Multi Sensor Motion Detector for Reliable Lighting Control

Electrical & Computer Engineering

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Team 21

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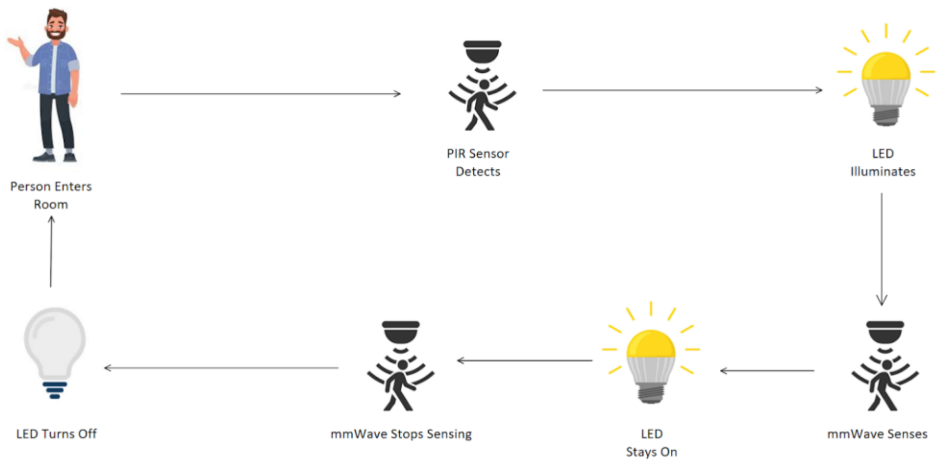
Introduction & Problem

Problem: Solve the Unreliable Design of Modern Motion Detectors

- Most motion detector lights utilize a PIR Sensor
- Detect larger movements (for example, walking)
- Tend to turn off when people are in a room, but idle



Main Goal: Create Dual Sensor Lighting System

- Utilizes an mmWave and PIR Sensor
- PIR Sensor turns on the light
- mmWave keeps the LEDs on
- Once everyone has left the room (mmWave stops detecting), the LEDs turn off
- Should keep LEDs on longer

Design

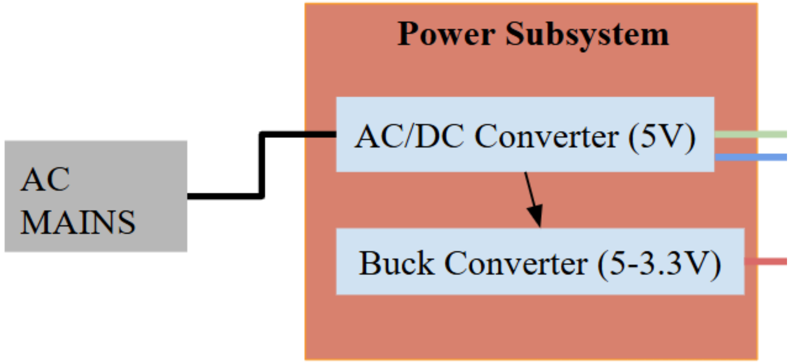
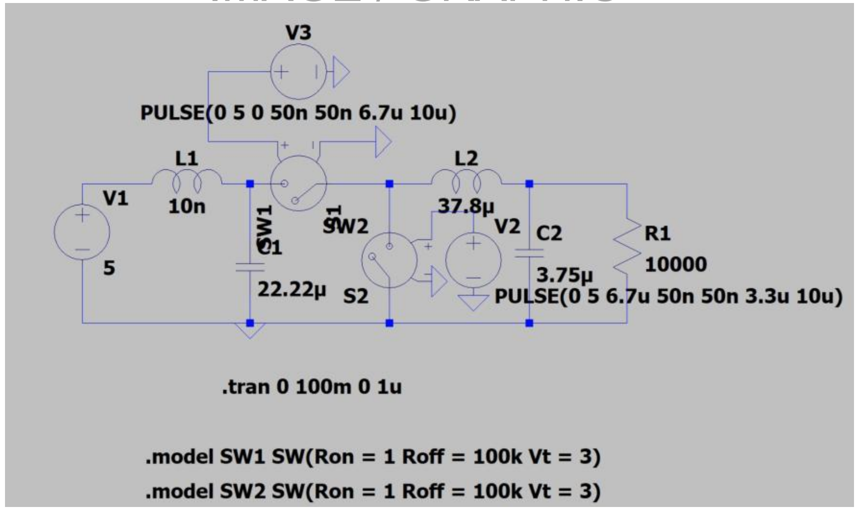


