiation emitted by warm bodies. Although effective for detecting large movements, PIR sensors struggle with micromotions, are prone to false triggers, and rely on fixed timeout settings. As a result, they fail to consistently recognize human presence.

1.2 Solution

Our approach introduces a two-stage verification system to improve reliability while preserving the strengths of current technology. The first stage utilizes a PIR sensor, which remains valuable for its fast response to initial entry and detection of larger body movements; this sensor will specifically capture when a person first enters the room. The second stage integrates a millimeter-wave (mmWave) radar sensor, which excels at detecting fine micromotions such as breathing or subtle hand movements. This stage ensures continuous detection of occupants even during periods of low activity. Together, the PIR sensor triggers the system upon entry, while the mmWave sensor maintains accurate presence detection until all occupants have left.

In addition, our design incorporates a multi-level lighting system to both conserve energy and enhance user comfort. Upon initial detection, the lights will gradually illuminate to the target brightness, avoiding abrupt transitions and providing a smoother user experience. When occupants remain in the room, the lighting will hold at the appropriate brightness level, informed by ongoing verification from the mmWave sensor. If no presence is detected for a designated interval, the system will first dim the lights to an intermediate level to signal a potentially empty room. Upon confirmation of vacancy, via an additional verification stage, the lights will go completely off.

1.3 Visual Aid

We have attached a high-level diagram for our sensing system in Figure 1. The PIR Sensor is used to turn on the light, while the mmWave sensor is used to either keep the light on or turn off the light.

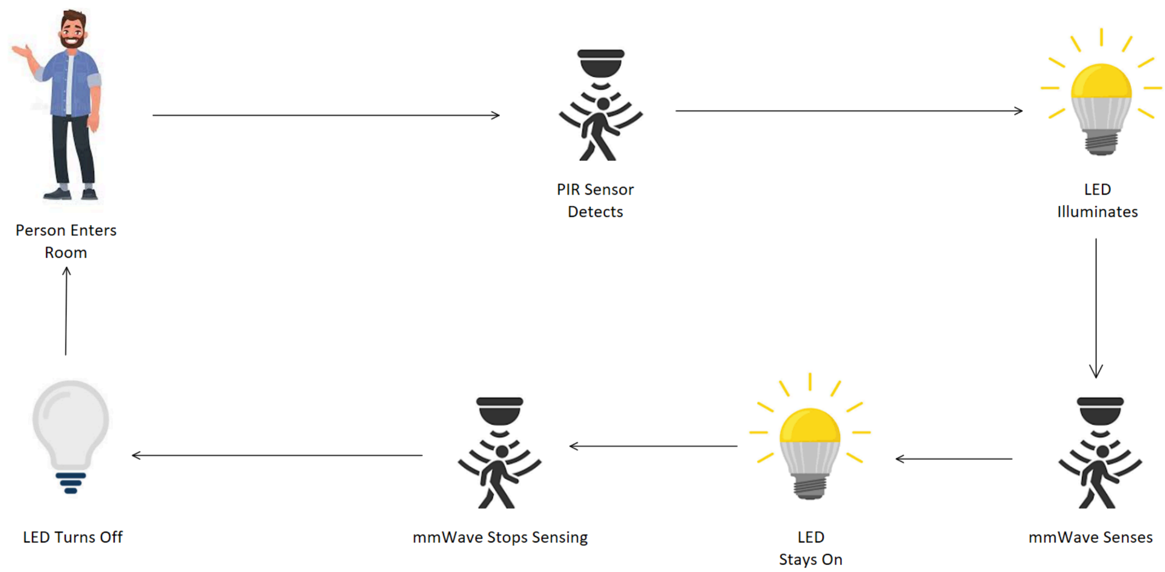


Figure 1: Overview of the Illuminate System

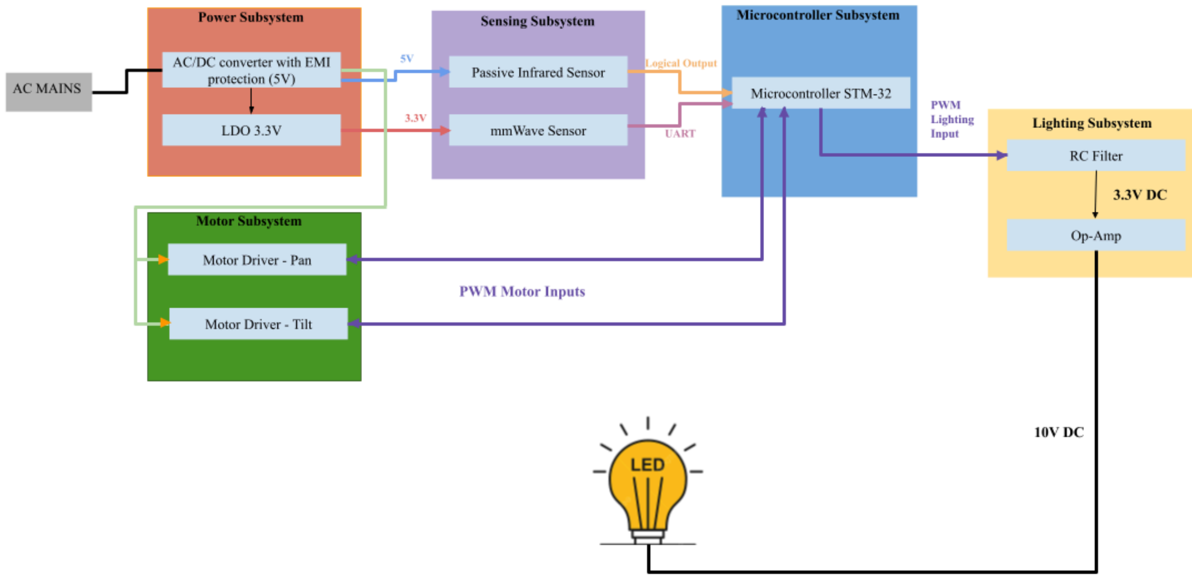
1.4 High-Level Requirements

To be considered successful, our project must meet the following objectives:

1. The light must begin to illuminate within 1 second of someone entering a room, stay on for 30 minutes with someone being in the room, and begin to turn off after 1 minute of not detecting anyone
2. Capable of detecting people in all parts of a 25’x40’ Room (or smaller).
3. The motor that controls the direction of the sensor should be able to sweep 180 degrees horizontally and 90 degrees vertically at the same time.

