A Smart Environmentally Friendly Lamps and Air Quality Improvement System Using Artificial Intelligence and IoT System (Internet of Things)

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Abstract

In recent years, environmental and technological concerns have rapidly approached, emphasizing the importance of energy consumption. The paper details the design and implementation of a motion detection-based lamp system, capable of switching a lamp on and off based on predefined conditions, leading to significant energy savings. The project includes two-way communication between devices, a user-friendly control interface, and an accurate way to save energy. Users can control their system through the application and specify the requirements to their likening. This application can help ease of life along with a reduced energy consumption. Careful testing has been done along with control cases to compare the findings and shows the amount of precision that must be used for intelligent control systems. The results show that automated lights or electronics can be extremely useful along with the ability to remotely control your devices with the application. This application is suitable for consumption and offers a great opportunity for those invested to save energy with minimal effort.

Keywords

Energy Consumption, PIR sensor, Motion Detection, Adafruit ESP32-S2

1. Introduction

The rapid advancement of technology, coupled with urgent environmental crises like climate change [1], global warming [2], and greenhouse gasses [5], highlights the critical need for innovative energy-saving solutions. One adverse effect is light pollution which is a now widely accepted terminology for the consequences of artificial light on nature and humans [9]. Light pollution impacts the wildlife, health, visibility, and even our own health [8]. Households around the globe must reduce their individual and collective fossil energy consumption to help mitigate the present and future effects of climate change [7]. Lighting systems account for a significant portion of energy use in commercial, industrial, and residential settings [3]. Traditional lighting systems often suffer from inefficiencies, leading to wasted energy and higher costs [4]. As a result, studies suggest that existing lighting systems may consume anywhere from 20 to 45% of total energy usage [6]. The clear solution is easier than one might expect, turning the light off when not in use. Lighting alone has shown that it can account for 15% of the typical electricity bill and this doesn't take account for all of the other electrical devices in a household such as a tv,

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air conditioning, computers, chargers, and appliances which all factor in [10]. However, forgetfulness, inconvenience, and situations where individuals are away from the light switch make this a more complex problem than it may initially appear. Even unplugging devices doesn't necessarily work because even when not in use electrical devices are still using power. All together in an era and future encompassed with technological advancements there is a clear need for user-friendly, controlled automation that will allow great improvements in energy efficiency.
Resurcher's Byun, Hong, Lee, Park tried to decrease the usage of energy in a household with controlled lighting. They found a 21.9% decrease in energy consumption. A shortcoming is a countdown timer that doesn't automatically adjust the lighting.

Scholars Roisin and Bodart work to find which of the three control lighting systems is the most efficient. The shortcoming is that they use a simulation rather than physical testing and our project used real data by using an energy meter to measure the power of the lamp.
Researcher Wang Fei looks to see the use of solar LED streetlamps to save energy in China. The shortcoming is the time of day and the battery state that needs to be maintained. Our project improves on this one as ours are controlled by a motion sensor.

This project allows for the user to have more control in the state of the lamp through the website buttons as well as changing the timer for the motion sensor to update.

To combat excessive energy consumption from inactive electronics, traditional solutions often fall short. Manually turning off devices can be inconvenient, while sleep modes still consume some power. We propose an alternative which offers a control system that will ensure that energy will be saved, through a PIR motion detection controlled light system. Manually controlled lights often remain lit in unoccupied spaces, leading to wasted energy and increased electricity bills. This inefficiency is particularly prevalent in areas with frequent movement, such as hallways, basements, or storage areas. Additionally, traditional lighting systems lack the ability to capture and transmit valuable environmental data. Our data will take into account environmental data as well as offering needed sources. This is impactful because it allows us to be able to actively use our device and help save energy when not in use. The solution is better than the proposed one since customers can take advantage of the quick switch between on and off from the active state. To ensure that the data will be accurate, countless testing will go into the detector so that efficiency of the controls are best optimized. The application that users of this system could take advantage of is a user-friendly web application that is connected to the lighting system. Users will be able to see temperature information and detect air quality with the use of this system. Specifically, users will also be able to detect the air quality by detecting levels of Volatile Organic Compounds (VOC). This is impactful since VOCs are emitted in the form of gasses or liquids that can lead to short and long term health effects [11]. Even away from home or the office the lights will be able to adjust to the ideal setting based off of motion and can easily switch the setting without even standing up. Overall, this motion-detection solution effectively addresses the issue of wasted energy from idle electronics while promoting energy savings, ease of use, and environmental benefits.