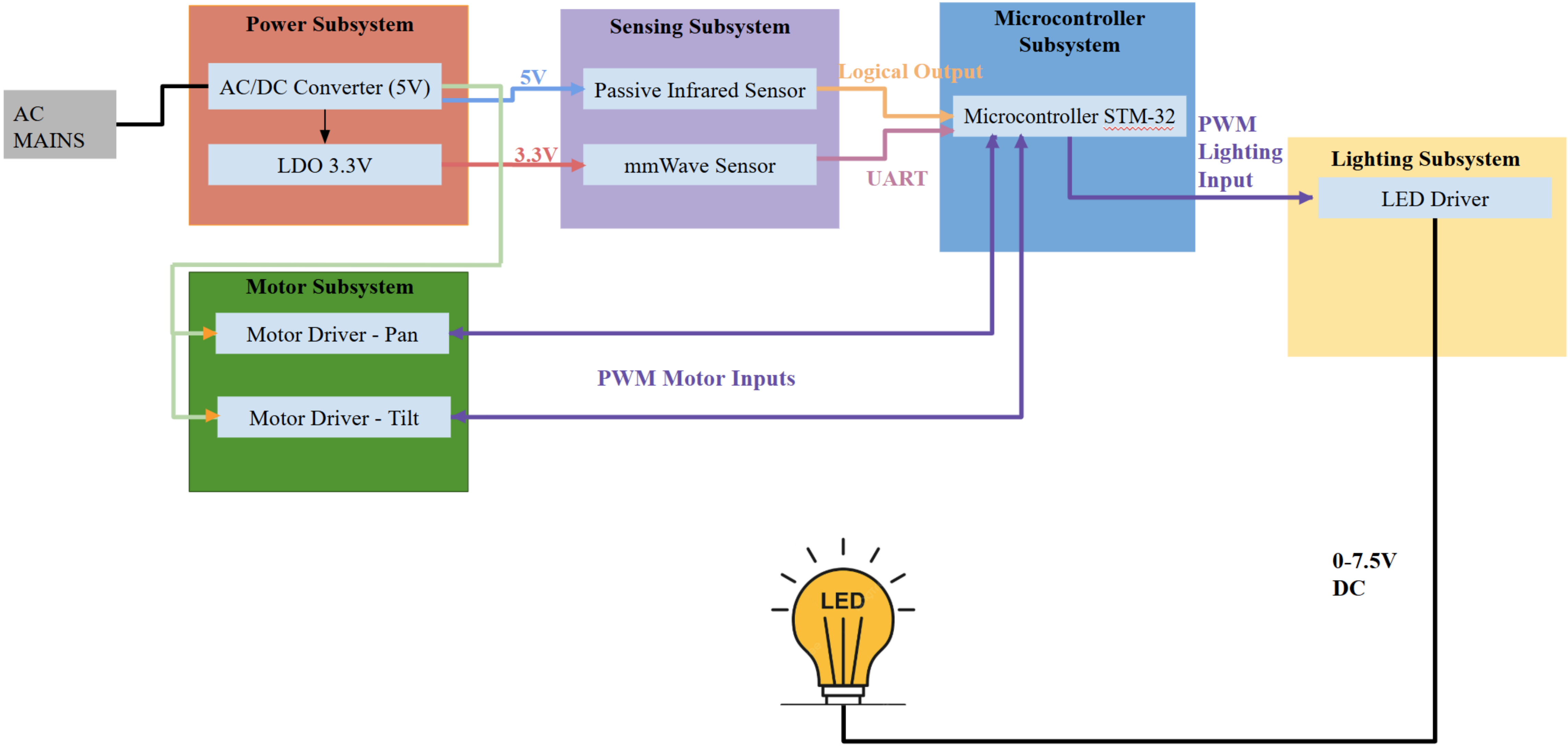
IMAGE / GRAPHIC



Main Difference: Buck Converter

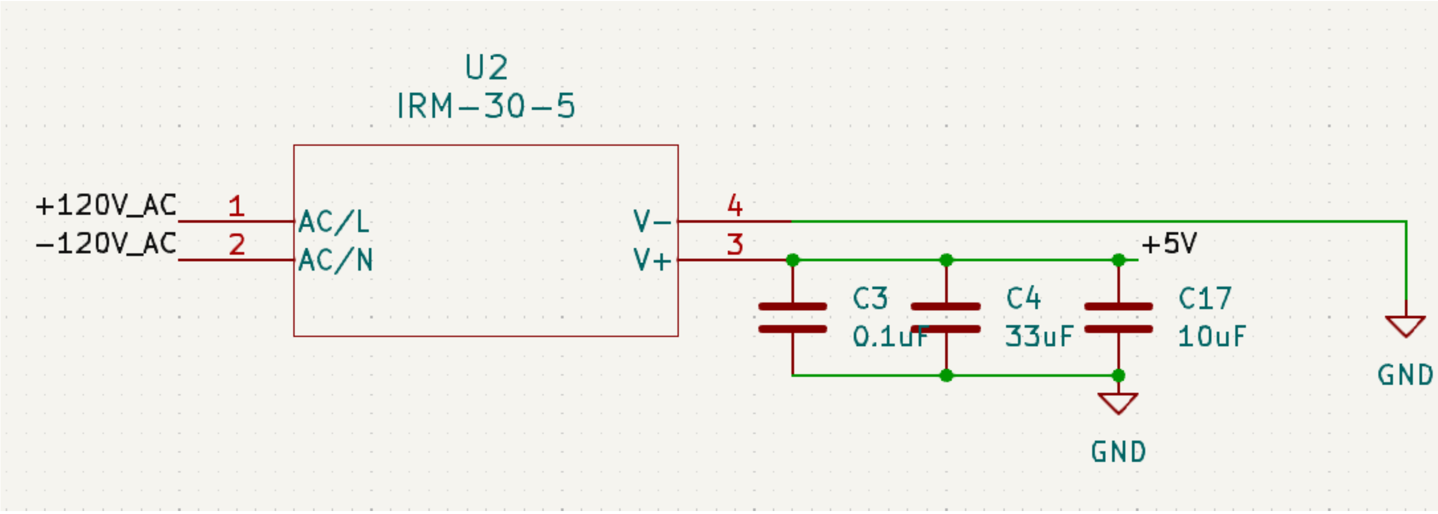
- Make our own Buck Converter - Impractical and inefficient
- Need MCU to send PWM to control switches
- MCU is powered by output from Buck

