ECE 445

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Design Document

Smart Availability Indicator for ECEB Study Rooms

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1. Introduction

1.1 Problem

The Electrical and Computer Engineering Building (ECEB) offers a limited number of study and discussion rooms across its five floors, which prove invaluable for students aiming to collaborate on assignments, prepare for exams, or engage in general study sessions. There is currently no system in place to identify vacant rooms and as a result, each day students tirelessly go back and forth, scouring each floor in hopes of finding an empty study room. Worse still, there are also many students who travel all the way to the ECEB only to discover that all rooms are occupied forcing them to then seek alternatives in different buildings.

1.2 Solution

Our proposal presents a solution aimed at enabling students to easily and conveniently check room availability via a website. We plan to implement a system that will replace the existing motion sensor and automation infrastructure. Our proposed system not only retains the current capabilities of automatically controlling room lighting based on occupancy and adjusting brightness levels but will also seamlessly transmit real-time occupancy data to a central server using Wi-Fi, allowing students to conveniently view room availability information from their smartphones or laptops on a website anytime/anywhere.

1.3 Visual Aid

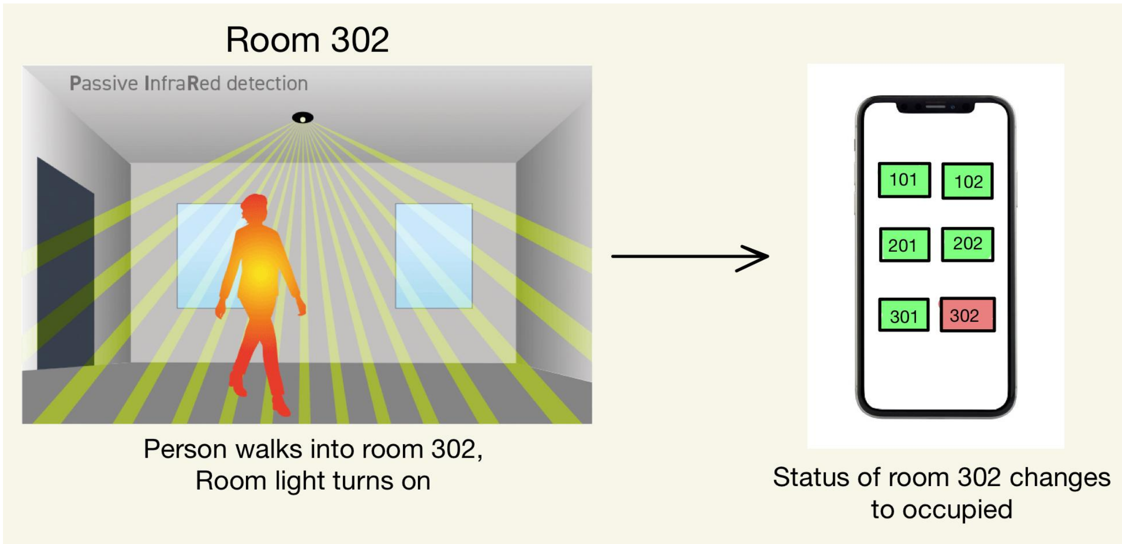

Figure 1: High-level illustration of our project [1][2]

1.4 High-Level requirements

- The lighting system should activate within 3 seconds upon detecting the presence of a user in the room. The light should turn off automatically after a five-minute period when the user leaves the room.
- Users should be able to adjust the light's brightness from dim to its maximum intensity using a dial/slider. (Demonstrable by displaying three distinct brightness levels: dim, intermediate, and bright.)
- Any changes in room availability should be reflected on the webpage within 10 seconds.