2 Design

2.1 Block Diagram



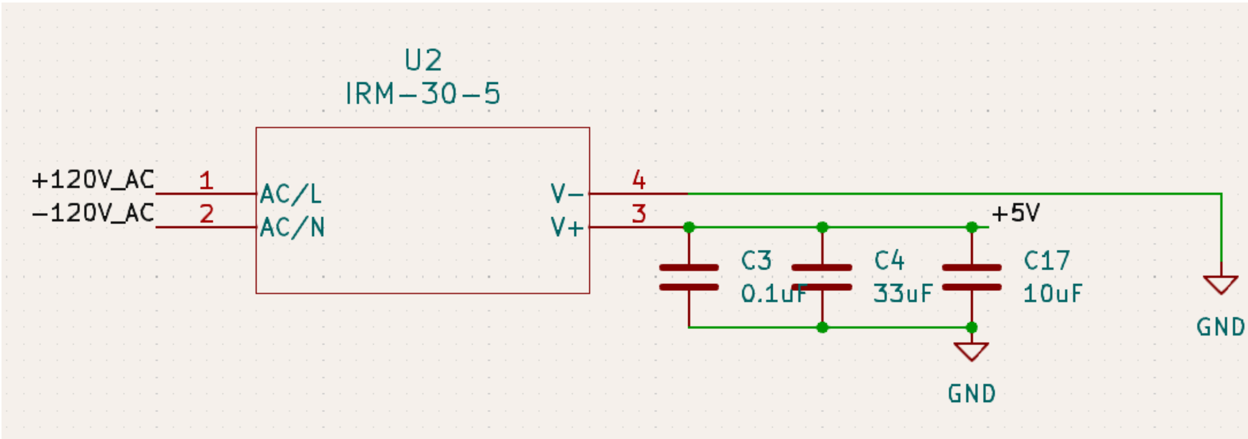
Our block diagram consists of 5 subsystems: Power, Sensing, Microcontroller, Lighting, and Motor. The power subsystem is responsible for powering all components within the scope of our project, and consists of taking power from 120 VAC AC mains. The sensing subsystem senses whether people are in the room, and outputs this data to the STM32 MCU. The microcontroller outputs PWMs for the lighting, and motor. The PWM for the lighting tells how much light, and if the lights should be on, and the PWMs for the motor tell the motors where to go. The Lighting subsystem drives the LEDs to ensure the correct power is sent to the LEDs so that they are ON, OFF, dimming, etc. The motor subsystem moves the mmWave sensor to ensure that the entire room is scanned.

2.2 Subsystem Overview

Our Project is split into 5 subsystems, each of which is implemented in both hardware and software.

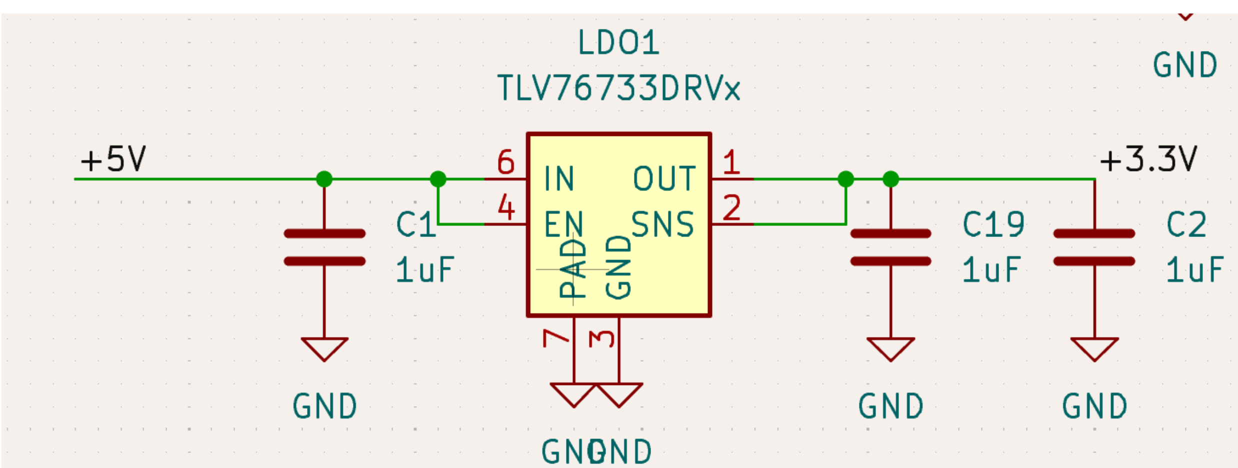
2.2.1 Power Subsystem

Our entire system will be powered by AC mains. We will require 5V for the HS-318 motors, 5V for the ADAFruit 189 PIR Sensor, and 3.3V for the C4001 DFRobot mmWave sensor. In addition, the STM32F103C8 requires a 3.3V input. First, one will have to plug in AC Mains. These AC mains will feed to an Inlet Board, which will contain a fuse. This will protect our circuit from overvoltage by stopping current when an overvoltage occurs (160 VAC). We will feed the output of this Inlet board into an AC/DC 5V converter with EMI Protection. EMI Protection is necessary since we deal with AC mains.