The first experiment we were testing the delay time that it would take for the lamp to turn on and off between the intervals of the motion sensor detecting and stopping motion.

The second experiment we tested the distance and the accuracy of whether or not the lamp would switch its state with movement.

2. CHALLENGES

In order to build the project, a few challenges have been identified as follows.

2.1. The Small Amount of Power

One of the challenges is the small amount of power that I'm using with the Adafruit ESP32-S3 Reverse TFT Feather. So, this can lead to delay with turning the light on and off, compared to when we actually want the switch to switch states. This can lead to issues where the light is flickering on and off super-fast or issues where the response time is far too late. We can use a more powerful controller and power source to toggle the on and off state of the light. Ultimately, the effectiveness will be predicated on a timer being set for the data to be correctly processed.

2.2. The Communication

One of our biggest concerns is the communication between all of the devices and the potential for delays or unexpected results. This can become a major issue with the code if one device is sending the wrong signals out and could jeopardize the rest of the results. This could especially be an issue with the on/off buttons from the HTML website working with the code. Now that one device has the wrong information that could leak into the other devices and cause unexpected results. We could use pins to make sure that each device can exchange data and seamlessly work together to do actions. In addition, error detection and debugging is vital to the success of a project with multiple device communication.

2.3. The Strength and Distance

Factoring in the strength and distance of the PIR motion sensor is a huge point of contention that must be taken into account. It becomes of serious importance to do numerous tests with the sensor to know its strengths and weaknesses for valid results. The sensor is essential in this project as it controls whether or not the lamp will be saving or using energy. There will be important signals that the sensor needs to send to the Adafruit ESP-32. To conduct experiments the most important device is the PIR motion sensor. The sensitivity of the motion detector will notice any changes in motion along with the potential issues of false positive detections. Controlling the test environment becomes extremely essential in combination with a clear detection zone for the sensor. Inconclusive and inaccurate data can not be accepted since this application strives to achieve efficiency along with practicality for the utmost findings.

3. SOLUTION

This project proposes an intelligent lighting and environmental monitoring system that utilizes an Adafruit ESP32-S2 board to automate a lamp, triggered by motion detection. The system also incorporates environmental sensors to capture data on temperature, gas, humidity, and pressure. To make this program we used CircuitPython in MU Editor to write out the code to instruct the controller on what it should be doing. We also made a web application in Replit that will display the sensor information as well as two buttons that can also control the state of the lamp even from a distance while on the same network. The main structure of the program is a two-way communication that consists of multiple devices. The Adafruit ESP is connected to the relay, the HTTP server, PIR motion sensor, and the BME680 temperature sensor. The PIR Motion Sensor sends critical information that tells the lamp to turn or off to BME sensor, relay, Google Firebase, and back to the Adafruit ESP. It is important to note that the PIR motion sensor is different from a traditional motion sensor, as it detects infrared changes in heat signals that can be more accurate than and lead to less false detections. The temperature sensor sends its data information to Google Firebase to record the history in an organized way and the website to display to the user. The website can also send information to the Adafruit to turn on and off the lamp as well. The IoT relay receives information from both the Adafruit and the motion sensor to tell the lamp what state it should be in. The three main components are AC/DC Control Relay, Adafruit ESP32-S2 Reverse TFT Feather and motion sensor, and HTTP server application. The motion sensor and controller tell the program whether or not the lamp device should be turned on or off if someone is near the motion detector. Then, it tells the relay device to toggle on or off which then sends the signal to the lamp to turn the lamp on and off.