2. Design

2.1 Block Diagram

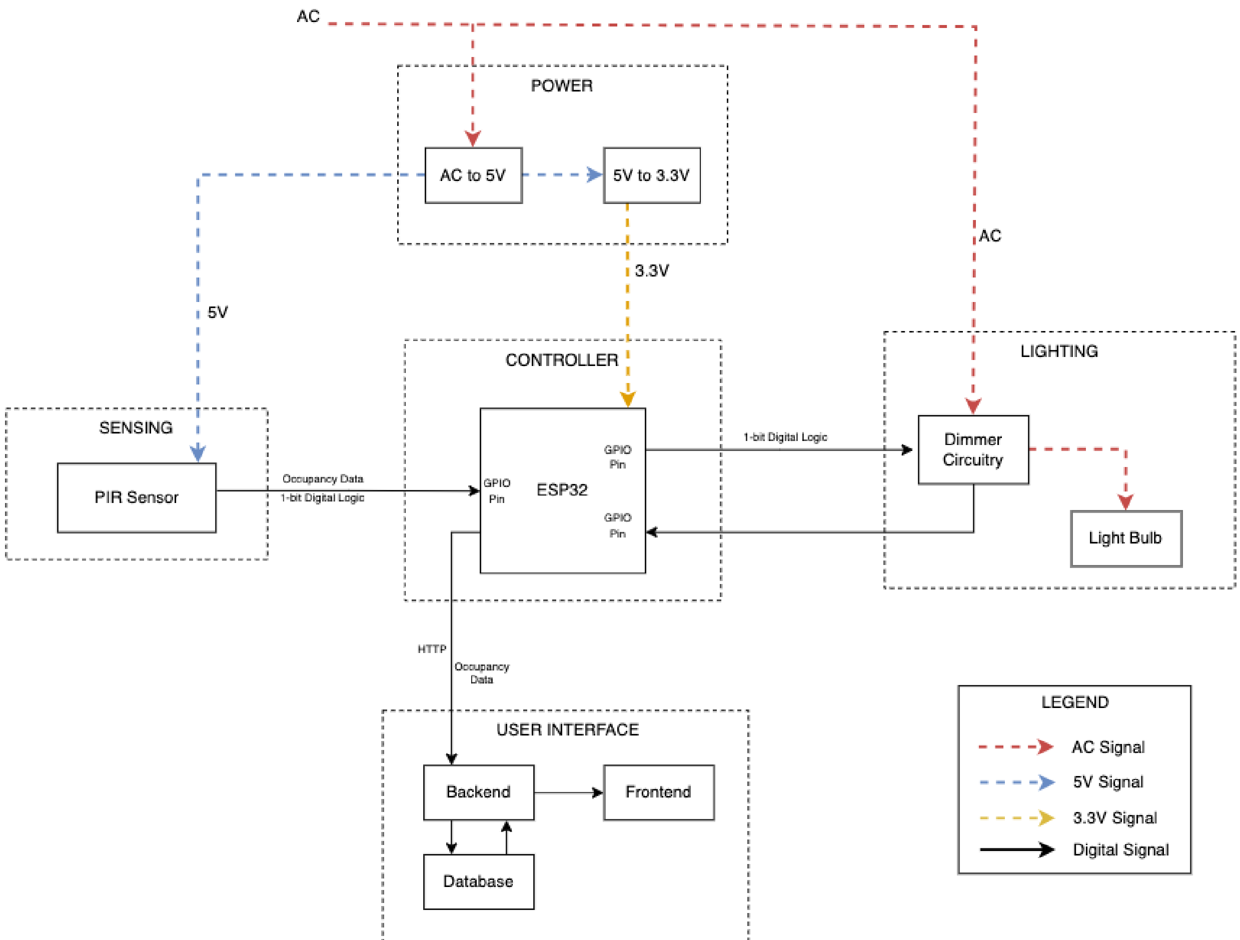

Figure 2: Block diagram depicting interactions between modules

2.2 Subsystem Overview & Requirements

- Power
    - This subsystem powers the hardware subsystems of this project (Sensing, Controller, Lighting). For the prototype, the system will be powered by an AC power outlet. The power subsystem will use an AC-DC buck to create a 5V rail. The 5 V output will then be inputted to a 5 V-3.3 V buck converter designed by us to create a 3.3 V rail. The 5 V and 3.3 V rails will be used to power various components such as the ESP 32 and PIR Sensor. Additionally, the submodule will route AC supply from the power outlet to the Lighting submodule to power the Light Bulb.