We will be using the IRM-30-5, which is rated at 6A (our current will not exceed 3A at worst case scenario) [8]. It is also class II, meaning that it is double-insulated and does not require a ground connection. The circuit configuration for this chip is simply the chip and some decoupling capacitors. Capacitor C3 serves as a ceramic decoupling capacitor, used as a high-frequency bypass, and placed very close to the output V+ pin of the IRM-30-5. Capacitors C4 and C17 serve as bulk capacitors, which prevents voltage sagging when there are big current surges. Their values come from the IRM-30-5 Datasheet [10], which recommends a 0.1uF ceramic + 47 uF bulk capacitor for decoupling. The electronic service's shop does not have 47 uF capacitors, so we have chosen to use a 33 uF and 10 uF capacitor in parallel to get close to the targeted value.

This 5V will be fed into a 5V to 3.3V LDO. This LDO is rated for 1A [9], which does not exceed our worst case current that the mmWave and LED Driver require. Rather than using a buck converter, an LDO is sufficient for a drop of 1.7V without avoiding too much power loss, as Texas Instruments states that 2V drops are acceptable [6].



Here is a schematic of our LDO circuit. It contains 2 1uF capacitors on the output of the LDO (3.3V side) and 1uF capacitor on the input side (5V side). The input capacitor is there to stabilize the input voltage to the LDO. The output capacitors are also there to stabilize the output voltage. This circuit comes from a typical application provided from the datasheet [9].

Requirements	**Validation**
The power subsystem must be able to accept 120 VAC from AC Mains in a building and convert it to 5V, with a tolerance of ±5%, for a continuous current load of up to 3A.	● Wait enough time to ensure that the circuit has been properly discharged. ● Plug in the AC Mains to start supplying power to the circuit. Wait a few seconds for components to power up. ● Measure the voltage output at the 120VAC-5VDC converter to ensure that this is within ±5% of 5V. This will be measured via oscilloscope/DMM. ● Apply some sort of motion near the PIR sensor, and wait for the lights to turn on (fully), and ensure they stay on. ● Next, wait for the motors to start moving, and while this is occurring, measure the voltage output at the 120-VAC-5VDC converter and ensure this is within ±5% of 5V (this is because the largest output current occurs when the LEDs are on, and the motors are moving). This will be measured via oscilloscope.
The power subsystem must be able to accept 5V (±5%) and output 3.3V with a tolerance of ±5% through the LDO during continuous current of 1A.	● Power up the circuit through the AC Mains. Ensure that the components are fully dissipated before powering back up to ensure safety. ● Turn on the light by applying motion near the sensors. ● Measure the output of the LDO through oscilloscope/DMM and ensure that it is within the requirement.
The 5 V rail must be less than or equal to 5.5 V during 140 Vac for 60 s	● Use a variac to sweep to 140 Vac ● Monitor the 5 V output with an

	oscilloscope/DMM ● Confirm that there are no resets/damage and perform a post-test functional check.
Ensure the Fuse/thermal link opens on sustained overvoltage	● Apply 160–170 Vac via variac for 60 s (supervised) ● Verify the primary fuse opens safely by measuring the current through the fuse through a clamp on DMM (safe for AC). ● Confirm no overheating or secondary over-voltage by measuring the secondary voltage through an oscilloscope/DMM.

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2.2.2 Motor Subsystem

The motor subsystem is powered from the system's regulated 5 V DC rail and drives two servo motors that together form a two-axis gimbal for the mmWave radar sensor. The pan servo provides rotation about the vertical axis, enabling horizontal sweeps across the room, while the tilt servo provides rotation about the horizontal axis, allowing the sensor to scan vertically downward from its ceiling-mounted position. By combining these motions, the subsystem expands the effective coverage area of the mmWave sensor beyond its inherent field of view.

To ensure reliable operation, the motors are powered through a dedicated supply rail capable of handling their peak current draw, isolated from the sensitive logic rails. Optional limit switches or built-in servo feedback can be incorporated to provide positional awareness and safe homing routines during startup. Mechanically, the servos are integrated into a compact gimbal mount that rigidly supports the mmWave sensor while minimizing vibration and backlash.

We will be using two HS-318 servo motors. These do not send any info back to the mcu, but can be controlled through PWMs sent by the microcontroller. To program the pan and tilt, we will be sending PWMs to control the position of the motors, and vary this over time. The pan will have to go much slower than the tilt motor in order to ensure that the tilt motor can go 90 degrees enough to scan the room.

We want to scan the whole room within 30 seconds. To do this, we must calculate the correct degrees/second in order to achieve this. For the pan motor, we need to have 6 degrees per second. However, the tilt motor must be able to achieve much more than this, as it has to go ±90 degrees much more. To tilt 90 degrees 8 times, the tilt motor must be able to go 24 degrees per second.

Requirements	**Validation**
The pan motor must be able to rotate ±180 degrees through mcu programming, and the tilt motor must be able to rotate ±90 degrees.	● Change the code to have the tilt motor start at 0 degrees, and end at 90 degrees at the end of the sequence. ● Plug in the AC power and wait for the motor sequence to start. ● Once the motor has stopped at one edge, unplug power to stop the sequence. ● Measure the angle of the pan and tilt motor during the off period with a protractor. ● Plug in AC Power again and wait for the motor to pan to the other side and stop. ● Unplug power again, and measure the angles of both the pan and tilt motors to ensure that they are 180 and 90 degrees away from the starting position.
Both the pan and tilt motors must be able to start in the same position (within ±5 degrees)	● Measure the desired starting angles with a protractor. ● Plug in AC power, and wait for the motor rotation to begin. ● When motor rotation begins, unplug power in the middle of the rotation. ● Modify the code to only have the motors start in their positions, and not move once the sequence begins. ● Plug in power again and wait for the motors to go to their starting positions. ● Measure the angles of both and ensure that it is within the requirement. ● Repeat this 3 more times (to make sure that the starting angle is accurate).
Endpoint repeatability: For both servos (pan and tilt), the settled angle at each endpoint shall vary by no more than 2.0 degrees across repeated commands.	● Mount a protractor (or IMU) rigidly to the joint. Command 50 consecutive moves to each endpoint (pan left/right;

