COAT HANGER LIGHT SWITCH CONTROLLER

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Abstract

This document discusses the design and implementation of an automated light switch controlled by a coat hanger. It demonstrates how simple tasks can be automated to create an ease of living and benefit the environment. We accomplished this by designing a system that automatically turns the lights off in a home when a coat or purse is removed from a hanger. This paper includes the requirements and verifications necessary to successfully detect removal of an item, process the results, and turn off the lights at the appropriate time. Finally, this paper discusses the ethical and safety concerns that were taken into account during the process of completing this project and future work.

Contents

1. Introduction

1.1 Problem Statement

The drive to reduce one's carbon footprint is steadily increasing in the US and across the world. However, it is often difficult for people with busy schedules to take time to make their life more sustainable. A simple way everyone can reduce their carbon footprint is by turning off lights in the home when they are not in use, but often times it is easy to rush out in the morning without remembering to turn anything off. On average, every kilowatt hour of energy produces 1.222 lbs of CO_2 [1]. Just one 60 watt bulb someone forgot to turn off would produce 0.659 lbs of CO_2 in 9 hours. This number, though seemingly small, can easily grow to have a serious impact on the atmosphere when accounting for the number of lightbulbs left on in each home as well as the number of homes that sit empty during a weekday across the globe.

Our design makes it easy to reduce CO_2 emissions by automating an easily forgettable task. To achieve this, we use a coat hanger to detect when a user removes an item, such as a purse or coat, from the hanger and turn the lights off one minute after the removal has been detected, giving the user plenty of time to leave their home and still be able to see their way out.

The coat hanger communicates with any light switches that are connected to it, indicating to stop the current to the outlet/light fixture. This way, the user only has to take their belongings with them, and the hanger will do the rest. Automating this task will ensure that it gets accomplished.

2 Design

The hanger and light switch fixture are designed to be completely modular such that the light switch fixture can be placed within a 30 meter radius of the home and still be controlled by the hanger wirelessly. For this to be achieved, we use a Raspberry Pi with a Z-Stick in the Hanger to control the light switch. The pressure detector and delay circuit send a signal as an input to the Raspberry Pi, which will determine the state of the light switch.

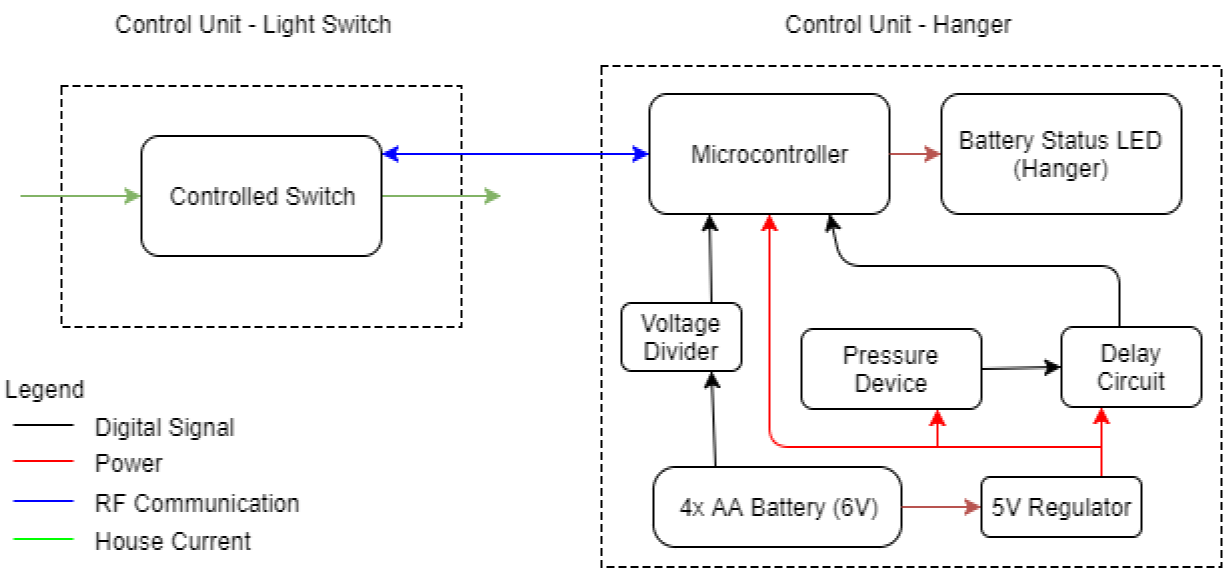

Figure 1: Block Diagram

The physical appearance of this project is identical to that of a standard hanger and standard light switch fixture, with the following modifications:

- The normally empty "inside" triangular space of the hanger is not hollow, and instead houses the necessary circuitry of the right side of the block diagram above.
- The "hook" of the hanger is abnormally wide to accommodate the force sensitive resistor.
- The light switch fixture is specified to be a paddle "toggle" switch instead of an "up/down" switch, to prevent confusion in the change in state of the lights that is not directly related to human control.

These design adjustments are intended to make the hanger easy to incorporate seamlessly into the normal routine of the user.

2.1 Hanger

2.1.1 Battery Pack

This battery pack was selected to power the Raspberry Pi, the pressure device, and the delay circuit. The battery pack consists of 4 AA batteries. This was chosen for its wide availability, as well as meeting the requirement of a 5V power source for the Raspberry Pi, our only limiting voltage requirement.

Output: 6V Power

2.1.2 5V Regulator

The 5V regulator in our circuit [20] is a step-down adjustable module buck converter. Since a partial goal of our project is environmental consciousness, the intention of choosing a more complex regulator is to limit the need to change batteries (and thus trade one environmental cost for another). While a traditional voltage regulator will require a constant draw from the batteries by bleeding the additional V through a resistor to ground, the buck converter stores the additional voltage in a capacitor and occasionally stops drawing from the battery, using discharge from the capacitor to provide the constant output instead.

Input: 6.5V – 5V DC from battery pack
Output: 5V DC

2.1.3 Battery Status LED

This LED indicates when the voltage from the battery pack is at 5.1 V, showing the user when it is necessary to change out the battery in the hanger itself (as the voltage regulator and thus circuitry will become ineffectual below 5V). This was omitted in the final iteration of the project.

Input: Voltage from battery as signal
Output: LED indication

2.1.4 Pressure Circuit

The functionality of the pressure device centers around a Force Sensitive Resistor (FSR). Increased force on the FSR results in a lower resistance. The remainder of the circuit below uses this functionality to cascade power to the delay circuit (which is otherwise unpowered). This is accomplished through use of a voltage divider circuit, voltage-pass Zener diode, and transistor.

Input: 5V
Anticipated Output: 5V (no force on FSR), 0V (force on FSR)
Final Output: 4.02V (no force on FSR), 0V (force on FSR)

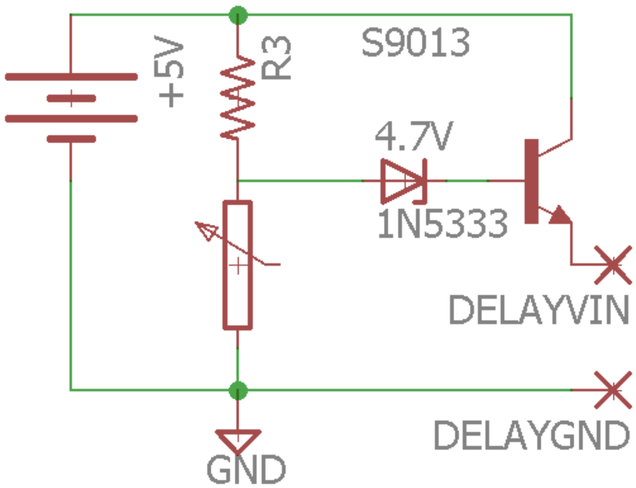

Figure 2.1: Pressure Circuit

Element	Characteristics
FSR	FSR406 (Adafruit)
Resistor	47 kΩ (Experimentally determined with FSR and Diode)
Zener Diode	4.7V (High to account for steep characterization slope of sensor)
Transistor	S9013 (NPN)

Table 2.1 : Pressure Circuit Elements

Notes:
In the final iteration of the project, the S9013 does not reach saturation voltage even when the FSR presents as an open circuit. As such, the output voltage is lower than intended. The final iteration of the delay circuit accounts for this lower value.