Block Diagram



Subsystem Overviews

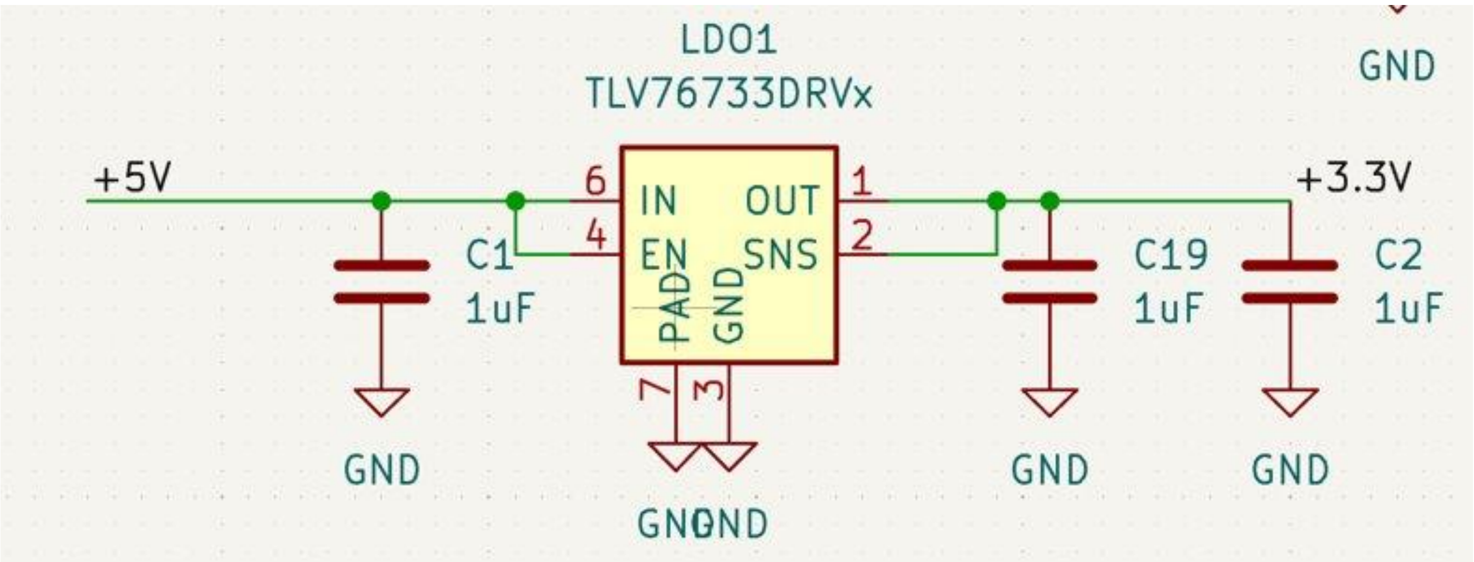
AC/DC Converter



IRM-30-5 AC to 5V DC Converter

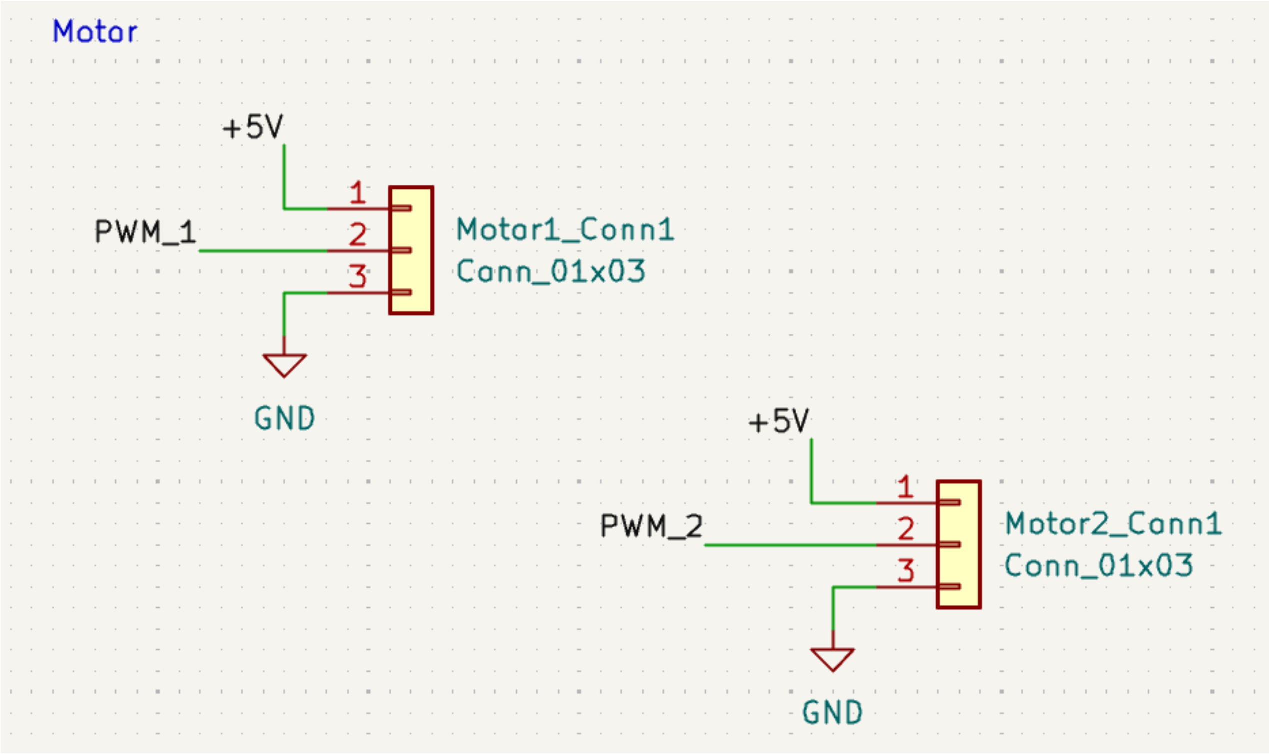
- 4kV AC isolation
- 5V @ 6A regulated output with built in protection
- Universal 85-264VAC input