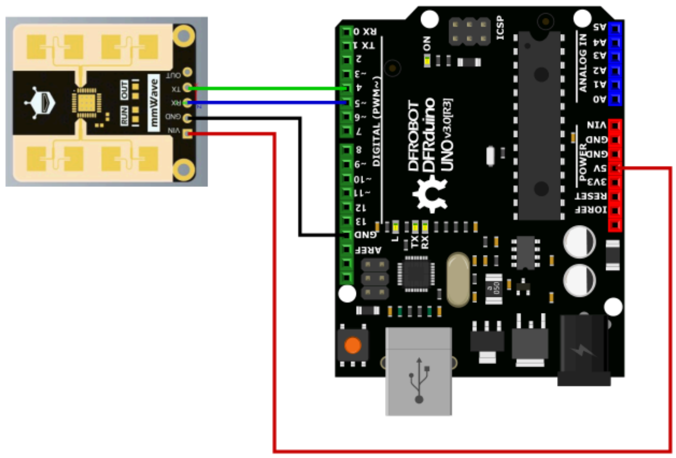
	tilt down/up). ● After each move, wait 300 ms and record the settled angle. ● For each endpoint, compute the mean angle and the maximum absolute deviation from that mean. Pass if the maximum deviation ≤ 2.0 degrees at all four endpoints.
The motors must complete a full sweep of the room within 30 seconds (can be less, but worst case 30 seconds).	● Plug in power and wait for the motor sequence to start. ● Once the motor sequence starts, use an electronic stopwatch and start a timer. ● Stop the timer once the motor rotation stops, and ensure the timer shows less than 30 seconds.

2.2.3 Sensing System

The sensing subsystem integrates both the Passive Infrared (PIR) sensor and the C4001 mmWave radar sensor, along with the necessary interface circuitry to ensure reliable operation. These two sensors work together to provide a two-stage verification system: the PIR sensor offers fast response to initial entry and large-scale movement, while the mmWave sensor provides continuous presence detection by recognizing fine micromotions such as breathing or typing of occupants within the room.

This subsystem requires two regulated power rails: a 5 V supply for the PIR sensor and a 3.3 V supply for the mmWave sensor, each routed from the power subsystem. The PIR sensor outputs a digital logic signal that connects directly to the microcontroller's GPIO, while the mmWave sensor communicates with the microcontroller over a UART interface for transmitting detailed presence and motion data. An optional interrupt line from the mmWave module can also be used to flag immediate detection events.

For the initial configuration of the mmWave sensor, we will be using an Arduino Uno to demo the use of this sensor before integrating it into our final design in order to ensure desired specifications.



We will be placing the mmWave in the middle of the room. We are assuming a 25x40(ft) room, but we will be placing it at the 20ft mark (middle), at the front of the room. Thus, the mmWave must be able to detect 20ft (left to right), and 25 front to back. Thus, we use the pythagorean theorem and find that the max distance that the mmWave will have to detect from.

$$max\ distance\ =\ 25^2 + 20^2,\ max\ distance\ =\ 32ft$$

Thus, the mmWave must be able to detect a human at a distance of 32 ft or less.

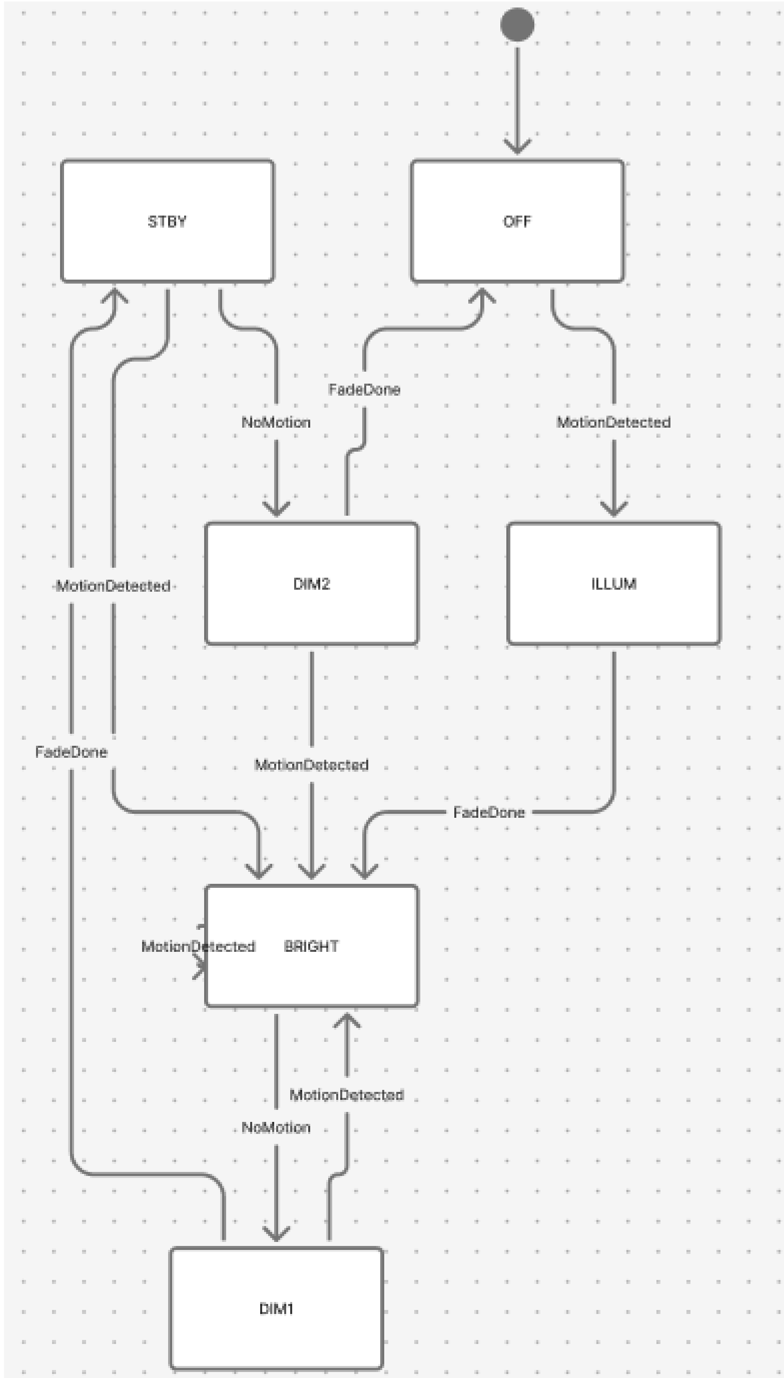
Requirements	**Validation**
The PIR sensor must be able to detect human presence at a distance of 20 ft. or less. (90% of the time)	• Stand 20 feet away from the PIR sensor. • Have somebody else plug in the AC power. • While staying around 20ft away, make motions to see if the PIR can detect and turn on the light (you need to move to turn on the light since PIR can't detect standstill motion). • If the light has turned on, that means that this is a successful test. You can also test this by probing the output from the PIR sensor and seeing if a high is output from the sensor.
The mmWave sensor must be able to detect human presence at a distance of 32ft or less. (90% of the time)	• Plug in the AC Power. • Stand near to the PIR sensor, and start moving, and wait for the light to turn on. • Once the light has turned on, move to a distance of 32 ft. away from the sensor. • Wait for 5 minutes. If the light has not turned off, this means that the mmWave is able to detect a