Requirements	Verification
● 5V-3.3V converter should be able to output 3.3 V (±0.3V).	● Using a power supply, provide a 5 V input to the 5 V- 3.3 V Converter. ● Connect a Voltmeter to the output of the converter and ensure voltage reading falls within the required threshold. ● Turn the power supply off and on. ● Repeat experiment 10 times and ensure that voltage reading falls within the expected threshold at least 9 out of 10 time
● The circuit should draw no more than 1 A of current	● Once the overall power circuit is completed, connect it to an outlet ● Connect an Ammeter to the output of the 5V-3.3V converter, and check that the current drawn falls within the required threshold ● Unplug and replug the circuit

	• Repeat experiment 10 times and ensure that current reading falls within the expected threshold at least 9 out of 10 time

- Sensing
  - The sensing sub-system is responsible for determining room availability. It makes use of a PIR sensor module designed by us to detect changes in heat energy emitted by humans. When a human is detected, the PIR sensor will send a 3.3 V Digital Pulse to a GPIO Pin on the ESP-32. The occupancy is determined based on the assumption that if motion is detected in the room, it is indicative of someone using it.

Requirements	Verification
• The PIR sensor module should output Logic Low (0 V) when there is no human present	• Connect VCC and GND Pins of PIR Sensor to 5 V and GND respectively. Connect the OUT Pin of PIR Sensor to a Logic Analyzer. • Ensure no human is present in front of the sensor. • In order to pass, the Logic Analyzer Trace should remain at Logic Low for the entire duration. Repeat 10 times and ensure above behavior is observed at least 9 out of 10 times.

• The PIR sensor module should output 3.3 V (±0.3V) digital pulse when a human is detected	• Connect VCC and GND Pins of PIR sensor to 5 V and GND respectively. Connect the OUT Pin of PIR Sensor to a Logic Analyzer. • Ensure no human is present in front of the sensor and the Logic Analyzer Trace remains at Logic Low. • Now, let a human walk in front of the sensor. • A logic high pulse should be seen on the logic analyzer. Additionally, a Voltmeter should be connected to the OUT Pin in parallel and should read 3.3 V (±0.3V) upon detecting a human. • Repeat 10 times and ensure above behavior is observed at least 9 out of 10 times.

- Controller
  - The ESP32 microcontroller receives occupancy data via a 1-bit digital logic output from the sensing module. This data is subsequently passed on to the backend of the user interface (website) via HTTP/TCP. If the sensing module indicates that there is movement in the room, the microcontroller sends a 1-bit digital signal to the lighting module to activate the dimmer circuitry and turn on the lightbulb. This signal is fired at a constant rate: at a specific phase measurement after the zero-crossing of the alternating current. The phase at which the signal is fired is inversely proportional to the potentiometer reading. The importance of the phase is elaborated in the lighting module overview below.

Requirements	Verification

• Upon receiving a 3.3 V pulse from the sensing submodule, the ESP32 should output a 3.3V digital signal pulse to the lighting module at a constant rate for 5 minutes (± 10 sec).	• Connect the Output GPIO pin meant to go to the Lighting Circuit to the Logic Analyzer. Also, connect the output of the PIR Sensor to the logic analyzer. While no human is present, ensure that Output of the PIR Sensor is Logic Low. • Now, let a human walk in front of the sensor. Ensure that the pin meant to be connected to the lighting submodule outputs a logic high pulse at a constant rate for 5 minutes (± 10 sec) after the falling edge of the pulse from the PIR sensor is seen. • Repeat 10 times and ensure above behavior is observed at least 9 out of 10 times.
• After not receiving a pulse from the PIR sensor for 5 minutes (± 10 sec), the ESP32 should output a constant 0 V digital signal to the lighting submodule to turn the light off.	• Connect the Output GPIO pin meant to go to the Lighting Submodule to the Logic Analyzer. Also, connect the output of the PIR Sensor to the logic analyzer. • Let a human walk in front of the sensor. • Ensure that after the falling edge of the pulse from the PIR sensor is seen, after 5 minutes (± 10 sec), the output GPIO pin outputs a Logic Low. • Repeat 10 times and ensure above behavior is observed at least 9 out of 10 times.