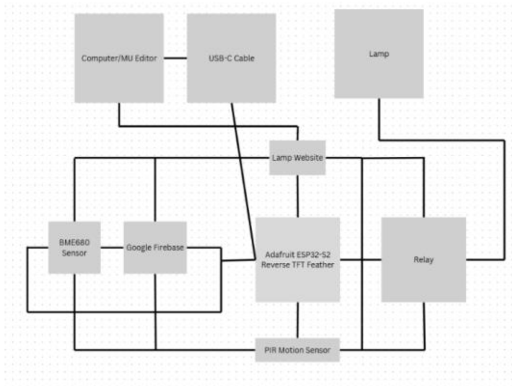

Figure 1. Overview of the solution

The first component is the lamp and more specifically how it is able to function using its connections to the Adafruit Reverse TFT, IoT relay, motion sensor, and BME temperature sensor. The main services being used are Google Firebase to store the temperature information from the sensor and CircuitPython to run the code.

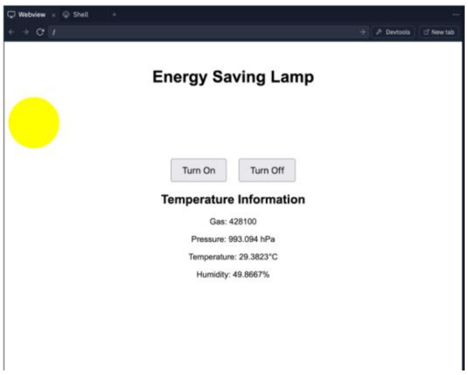

Figure 2. Screenshot of the website

```
if pir_value:
    if not motion_detected:
        print('Motion detected!')
        relay.value = False  # Turn on the relay
        if relay.value == False:
            print("The lamp is turning on")
        motion_detected = True

        motion_label.text = "Motion Detected!"  # Update display label

        print("\nTemperature: %0.1f C" % temperature)
        print("Gas: %d ohm" % gas)
        print("Humidity: %0.1f %%" % humidity)
        print("Pressure: %0.3f hPa" % pressure)

        data = {
            'temperature': temperature,
            'gas': gas,
            'humidity': humidity,
            'pressure': pressure
        }

        requests.post(firebase_path, json=data)

        # Update display
        temp_text.text = "Temperature: %0.1f C" % temperature
        gas_text.text = "Gas: %d ohm" % gas
        humidity_text.text = "Humidity: %0.1f %%" % humidity
        pressure_text.text = "Pressure: %0.3f hPa" % pressure

        # Set a timer for quick checks (adjust the sleep interval as needed)
        motion_timer = time.monotonic() + 2  # Check every 2 seconds

elif motion_detected and motion_timer is not None and time.monotonic() > motion_timer:
    # Motion has stopped, perform actions for motion end
    print('Motion ended!')
    relay.value = True  # Turn off the relay
    if relay.value == True:
        print("The light is turning off ")
    motion_detected = False
```

Figure 3. Screenshot of code 1

This is the main code for the program that allows the PIR motion sensor to be able to detect any movement. The pir_value is the variable that holds the condition (True or False) of whether or not the sensor is detecting any movement. The code first checks if pir_value is True, then ensures that the motion is only detected once and not continuously. The relay is then turned on, and temperature information will be stored in Google Firebase to keep track of the data. Also, the screen display shows the BME information such as temperature, gas, humidity, and pressure. The motion_timer adds a timer for 2 seconds to see if motion is happening. The other condition is for when there is no motion being detected and waits for a timer to switch the state of the lamp from on to off. When there is no motion detected, pir_value is False which means that the motion has ended and the relay should turn off.

The second component of the program is the application that the user can view and control the control system. From the webpage, there are two buttons to control the relay of the lamp that turns it off or on. This component relies on communication through network ip from the Adafruit and the web server, which allows the Adafruit to receive and send information also allowing for the server to do the same.