2.1.5 Delay Circuit

The delay circuit is located on the hanger component between the pressure detector and Raspberry Pi. It will delay the signal to turn off the light by an amount of time so as not to turn out lights before the user leaves the house. This is accomplished using a purely hardware delay. In the current iteration of the project, this delay is invariable, and lasts approximately 60 seconds. [5][6][7][8]

Anticipated Input:	*5V power (battery pack), 5V analog signal (pressure circuit)*
Final Input:	*5V power, 4V analog signal (pressure circuit)*
Output:	*Logical True/False (1.3 V; 60 second delay from signal)*

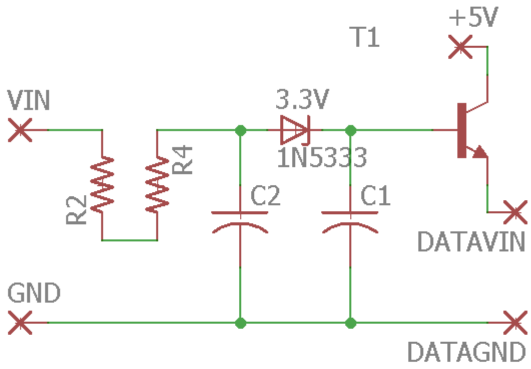

Figure 2.2: Delay Circuit

Element	Characteristics
Resistors 1,2	Total of 56 kΩ (in series to allow flexibility when selecting value)
C2	1000µF
C1	100µF (Provides forward bias on transistor for steady function, not used in calculations)
Zener Diode	3.3V (approximate time constant voltage for 5V)
Transistor	2N3904 (NPN) (Lower forward base saturation current than s9013)

Table 2.2: Delay Circuit Elements

<table>
<tr><td colspan="2">Calculations</td></tr>
<tr><td>Given:
$$Q = CV_{in}\left[1 - e^{-\frac{t}{RC}}\right]$$
$$V_{in} = IR + \frac{Q}{C}$$
$$V_{in} = 5V$$</td><td>Derived:
$$V_{C_2} = .632\,V_{in} \text{ @ } t = RC$$
$$V_{C_2} = 3.16V \text{ @ } t = RC$$</td></tr>
<tr><td colspan="2">Selected ZD to be 3.3V (Closest to 3.16)</td></tr>
<tr><td>Given:
$$t = RC$$
$$t = 60s$$</td><td>Derived:
$$R_{2,4}C_2 = 60$$</td></tr>
<tr><td colspan="2">Selected C to be 1000µF (Largest available)
Selected R to be 56kΩ (closest to 60kΩ)</td></tr>
</table>

Table 2.3: Delay Circuit Calculations

Notes:

V_{in} ended up being closer to 4V in the final implementation, which should have made the capacitor charge too slowly to accomplish the 60s goal originally intended. However, the Zener diode we selected (3.3V) began to “leak” current to the transistor, which counteracted the deficient V_{in}. As a final adjustment/fix to the delay circuit, which was still turning on a little too slowly, we replaced the original transistor (S9013) with a physically-identical transistor (2N3904) with a lower base saturation current. This turned the transistor on more quickly, and brought the time back to 60-70s consistently.

2.2 Light Switch

2.2.1 Microcontroller

The microcontroller we use to control our Z-Wave components is a Raspberry Pi. We couple this with a Z-stick to create a hub to control the GE Z-Wave 960-Watt CFL-LED Indoor In-Wall On/Off Rocker Switch that we used for our light switch. This apparatus of the Z-Stick and the Raspberry PI can be placed anywhere in the home up to 100ft away from the Z-Wave device. The Raspberry Pi runs Home Assistant, an open source Python project designed to control Z-Wave technology.