	human presence.
The sensors must detect human presence with an accuracy rate of 95%.	● Place the device at its intended mounting height. Connect C4001 via UART/GPIO to the MCU (or USB-UART) and log a binary “presence” flag at 10 Hz with timestamps. Set up a synchronized ground-truth source: (a) overhead camera at 30 fps or (b) a handheld clicker app that toggles “present/absent” with timestamps. ● Collect ≥ 600 labeled 1-second windows across scenarios (balanced ~50% present / 50% absent) ● Build a confusion matrix (TP, TN, FP, FN) and compute Accuracy = (TP+TN)/(TP+TN+FP+FN). Also report precision/recall for context.
The PIR Sensor must be able to send a ON signal within 1 second of seeing motion.	● Make sure that the sensors are powered through AC power. ● Connect an oscilloscope to probe the output of the PIR, and in channel 2, probe the output of the PWM that sends to the LED Driver. ● Standing near to the PIR sensor, do some sort of motion (walk, wave, etc.). ● Once this has happened, look at the oscilloscope and ensure the time between the rising edge of the PIR channel and the rising edge of the PWM sent to the LED Driver is less than 1 second.

2.2.4 Microcontroller Subsystem

The microcontroller controls the movement of the two Servo motors by generating PWM signals to the motor drivers, which translate these signals into motor currents.

The microcontroller controls the LED through 6 states: OFF, Illuminate, Bright, dim1, Standby, and dim2. OFF is self explanatory: the LED is off. Illuminate means that the LED is gradually turning on after detecting motion. In the Bright State, the LED stays at its max brightness. In dim1, the LED begins to gradually turn off. In Standby, the microcontroller analyzes whether any extra movement is seen before fully turning the light off, and once it finds that there is still no movement, it sends a signal to turn off the light.



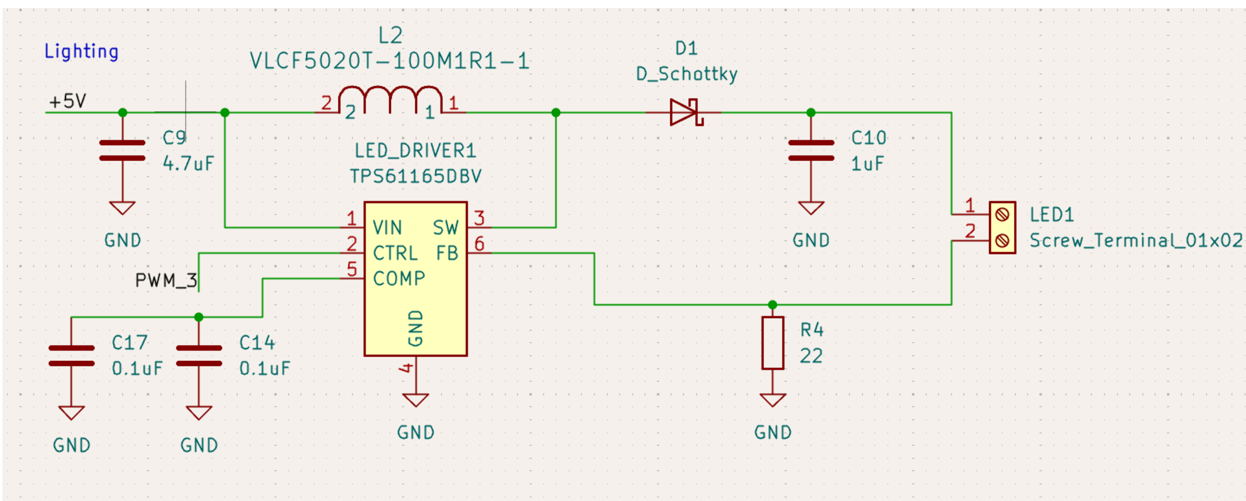
The microcontroller will need to have a GPIO input to receive data from the PIR sensor. It will also need a UART_RX and UART_TX signal to receive and communicate with the mmWave sensor. It also will need to send out 2 PWMs to the motors, which will use 2 more outputs on the microcontroller. Lastly, it will need to send out PWMs to the LED Driver. The microcontroller that we will be using is the STM32F103C8. This is an STM based microcontroller, and has 48 pins. It also has enough timers, PWMs, and GPIOs for our implementation.