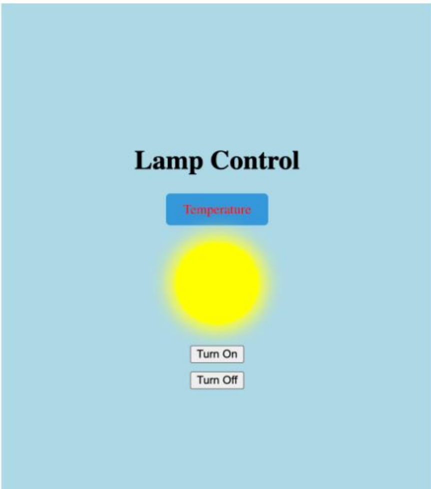

Figure 4. Screenshot of the main page

```
const app = initializeApp(firebaseConfig);
const analytics = getAnalytics(app);

// Get a reference to the database service
const database = getDatabase();

// Function to send data to Firebase
function sendData(state) {
  console.log("Button clicked. State:", state);
  set(ref(database, '/relay_state'), state);

  // Update the light based on the state
  const light = document.getElementById("light");
  if (state) {
    light.classList.add("on"); // Turn on the light
    alert("Relay turned on!");
  } else {
    light.classList.remove("on"); // Turn off the light
    alert("Relay turned off!");
  }
}

// Bind event handlers to buttons
document.getElementById("turnOnButton").addEventListener("click", function() {
  sendData(true);
});

document.getElementById("turnOffButton").addEventListener("click", function() {
  sendData(false);
});
</script>
```

Figure 5. Screenshot of code 2

Code explanation: The handle_connection function provides an HTTP server that helps control the lamp and obtain sensor information through a local connection. The client_socket argument in the function represents the connection between the server and the client. The function splits the request into lines and extracts the method, path, and protocol from the first line of the request. When the method is set to post and the path is "\lamp". The content_length, request_body, and action parse an HTTP request to extract the content length, retrieve the request body, and extract a specific parameter value from the body. There are two types of actions ("on" or "off"). If the state is "on", the code will turn the relay.value from to false if the button clicked on the website and likewise if the state is "off" then the relay.value is true. Doing this ensures that the user is able to control the lamp status from the buttons remotely as long as the Adafruit and the computer are on the same server. Changing the method to "GET" allows for the retrieval of sensor information from the BME680 sensor (gas, temperature, pressure, and humidity). The response variable sends an HTTP response in the form of a json of the sensor data and sends back to the client an OK status code. This function is constantly being called in the main() function which means that the website is constantly updating, controlling, and monitoring the status of the lamp and the environment.

The third component is the website itself, which displays information from the temperature sensor and can also transmit HTTP requests to turn the lamp on and off. This website was made using HTML in Replit for a simple application to work along with the project.

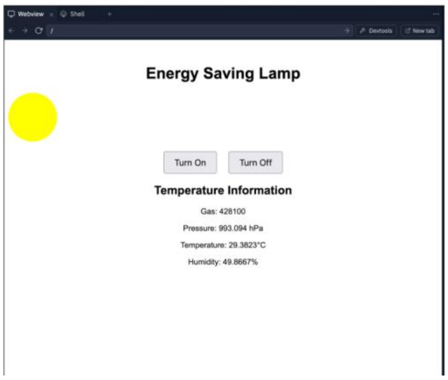

Figure 6. Screenshot of the website

```
<script>
  function fetchTemperature() {
    fetch('http://<your-device-ip>/temperature')
      .then(response => response.json())
      .then(data => {
        document.getElementById('temperature').textContent = data.temperature + ' C';
        document.getElementById('gas').textContent = data.gas + ' ohm';
        document.getElementById('pressure').textContent = data.pressure + ' hPa';
        document.getElementById('humidity').textContent = data.humidity + ' %';
      });
  }

  function toggleLamp(action) {
    fetch('http://<your-device-ip>/lamp', {
      method: 'POST',
      headers: {
        'Content-Type': 'application/x-www-form-urlencoded',
      },
      body: 'action=' + action
    });

    // Change lamp color based on action
    if (action === 'on') {
      document.getElementById('lamp').style.backgroundColor = 'yellow';
    } else {
      document.getElementById('lamp').style.backgroundColor = 'gray';
    }
  }
```

Figure 7. Screenshot of code 3

The fetchTemperature function is accountable for obtaining temperature information from my Adafruit ESP32-S2 Reverse TFT Feather that is connected in tandem through a network ip. Then it will process the response asynchronously using promises and once the response is received the sensor information being passed over will be stored into HTML with the fetched temperature data from the BME680 sensor. The toggleLamp function will toggle the status of the lamp that is connected. First the action parameter holds the specification of whether or not the lamp should be on or off. Also using the fetch API, a POST request will be made telling the Adafruit to then pass on the information to the relay to control the lamp. Next the action can be either "on or off" that will show the lamp on the website either lighting up if the turn on button is clicked or the lamp becoming gray if the turn off button is clicked. These functions are essential in order for the sensor data to be passed into the website and also manually controlling the lamp state with the buttons.