The Raspberry Pi takes an input from the delay circuit and uses this to determine when to toggle the light switch to off. When the light switch is on and the signal coming from the delay circuit goes from off to on, the light switch will turn off.

```
configuration.yaml:
zwave:
  usb_path: /dev/ttyAMA0
-platform: rpi_gpio
 ports:
   19: Coat Hanger
   20: Battery
 pull_mode: DOWN
switch:
  - platform: rpi_gpio
  ports:
    17: LED
```

```
automations.yaml:
automation:
  -alias: "Light Control"
   trigger:
     -platform: state
      entity_id: binary_sensor.coat_hanger
      from: 'on'
      to: 'off'
   condition:
    -condition: state
      entity_id: ge_switch.14291
      state: 'on'
   action:
     service: switch.turn_off
     entity_id: ge_switch.14291
```

Figure 2.3: Code for Raspberry Pi

Input: 5V power, Signal from Delay Circuit
Output: Light Control

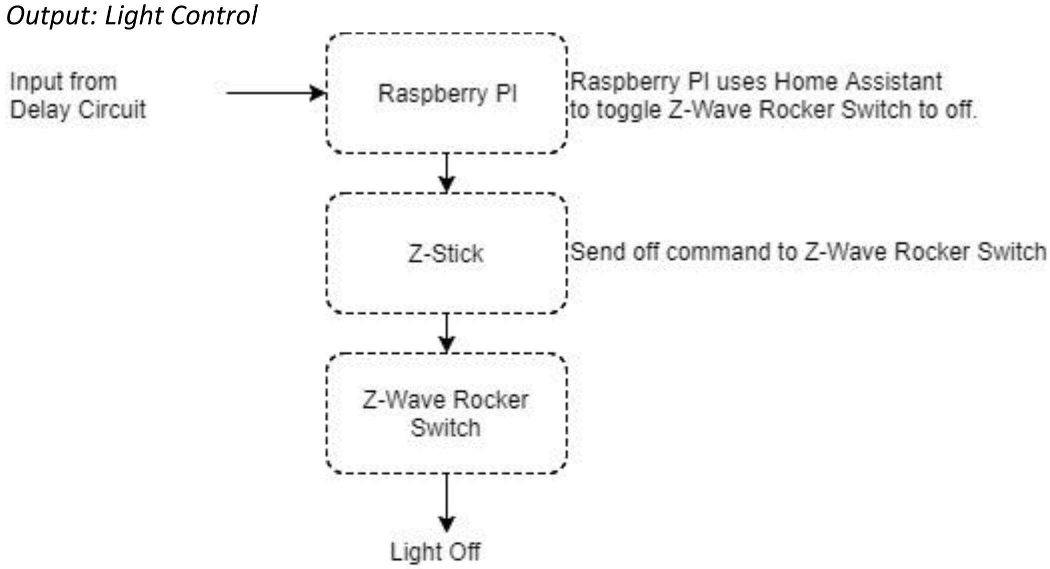

Figure 2.4: FSM for Z-Wave Technology

3. Design Verification

3.1 Hanger

3.1.1 Battery Pack

We verified our batteries and battery pack voltage with constant voltage monitoring over time. The battery pack took approximately 10 hours of time fully connected to the circuit to discharge to unusable voltage, drastically failing the requirement.

3.1.2 Battery Status LED

The battery status LED was not included in the final iteration of the project due to time constraints.

3.1.3 Delay Circuit

We verified the Delay Circuit by plugging the output into a multimeter and powering it with the battery pack. When the signal was sent, we began a timer and stopped the timer when the output had reached 1.3 V, the turn-on voltage for the Raspberry Pi GPIOs.