- Lighting

- This submodule is responsible for turning on/off the lightbulb and allowing the user to adjust its brightness using a potentiometer. The potentiometer value is read by the GPIO pin of the ESP32, which subsequently sends a 1-bit digital signal back to the lighting module. When this signal is received by the Diac in the lighting module, power is supplied to the lightbulb until the zero-crossing of the alternating current. By increasing the potentiometer value, the microcontroller could be told to send the signal at an earlier phase in the current wave, thereby supplying more power to the bulb and making it shine brighter.

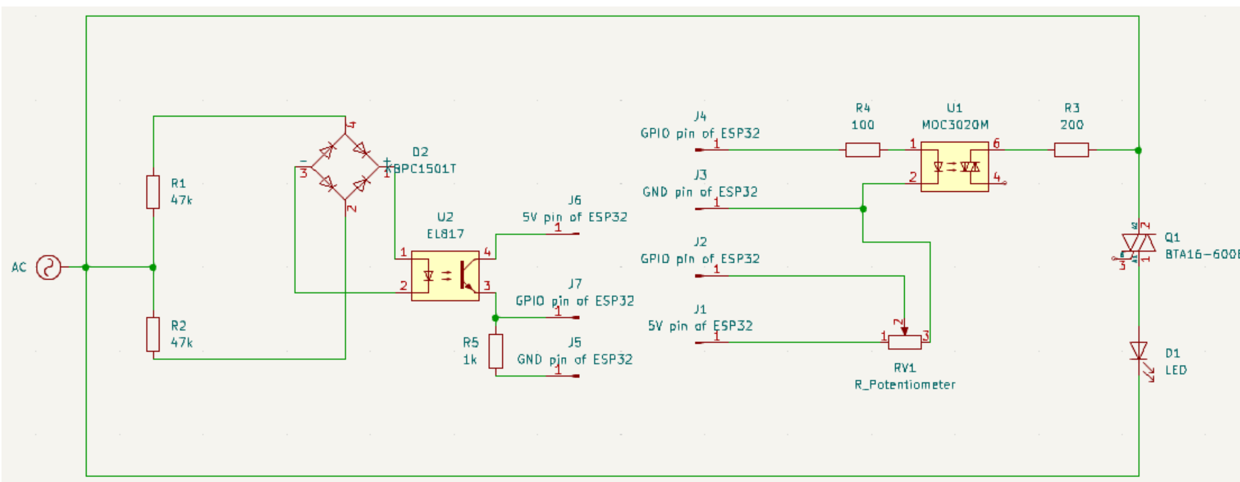

Figure 3: KiCad circuit diagram for the Lighting module [3]

Requirements	Verification
• When a 0V signal is sent to the Diac in the lighting module, the bulb should be unlit.	• The input to the Diac should be connected to GND (0V). The rest of the circuit should be connected as shown in Figure 3. • Connect an oscilloscope to the wire going to the bulb. • In order for this test to pass, the voltage in this wire should 0V (± 0.3 V)

● Tuning the Potentiometer modifies the duty cycle of the output leading to the lightbulb from low to high	● Connect 110 V AC to the input of the dimmer circuit. Connect the output going to the light bulb to an oscilloscope. ● Tune the potentiometer to the lowest extreme. Observe a low duty cycle on the oscilloscope. ● Gradually tune the potentiometer up and observe the duty cycle increase.

- User Interface
  - This subsystem consists of an online server with a database and a website that presents this data to the user. The ESP32 will post occupancy data via the HTTP Protocol to the website's backend. This data would be in the form of a tuple with the first element being the room number and the second being whether the room is occupied or not. The backend will then store this data in the online database. Lastly, the backend will pass this information onto the frontend section of the website which will format the occupancy data for the user to view.

Requirements	Verification
● There should be a data loss of <5% when information is transmitted by the ESP32 via TCP.	● Write a test case that sends 1000 room occupancy updates from the ESP at a rate of 1 update per second. ● Count the number of updates received at the backend. In order to pass, this number should be at least 950.
● The website update lag should be within 10 seconds (±2 sec).	● As soon as movement is detected by the sensor (indicated by the light turning on), using a stopwatch, the time taken for the room to be updated on the website will be measured.

	• This test would be performed 20 times and the mean time should be at most 10 seconds with a variance of 2 seconds.