Requirements	Validation
The MCU must be able to generate a PWM signal to send to the LED driver, and must vary from a duty cycle of 0-100% during the dimming and gradual illumination stage.	● Plug in AC power to the lighting project. ● Probe the output that feeds to the LED Driver from the microcontroller with an oscilloscope. ● Make motion near the PIR sensor, and observe the oscilloscope. ● Observe to see if the output from the oscilloscope varies (gradually) from a PWM with a duty cycle of 0% to a duty cycle of 100%.
The MCU should be able to detect the PIR input being high in less than or equal to 0.1 seconds.	● Make two variables in the code, one being t_start, and t_detect. ● Configure the code to have t_start count up and stop once the PIR rising edge occurs. ● Configure the code to have t_detect count up and stop once the MCU has detected the PIR rise. ● Subtract t_start from t_detect, and see if the value is less than or equal to 0.1 seconds.
The MCU shall be able to hold its Bright state for at least 30 minutes with people being in a room.	● Ensure that AC Power is plugged in to power the project. ● Turn on the lights by applying motion near the PIR sensor. ● Once this has occurred, start your stopwatch. ● Stay in the room for 30 minutes, and do anything you really want, as long as you are not waiting. ● If the LED stays bright for 30 minutes, the test has passed.
MCU <-> mmWave UART link shall operate at 3.3 V, 8N1, configured baud (e.g., 115200), and deliver correctly parsed presence packets during a 5-minute run under normal operation.	● Connect a logic analyzer to TX/RX to confirm idle high, 8N1 framing, and correct voltage levels. ● Power on and log raw bytes plus parser results for 5 minutes while moving in front of the sensor.

	• Compute parsed/total packets and confirm >= 99.5% success. • Time-stamp ISR entry on first RX byte and the event post (via two GPIO toggles) • Measure the distribution; verify median and 99th percentile are both <= 100 ms.

2.2.5 Lighting Subsystem

Our lighting subsystem's primary responsibilities are to keep the lights on and to gradually turn the lights on and off. The microcontroller generates a PWM proportional to the desired brightness, and we will also use a LED Driver to take in this PWM. The LED Driver will take this PWM and output the correct current and voltage (boosted to the LED rated voltage).