4. EXPERIMENT

4.1. Experiment 1

One potential blank spot in our program is checking the motion sensors range of detection. We will test the light if it can turn on or off if the movements are far away and also close to check the accuracy.

Measuring the lamp energy when someone is moving by the lamp, but we are controlling the light on and off using our html application by hitting the on and off button. The experiment is set up to compare the difference in energy between light constantly on for five minutes versus the user controlling the light. The control data is measuring the light constantly being left on. We will be using the formula Power = Energy * T, we will also use a watt meter to measure the power of the lamp and the time will be five minutes. Next, we will be comparing the average energy between the two experiments to see which is more efficient.

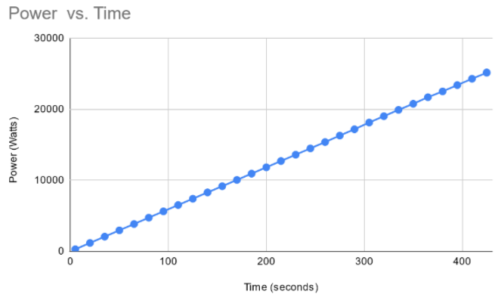

Figure 8. Figure of experiment 1

The lowest value from the data is using 0 W of energy when no motion is being detected when the light is off, and the highest value of the data was around 59.5W of energy due to the heat being exerted from the lamp. The biggest impact of these results is the sensitivity of the motion detector which can either leave the light on or turn it off. The data was able to reach the expectations due to the timer implemented with the motion sensor, although experienced some delay issues where the motion sensor should detect movement but a two or three second delay would sometimes persist. From the BME680 sensor the gas readings also gave out a value of , which means low VOC that correlates with healthy air quality in the room.

4.2. Experiment 2

Provide a possible blind spot in your program that you want to test out (for example, an AI's accuracy). Why is it important that this part of your program works well?

The other blind spot that will be tested is checking and changing how frequently the motion sensor can turn the relay for the lamp on and off. This is important because of the interaction with the website buttons which need to be able to communicate with each other to get instant results rather than being delayed.

Explain how you will set up the experiment to test it. Why is the experiment set up that way? State where you're sourcing control data from, if at all.

This control experiment will have a similar control setting to the previous experiment with a timer of 12 seconds and the motion detector being close to the source of movement. This will lead to accurate testing and a control setting that ensures that the timer and the sensor work together in harmony to send sensor information to Google Firebase to store the data. Now we will be testing out the range of the motion sensor and the effect of long range detection vs short range detection in terms of temperature. It will be very important that there is no other movement around other than the movement from a distance that is being checked, this is because the PIR motion detector is very sensitive to any changes in motion. This research is being performed like this in order to mimic a person walking into a room or out of a room where the light should be able to adjust accordingly to the situation based off of the relay.

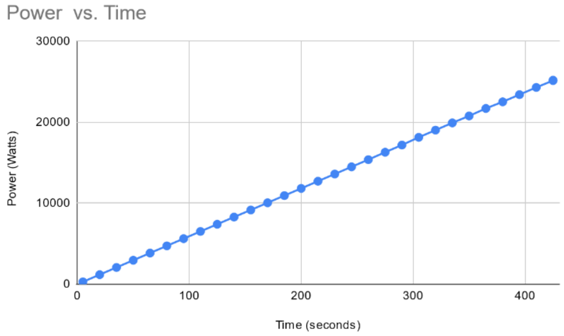

Figure 9. Figure of experiment 2

Analyze the data. What’s the mean and median? What’s the lowest value? What’s the highest value? What data surprised you or did not meet your expectations? More importantly, why do you think that it turned out that way? What has the biggest effect on your results?