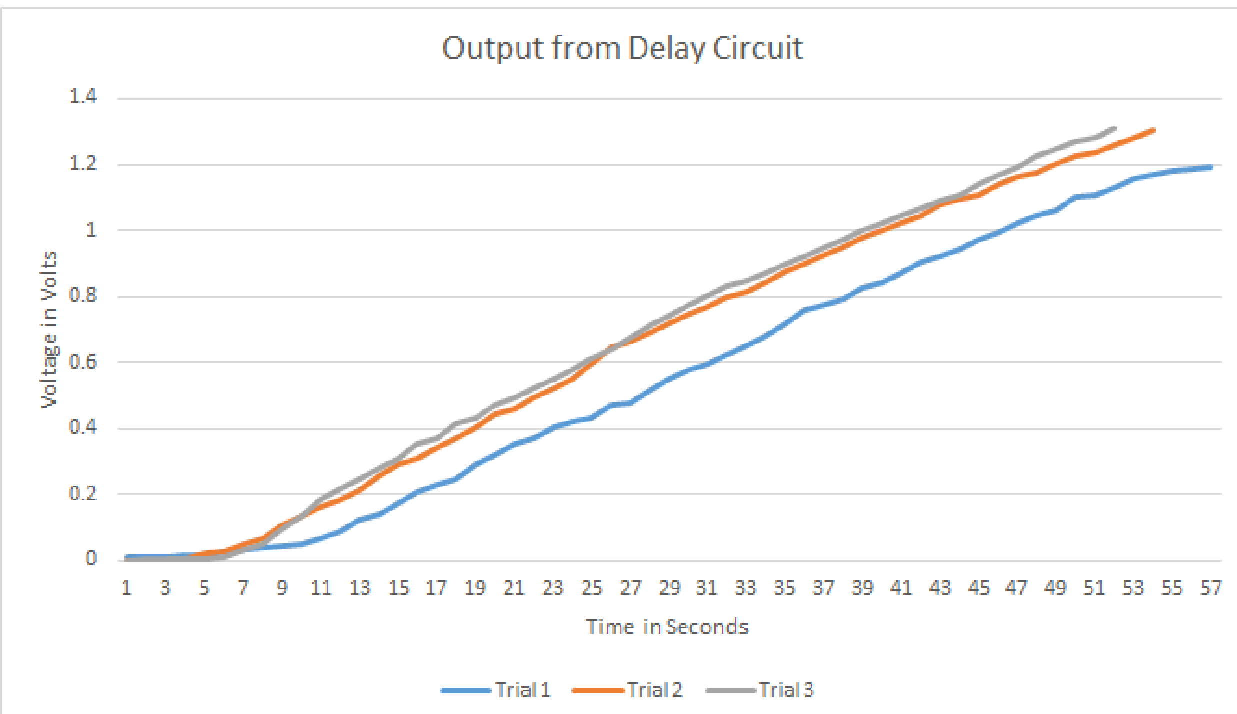

Figure 3.1: Delay Circuit Output

3.1.4 Pressure Detector

We verified the performance of our pressure detector by hanging up the coat hanger with the pressure resistor affixed inside with multiple weights and measuring the resistance using a multimeter. This verified that the turn on point was between 0.3-0.6kg, the weight of a standard coat or purse.

Kg	Ohms									
0	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞

0.389	78k	∞	57k	56k	35k	2.2M	203k	63k	∞	105k
0.715	29k	67k	92k	12.5k	20.5k	82k	80k	62k	96k	64k
0.878	25k	27k	30k	30k	38k	20k	24k	36k	69k	37k
2.619	5.6k	2.3k	5k	9.5k	8.8k	3.4k	9.7k	15.3k	6.1k	5.9k

Table 3.1: Pressure Detector Characterization

By omitting some outliers (specifically, 2.2MΩ in the .389kg row and the 69kΩ in the .878kg row), we can achieve the below graph:

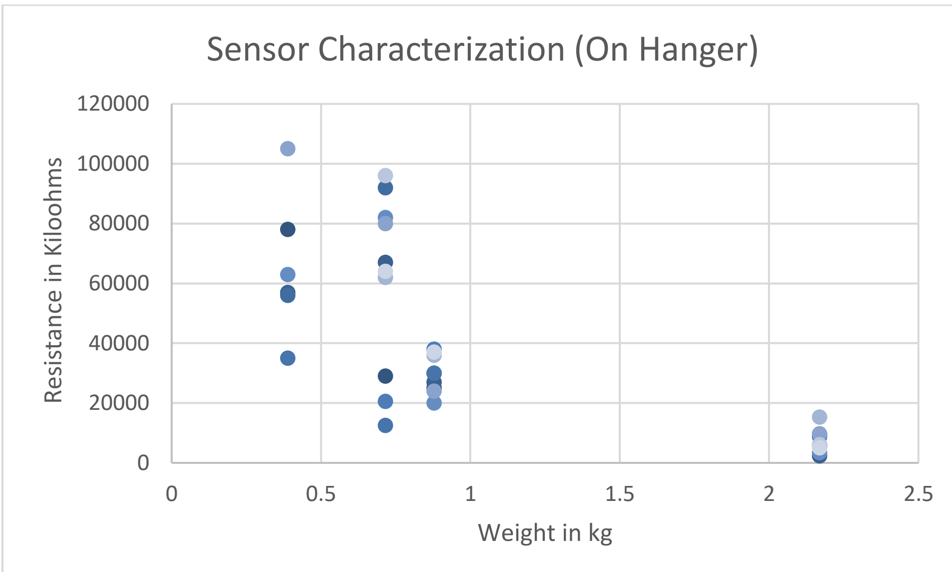

Figure 3.2: Pressure Detector Characterization

This graph shows that some specificity can be recognized between .715kg and .878kg, which we utilized in selecting our final resistor (47kΩ). The majority of readings from below .715kg are above 50 kΩ; the majority of .836kg and above read below 50kΩ. In future iterations of this project, we would choose a more precise pressure monitoring device, as this one provided barely enough specificity.

3.2 Light Switch

3.2.1 Z-Wave Light Control

We verified our Z-Wave Light control using a function generator plugged into the Raspberry Pi GPIO which controlled the light switch. We swept from 0V to 1.4V while the light was turned on, and visually verified that it turned off once the function generator reached an output of 1.3V. We also verified the light could be toggled both below and above this 1.3V threshold. We made sure that sweeping from above to below 1.3V did not change the state of the light, as well as sweeping from below to above with the light turned off.

4. Costs

4.1 Parts

Part	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
Transistors, Diodes, Resistors, LEDs, Capacitors, Wires	Mouser Electronics, Assorted	30.97	n/a	0.40
6V Battery Pack (Amazon)	Wingoneer	5.99	n/a	5.99
4x AA Batteries (Walmart)	Energizer	3.79	1.77	1.77
PCB (PCBWay)	PCBWay	5.00	n/a	0.38
5V Regulator (ReadyToFlyQuads) [20]	ReadyToFlyQuads	0.99	n/a	0.99
Pressure Sensor (Adafruit)	Interlink Electronics	7.95	6.36	7.95
Raspberry Pi 0 W (Adafruit)	Raspberry Pi Foundation	10.00	n/a	10.00
ZStick (Amazon)	Aeotec	44.95	n/a	44.95
ZWave Compatible Switch (Amazon)	General Electronics	30.60	n/a	30.60
Hanger (Walmart)	Walmart	5.03	n/a	5.03
Total		**145.27**		**108.06**

Table 4.1: Parts/Cost Analysis

4.2 Labor

Labor was ensured to be equal between both participants in the project, and as such are calculated to be equivalent.

$$12.5 \frac{hr}{wk} * 14\ wk * 30 \frac{\$}{hr} * 2\ team\ members = \$21{,}000$$

This brings the total cost of the project to be $21108.06.

5. Conclusion

5.1 Ethical considerations

There are several potential safety hazards in our product. One major safety concern is that the light switch directly interacts with the house current, which contains up to 120 V. This could easily electrocute a user if not correctly implemented. To prevent this, we house our light switch control unit inside the conventional light switch casing for protection against electrocution.

We are responsible for not causing harm to users of our product. If a user plugged in a life support device into an outlet that was controlled by a light switch that communicated with our coat hanger, it could have devastating consequences. This would go against the IEEE code of ethics #9, as we could be injuring someone [2]. To avoid this situation, we would put a warning on the product if it were to go to market warning that a user affixing our device to a light switch that controls an outlet should consider what they use the outlet for and to avoid installing it where it could turn off a critical device. Another safety concern related to this same IEEE code is taking the hanger outside. This is not advised, as if a user is doing something light-critical and another person triggers the pressure detector, they could injure themselves. To combat this, there will be a warning on the hanger itself stating not to take it outside the home without disabling its functionality.