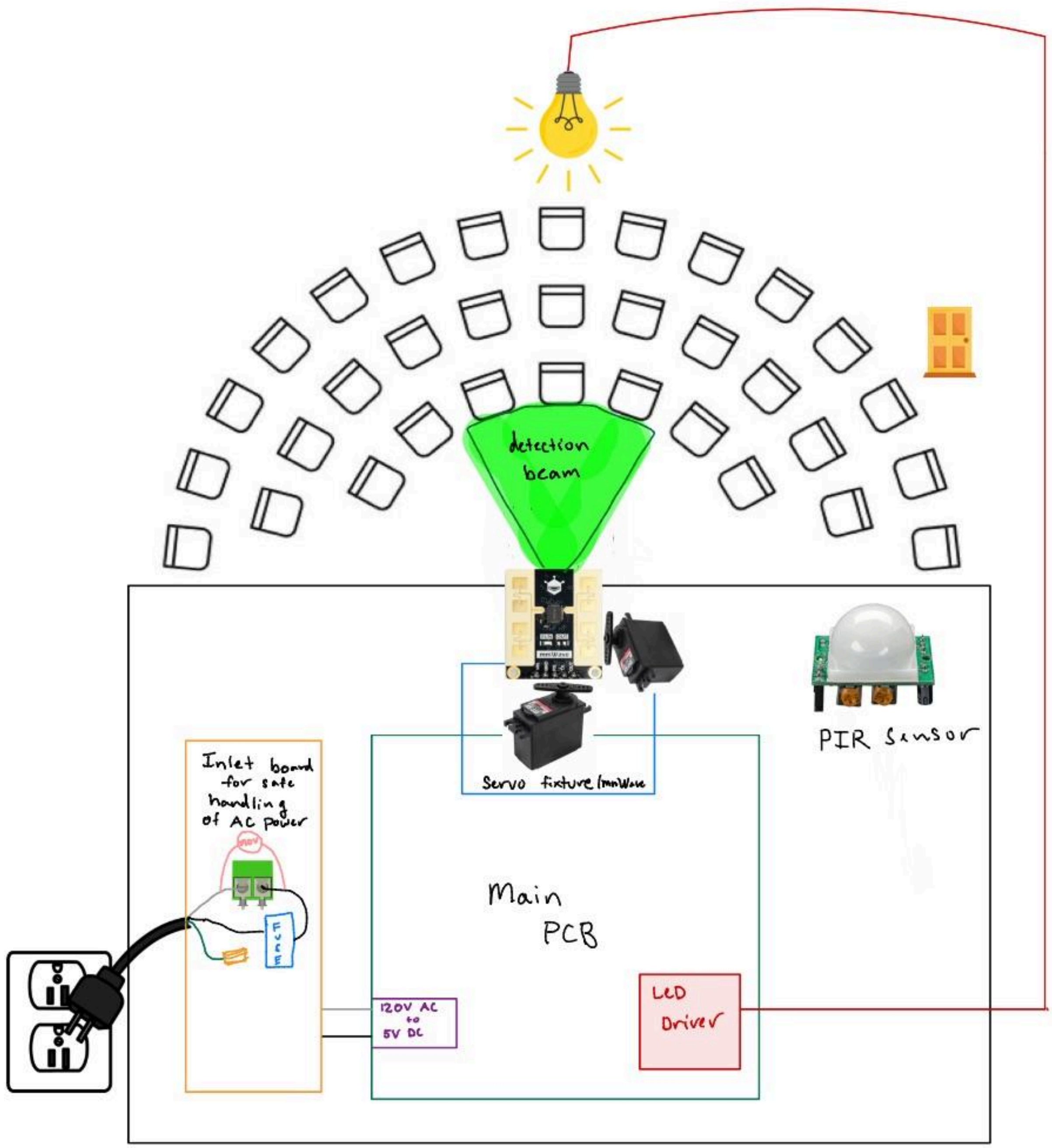


The lightning system centers around the TPS61165DBVR chip from Texas Instruments, which is a high brightness white LED driver. The circuit was designed based on the typical application circuit found in the chip's data sheet [11]. The input and output capacitors, C9 and C10 respectively, are used for decoupling purposes; they help to meet the chip's requirements for ripple and loop stability. Their values were chosen based on recommendations made by the datasheet. Capacitors C17 and C14 are compensation capacitors, and are used to stabilize the feedback loop of the chip. The recommended value of the compensation capacitor is 220 nF, which isn't a capacitance we have access to through the Electronic Service's shop. Thus, we have chosen to use two 0.1 uF capacitors in parallel to get close to the recommended value. The inductor is arguably the most important component in power regulator design; it affects steady state operations as well as transient behavior and loop stability. The inductor was chosen from the table of recommended inductors on the data sheet. The Schottky Diode helps fulfill the high speed rectification that is required because of the high switching frequencies of the TPS61165. The resistor is a current-sense resistor, whose value was determined by the feedback regulated voltage and the LED Current Ratings. Put together, this circuit allows our microcontroller to control 3 LEDs through PWM outputs.

When CTRL is held HIGH (100% duty), the LED current should be 9.1 mA ±10%.	● Power the board from a 5 V bench supply. ● Set CTRL to 100% Duty. The LED current should be about 9.1 mA. Verify by measuring the feedback voltage V_FB across R4 and calculating I_LED = V_FB / 22 ohms. ● The test passes if the calculated current is between 8.2 mA and 10.0 mA (±10%) and the converter is stable. ● The SW pin should show normal switching with no obvious low-frequency or large-amplitude oscillations.
When CTRL is a 1 kHz PWM (0–3.3 V), the average LED current should scale with the duty cycle D. At D = 10%, 50%, 90%, the measured average current must be within ±10% of 0.1*I_SET, 0.5*I_SET, 0.9*I_SET respectively.	● Drive CTRL from a function generator and set each duty. ● On the scope, smooth the FB node (use a bandwidth limit) to get V_FB,avg. Compute I_LED,avg = V_FB,avg / 22 Ω. ● Pass if the results are within ±10% of the expected values at each duty. ● Targets: 10% duty → 0.91 mA (accept 0.819–1.001 mA) 50% duty → 4.55 mA (accept 4.095–5.005 mA) 90% duty → 8.19 mA (accept 7.371–9.009 mA)
With CTRL = 100% and the normal load attached: The LED current ripple must be ≤ 20% peak-to-peak of the targeted LED current I_SET. The input-pin ripple (VIN at the IC) must be ≤ 100 mV peak-to-peak.	● Drive CTRL from a function generator at 100% duty with the nominal load connected. ● Scope setup: Set both probes to 10× and enable 20 MHz BW limit. Create Math = CH1 − CH2 (DC coupling). ● LED ripple: Connect the CH1 tip to FB(top of R4), connect the CH2 tip to the nearest GND via/pad by R4. Read Vpp on Math = Vpp_FB. Compute Ipp = Vpp_FB / 22 Ω. Pass if Ipp ≤ 1.82 mA p-p (equivalently, Vpp_FB ≤ ~40 mV p-p). ● VIN ripple: Connect the CH1 tip to the IC VIN pin (or its VIN decoupler pad), connect the CH2 tip to the nearest IC GND via/pad. Read Vpp on Math = Vpp_VIN. Pass if Vpp_VIN ≤ 100 mV p-p.

Open-LED protection: If the LED output is opened while running, V_OUT must remain below the IC OVP limit and switching must cease within 10 ms. No damage after reconnecting.	- Drive CTRL from 50%-100% with nominal input and load. Connect a switch in series with the string of LEDs. - With LEDs on, open the series LED switch to simulate an LED open - Record VOUT_peak and the time from open to SW activity ceasing. - Check: - VOUT_peak ≤ OVP limit (TPS61165 datasheet) - SW switching halts within ≤ 10 ms of the open. - After reconnecting the LED, driver resumes normal operation (I_LED returns to spec, no abnormalities)

2.3 Physical Design



2.4 Tolerance Analysis

Requirement: For both servos (pan and tilt), the settled angle at each endpoint shall vary by no more than 2.0 degrees across repeated commands.

Assumptions from datasheet behavior (HS-318):

Command range 900 us to 2100 us maps to about 120 degrees (±60).
So span is 1200 us; sensitivity is about 10 us per degree.

MCU timing plan

Timer base = 1.000 MHz (1 us tick) inside a 20 ms frame (50 Hz PWM).
Quantization error = ±0.5 us (one LSB).
Jitter from ISR and DMA contention budget = ±0.5 us (measured later).
Servo internal deadband ~5 us (typical).

Angle error budget (1 sigma approximations, combined worst-case for design):

Quantization: 0.5 us -> 0.05 deg
Jitter: 0.5 us -> 0.05 deg
Deadband: 5 us -> 0.5 deg
Connector/pcb skew: 0.2 us -> 0.02 deg
Total worst-case approx = 0.05 + 0.05 + 0.5 + 0.02 = 0.62 deg

Given that these are very conservative estimations as according to the datasheet, and endpoint repeatability is < 1 degree, this meets the 2 degree requirement stated above.

3 Cost and Schedule

3.1 Cost Analysis

In our labor cost estimation, we will use the formula present on the design document overview on the ECE 445 website, and assume 6 hours worked per week. We will also assume that an average ECE grad from UIUC makes $40/hr.

Labor Costs

Joseph Paxhia	14wks*(6hr)*2.5*(40$/hr) = $8400
Lukas Ping	14wks*(6hr)*2.5*(40$/hr) = $8400
Siddarth Boinpally	14wks*(6hr)*2.5*(40$/hr) = $8400
Total	$25200

In addition, we also have added costs based on the components that we plan to use in our project. We have included the costs of everything non-standard, and have not included parts such as resistors and capacitors that will be sourced from the Electronics Services Shop.