The lowest value from the experiment was a power of 0W, this is the expected value as this is the condition where the lamp is turned off from the website turn off button. The highest value from the dataset. The biggest impact of the results would be the timer that has been implemented to ensure that the relay can’t be repeatedly clicked to help hold more validity and accuracy towards the results that were obtained.

The data that surprised me was that when compared to the control test case, it seemed that the temperature data was very similar in terms of Celsius. In this case the lamp turning on or off did not have much impact on affecting the overall temperature that the BME sensor was able to detect. This is due to the fact that the lamp would stay at a constant wattage and hence the same temperature so this would allow for the relatively constant temperatures that are being shown.

5. Related Work

Researchers Wagiman and Abdullah sought to implement an intelligent lighting control system used in office buildings for additional energy saving. They found an increased savings in energy of 34%, by using an artificial neural network called ANN and controllers that have the capability of dimming light fixtures within office buildings. ANN are computer programs that accumulate information from data patterns and recognition and are best used in non-linear relationships [13] . The limitations of the study showed that during the morning the energy consumption was significantly higher than any other time during the day, where brighter light is needed [12]. Our project attempts to improve on this to allow ease of use regardless of whether the user is situated in the room or not. Also, the project still allows for dimming the light in comparison to this where the lights will turn off if no motion is being detected.

Engineers Jinsung Byun, Insung Hong, Byoungjoo Lee, and Sehyun Park opted to experiment on intelligent household lighting with the use of LED lighting [14]. Using multiple sensors along with wireless communication, the LED being controlled was able to maximize the energy efficiency by adjusting the minimum light intensity that would be necessary, coinciding with a 21.9% decrease of energy in a household. One limitation that arises is that the system suggested doesn’t automatically adjust the lighting rather waits for a countdown timer, this can lead to inconveniences for the household. Our method tackles the automatic control system by turning off or on the light whenever there is some movement being detected.

The problem that researcher Wang Fei is trying to solve is that they want to make a solar LED streetlamp to save energy using microcontrollers. China is rapidly urbanizing and estimates that streetlamps will cover nearly 100% of all roads and 97% of streetlamps will be illuminated. The downside of this project is that the batteries constantly need to be checked and maintained as over time the battery will degrade with use. Another limitation is the time of day where during the night the solar LED is less effective compared during the day. The main difference is that our project uses a motion detector and a temperature sensor.

They are trying to solve the light problem. Roisin and Bodart look to find which control system is the most efficient of IDDS (individual daylight dimming system), occupancy control system and a combination of both of the systems [15]. The experiment was conducted by an automatic light control switch and measuring the total voltage by connecting the wattmeter to the ballast. The solution is effective because the testing simulation was done in three separate locations across the world. The limitation is that the user will not always turn off the light even if 500lx are not reached which would save even more energy at the expense of eyestrain and comfort. Our project improves on the researcher's method by physical testing of energy usage rather than practical testing in an imaginary room.

6. CONCLUSIONS

One of the limitations include a time delay from the code that takes time to process some of the information. Also accounting for the numerous communications between the devices it seems that a lower motion timer encounters issues with efficiency. More testing needs to go into finding the perfect timer that allows for the correct relay state for the lamp while also being able to take in information from multiple sources at the same time. With more time some implementations that we would make is using a more powerful relay device to control the status of all electronic devices. While testing multiple electronic devices some of them wouldn't be able to turn on resulting from too much power being needed from the IoT relay. Another limiting factor was the length of the cables which made the setup for the electronics inflexible and the connections are short. To properly fix inaccuracy issues it seems that an AI model would be an extremely useful feature to help the sensor determine what is and is not movement that requires any changes to the lamp. The effectiveness of the project could be improved through optimization of the testing environment, addition of testing modules, and more reliable components.

In order to make the lamp more effective, a stronger motion detector could be used to tell whether someone is in the room. Also, object detection using AI to train what movement looks like, this way the lamp isn't constantly turning on or off when idle for a brief moment. Another observation is that in a future project a lighting dimmer/timer might be better than completely turning on or off to save more energy. This is a more practical application of energy saving devices.

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