5.2 Future work

There are facets of our project that could be improved with future work and design adjustments.

5.2.1 Power Management

One of the main goals of this project was to reduce the carbon footprint of the user by reducing the energy consumed. However, because the batteries would need to be replaced so frequently, the environmental benefit is debatable.

The main power draw in this circuit is from the Raspberry Pi 0w, which has far more computational power than required to accomplish the sensing/actuating goals of the project. Thus, this project could be improved by isolating the Raspberry Pi 0w in a remote “Hub” powered by plugging it into a normal house socket. This would need to cost less energy-wise per day than a lightbulb powered for 8 hours in order to be energetically favorable. Furthermore, an additional low-energy RF transmission element would have to be added to the hanger to communicate with the Hub. However, this would reduce the need to change batteries as several RF elements have a much lower energy requirement and draw than the Raspberry Pi. This solution is also cost effective when acquiring more hangers in a single home, since each additional hanger would only have to be added to the mesh network (connected to the single Hub) instead of being its own hub (reducing cost by approximately 45$ per additional hangar).

5.2.2 Delay Circuit Repeatability

Though the delay circuit was effective in providing the proper delay, testing the circuit proved to be difficult as the capacitors often did not have time to discharge between tests. This is a flaw in the product, which should be able to consistently produce a 1-minute delay after replacing the hanger, regardless of the amount of time since the last signal.

To this end, the project could be improved by adding a mechanical contact that would discharge both capacitors upon removing the hook of the hanger from a rod, then retracted when the hook was replaced to allow normal use. This would ensure that charging could begin exactly when the hanger was replaced (empty), and that the delay would be more consistent and repeatable despite irregular use.

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Appendix A: Requirement and Verification Table

Requirement	Verification	Verification status (Y or N)
Hanger Battery		
1. Must last 10-20 days	Leave battery in for 10 days without loss of functionality.	N
2. Cost effective (<5 dollars/battery).	Purchase battery for under $5.	Y
3. Must have 5-7 V potential to power the communication element.	Output voltage will be measured with a standard Hewlett-Packard DMM as available in the lab.	Y
4. Must be replaceable by a standard consumer (easily removed/inserted)	Have multiple people with no knowledge of project try to replace battery.	Y
Battery Status LED		
1. Must turn on when the associated battery is running below 5.1 volts.	Put dead battery in place of full battery and visually confirm LED output.	N
2. Must be visible from 3 meters away.	Visually confirm LED visibility by standing 3 meters away while being able to see the LED illuminated	N
Delay Circuit		
1. Should delay signal by 50 – 70 seconds	A cell phone timer will be used to measure the time duration between replacing an empty hook on the bar it hangs from and the test fixture turning off (the test fixture being a simple circuit representing a standard household 120V/60Hz AC power source, light switch, and standard light bulb)	Y
2. Should output a voltage of 1.3 – 3.3 V	Output voltage will be measured with a standard Hewlett-Packard DMM as available in the lab.	Y
3. Should never output more than 3.3 V to protect communication circuit	The performance of the circuit will be tested by repeatedly signaling the circuit with intermittent high and low voltage. The output will be monitored to never exceed 3.3V so as to protect downstream circuitry.	N
Pressure Detector		
1. Pressure detector will activate when an item is placed on the hanger, and will not send a	Should provide a logical TRUE signal when experiencing less than .3-.7kg of	Y

signal if there is nothing placed on the hanger.	weight [1] [2] and a logical FALSE when experiencing more than the threshold.	
2. Pressure detecting device doesn't lose efficacy over time.	Should perform correctly at threshold weight when removing and replacing the hanger at least 30 times without recalibration.	Y
Z-Wave Light Control		
1. Upon receiving input from the communication device, the Raspberry PI will send a signal via the Z-Stick to the Z-Wave Rocker Switch, turning the lights off.	Open-source Home Assistant program compiles and runs successfully.	Y
	Visually verify that the signal to the Z-Wave Rocker switch is successfully executed by observing light turning off.	Y
	Visually verify that the light functions normally (rocker turns light on and off) independent of assumed control	Y