Equipment Costs

Description	Manufacturer	Quantity	Price	Link
C4001 mmWave Sensor	DFRobot	1	$13.90	Link
ADAfruit PIR Sensor (ID 189)	ADAFruit	1	$9.95	Link
HS-318 Servo Motor	ServoCity	2	$11.99	Link
Micro Controller - STM32F103C8	STMicroelectronics	1	$3.26	Link
IRM-30-5 AC/DC Converter	MEAN WELL USA Inc.	1	$12.50	Link
NEMA 5-15P to Standard Roj Power Cord, Black, 18/3 (18AWG 3 Conductor) SVT, 10 Amp / 125 Volt, 6 Foot	CableWholesale	1	$9.21	Link
2-pos terminal block	Phoenix Contact	1	$1.59	Link

(1715721)				
TLV76733DRVR LDO 5 to 3.3V	Texas Instruments	1	$0.65	Link
TPS61165DBVR LED Driver	Texas Instruments	1	$2.15	Link
ED1543-ND Connector ST (02x05)	On Shore Technology Inc.	1	$0.26	Link
PPTC041LFBN-RC Connector ST (4 pos)	Sullins Connector Solutions	1	$0.37	Link
PPPC031LFBN-RC 3 Connector ST (3 pos)	Sullins Connector Solutions	1	$0.31	Link
VLCF5020T-100M1R1-1 10uH Inductor	TDK Corporation	1	$0.59	Link
STLink Programmer	STMicroelectronics	1	$22.29	Link
TOTAL			$101.01	

Therefore, the total cost, with labor included, is 101.01+25200 = $25301.01.

3.2 Schedule

Week of 10/13	• Design Schematics and PCB in time for 2nd PCB Design Review (For inlet board) • Complete all orders for parts (including STLink programmer for microcontroller) • Complete teamwork evaluation • Finalize revisions for assembly needed from machine shop (servo motor fixture)
Week of 10/20	• Solder all components onto first PCB design order • Begin testing and interfacing with mmWave sensor to set up configuration as desired using Arduino Uno • Setup breadboard demo to accommodate servo motors along with mmWave sensor through microcontroller interface

Week of 10/27	● Breadboard demo first half of the week ● Verify current draws of individual components aligns with expected values that were used in trace calculations ● Assemble servo motor barrack ● Program microcontroller to interface with servo motors, sensors, and LED driver ○ Start testing basic functionality of software (UART with mmWave, pwm outputs to motors and LED driver) ● Test and debug board with 120V AC power supply and modify PCB design to address any discrepancies
Week of 11/3	● Finalize PCB modifications of main board such that order will be ready by Monday ● Test LED driver functionality with external LED breadboard with properly configured load parameters ● Complete individual progress reports ● Begin PCB design of external board that will house the LEDs that will be powered. Connects to the output of the LED driver on the main PCB.
Week of 11/10	● Start full design testing and ensure that high level requirements are met ● Adjust mechanical setup in accordance with room layout and configuration ● Finalize lab notebooks and prepare for Mock Demo
Week of 11/17	● Prepare for Final Demos and Mock Final Presentation
Week of 11/24	**FALL BREAK**
Week of 12/1	● Present Final Presentation ● Write Final Paper ● Submit lab notebooks

4 Ethics and Safety

Ethical and Safety Issues

Our project must be developed in accordance with the professional responsibilities outlined in both the ACM and IEEE Codes of Ethics. The ACM Code stresses avoiding harm, respecting privacy, and being honest and trustworthy, while the IEEE Code emphasizes prioritizing public welfare, ensuring safety, and maintaining integrity. Since our system uses a PIR sensor and a mmWave radar to detect occupancy, a key ethical concern is privacy. Even though our design does not capture video or personally identifiable data, it can still reveal sensitive patterns of room use. To mitigate this, we will process all data locally, store nothing by default, and clearly disclose to users the system’s intended scope so it cannot be misinterpreted as a surveillance device. Another ethical responsibility is honesty about performance and limitations. We will not exaggerate the detection range or accuracy of our design, and we will explicitly state that it is not intended for life-safety or emergency lighting applications. To further align with the ACM and IEEE principles of competence and fairness, we will seek expert consultation for areas outside our expertise, document all assumptions, and ensure accessibility so that users with limited mobility or sensitivity to light changes are not disadvantaged.

From a safety and regulatory perspective, our project must also comply with established standards and policies. Electrical safety for our LED driver and control electronics is defined by UL 8750 (LED equipment safety) and IEC 61347-2-13 (LED controlgear requirements). Our 0–10 V dimming interface will follow ANSI C137.1-2022, which specifies voltage levels and compatibility between controllers and drivers. Because our system includes digital electronics, it falls under FCC Part 15 Subpart B (Class B) for unintentional radiators, and the mmWave radar module must operate under the grant conditions of FCC Part 15.255. We will use pre-certified modules and avoid any RF hardware modifications. In the laboratory, we will comply with the University of Illinois ECE 445 safety policies, which include completing mandatory training, never working alone with high-voltage circuits, and obtaining TA approval before connecting to mains power. To protect against accidental harm, our system will incorporate galvanic isolation through an isolated AC-DC converter, include fuses and MOVs for surge protection, and default to a failsafe “lights on” mode in the event of a fault. By explicitly addressing these ethical and safety concerns, we reduce the risks of accidental misuse, privacy harm, and electrical hazards, and we demonstrate adherence to both professional codes of conduct and regulatory expectations.

In addition, one must ensure that when testing using high AC voltage, the proper safety precautions are taken. When probing on the AC side, you can’t just use a normal oscilloscope/dmm to measure voltage/current. You have to use the correct equipment, such as using different wires on an oscilloscope that step the voltage down from 120VAC, or by using a

Clamp On DMM to measure the current to ensure that you do not damage any equipment, or hurt yourself.

5 References

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