2.3 Tolerance Analysis

One aspect of our design that could pose a risk to successful completion of our project is the PIR sensor. Our PIR sensors will have a field-of-view of approximately 120 degrees. This could lead to movement in the corners of the room being undetected.

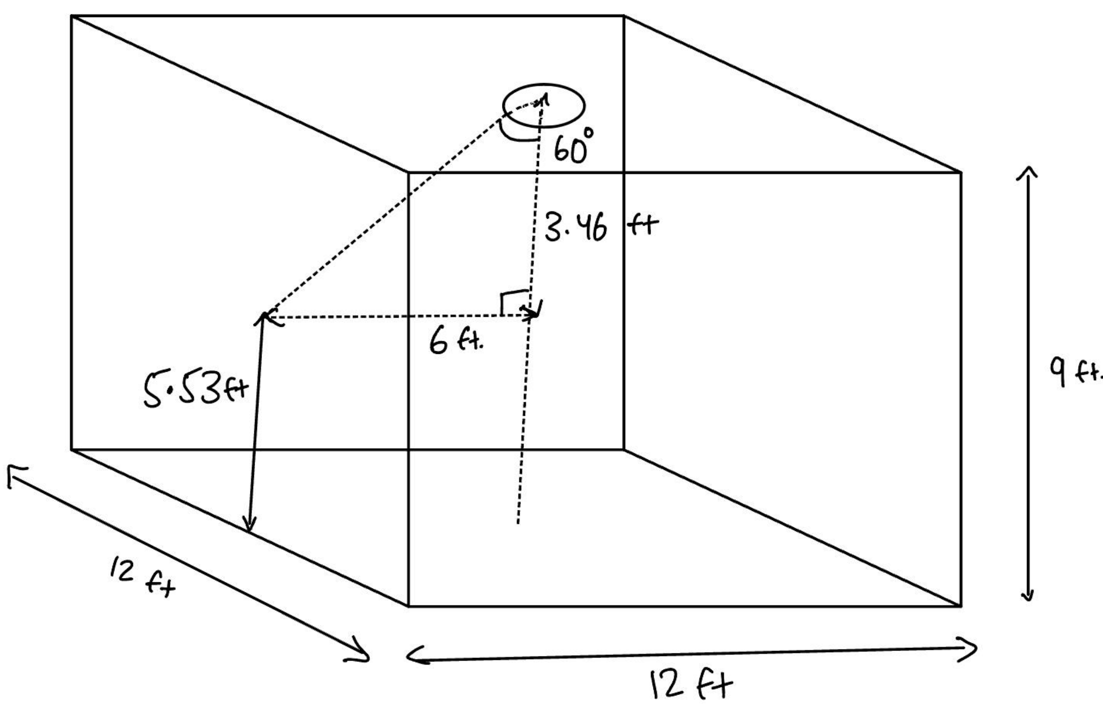

Figure 4: Cone of view of the PIR sensor in an average study room

The approximate dimensions of the ECEB study rooms are indicated in the diagram above. The field of view of the sensor can be depicted as a cone of angle 120 degrees (and height 3-7 meters). The edge of the room is a horizontal distance of 6 feet away from the sensor. We can then calculate the height at which the beam intersects with the wall (= 6ft / tan(60) = 3.46 ft). Thus we know that the sensor will detect movement even at the edge of the room below a height 9 - 3.46 = 5.53 ft. This height should be sufficient to detect movement by most individuals in all corners of the room.

Additionally, we suspect that the dimmer circuitry portion of our project poses the greatest risk, largely because neither of us have worked with this hardware before. Varying current to the bulb using a series resistor (rheostat, potentiometer) leads to far too much energy loss. Ideally there would be zero energy loss, but an acceptable loss would be if we are able to integrate a Triac Switch in our design.

3. Cost and Schedule

3.1 Cost Analysis

Description	**Manufacturer**	**Quantity**	**Total Cost**	**Link**
HC-SR501 PIR Sensor	Adafruit Industries LLC	5	$9.99	Link
BTA16-600CWRG Triac	STMicroelectronics	2	$4.34	Link
MOC3020 Triac 6DIP	Lite-On Inc.	10	$4.10	Link
PBO-3C-5 Buck Converter	CUI Inc.	4	$10.68	Link
KBP304G Full-bridge Rectifier	Diodes Incorporated	5	$4.15	Link
Resistor Kit	Allecin	1	$7.99	Link
ESP32 Dev Board	DFRobot	2	$14.76	Link
Capacitor Kit	Allecin	1	$9.99	Link

LTV-817 Photocoupler	Lite-On Inc.	10	$3.80	Link
AMS117 Regulator	Bridgold	10	$7.99	Link
7133-1 IC	UMW	10	$3.41	Link
PDB181 Potentiometer	Bourns Inc.	3	$4.56	Link

Figure 5: Itemized list of components and costs

- Labor
    - Salary per hour per person: $40
    - Total number of hours per person on project: 60
    - Team members: 2
    - Total Labor Cost: 40 * 2.5 * 60 * 2 = $12000
- Parts
    - Cost of parts: $85.76
    - 5% shipping: $4.29
    - 10% sales tax: $8.58
    - Total cost of parts: $98.63

- Final Cost
    - Labor + Parts: 12000 + 98.63 = $12098.63

3.2 Schedule

Week	Task	Person
September 25th - October 2nd	Order components for development and prototype	Everyone
	Research and finalize on dimmer and relay circuit	Siddarth

	Research on communication b/w ESP and server	Ritvik
October 2nd - October 9th	Finalize overall circuitry and complete first round of PCB Design	Everyone
	Set up Server + Basic Front end and test out communication between ESP 32 and Server using Dev Board	Ritvik
	Test Dimmer and Relay circuitry on a breadboard/perfboard using an oscilloscope	Siddarth
	Bring up sensor firmware and test using a Logic Analyzer	Ritvik/Siddarth
October 9th - October 16th	Complete 2nd iteration of PCB	Everyone
	Complete website front end and back end	Ritvik
	Complete first iteration of ESP 32 software	Siddarth
	Assemble and test 1st iteration of PCB	Everyone
October 16th - October 23rd	Complete final iteration of PCB	Everyone
	Assemble and test 2nd iteration of PCB	Everyone
	Continue development of firmware based on testing	Everyone
October 23rd - October 30th	Start 3D Printing Design for modules	Ritvik
	Assemble and test 3rd iteration of PCB	Everyone
	Finalize penultimate Firmware iteration for ESP 32	Siddarth
October 30th - November 6th	Finalize 3D Design and get it Printed	Ritvik
	Assemble various submodules together and verify all the requirements	Siddarth
November 6th - November 13th	Assemble final module including 3d printed casing	Everyone

	Finalize firmware for ESP32	Everyone
November 13th - November 20th	Address any issues brought up at the mock demo	Everyone

Figure 6: Timeline of tasks and responsibilities

4. Ethics and Safety

On the surface, our project does not seem to present an ethical problem. However, a problem could arise if this project were expanded to be more accurate using computer vision. This would violate the privacy of the individuals using the study room (taken from the IEEE Code of Ethics [4]). Hence, we will focus our efforts into making the PIR sensing system as accurate as possible. Additionally, this system should easily integrate with the existing power lines in the ECEB study and not pose a risk (electrocution, fire) to the users in the case of failure. Lastly, all team members will be undergoing High-Voltage Training so we will be adequately trained to handle the 110V coming from the main power line.

5. References

[1] Pippa, "Pir Vs microwave sensors: Which do you need?," Green Lighting, https://greenlighting.co.uk/pir-vs-microwave-sensors-need/.

[2] Bombuscreative, “The new Apple iPhone X Silver Color 256GB model with white blank...,” iStock, https://www.istockphoto.com/photo/apple-iphone-x-silver-white-blank-screen-gm892510910-247013254.

[3] ElectroNoobs, “Bluetooth controlled TRIAC DIMMER,” Arduino TRIAC dimmer AC bluetooth, http://electronoobs.com/eng_circuitos_tut20.php (accessed Sep. 28, 2023).

[4] “IEEE code of Ethics,” IEEE, https://www.ieee.org/about/corporate/governance/p7-8.html.