Low Dropout Linear Regulator



TLV76733DRVR 3.3V Linear Voltage Regulator

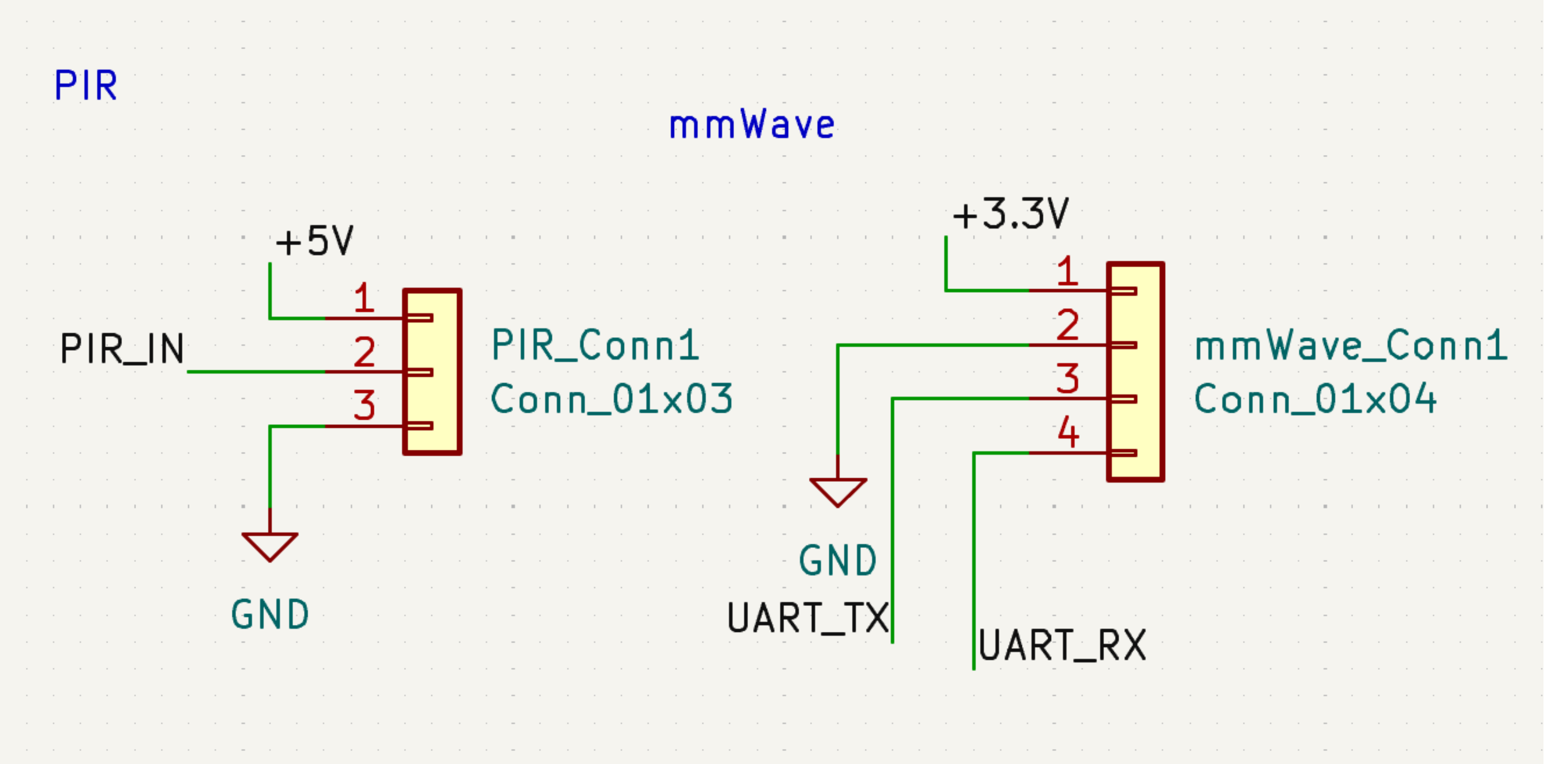
- Regulated 3.3V Output with 1 A Capabilities
- Thermal and Overcurrent Protection



2 HS-318 Servo Motors

- 0.5° of movement capabilities
- Smallest Meaningful PWM Change of 5 µs

Sensing Subsystem



HC-SR501 PIR Motion Sensor Module

- Simple HIGH/LOW motion detector trigger
- Low power (0.325 mW Operating Power), low noise (Band-pass filtered, AC-Coupled, built in low-pass filtering)
- 7 Meters detection, 120 degree cone

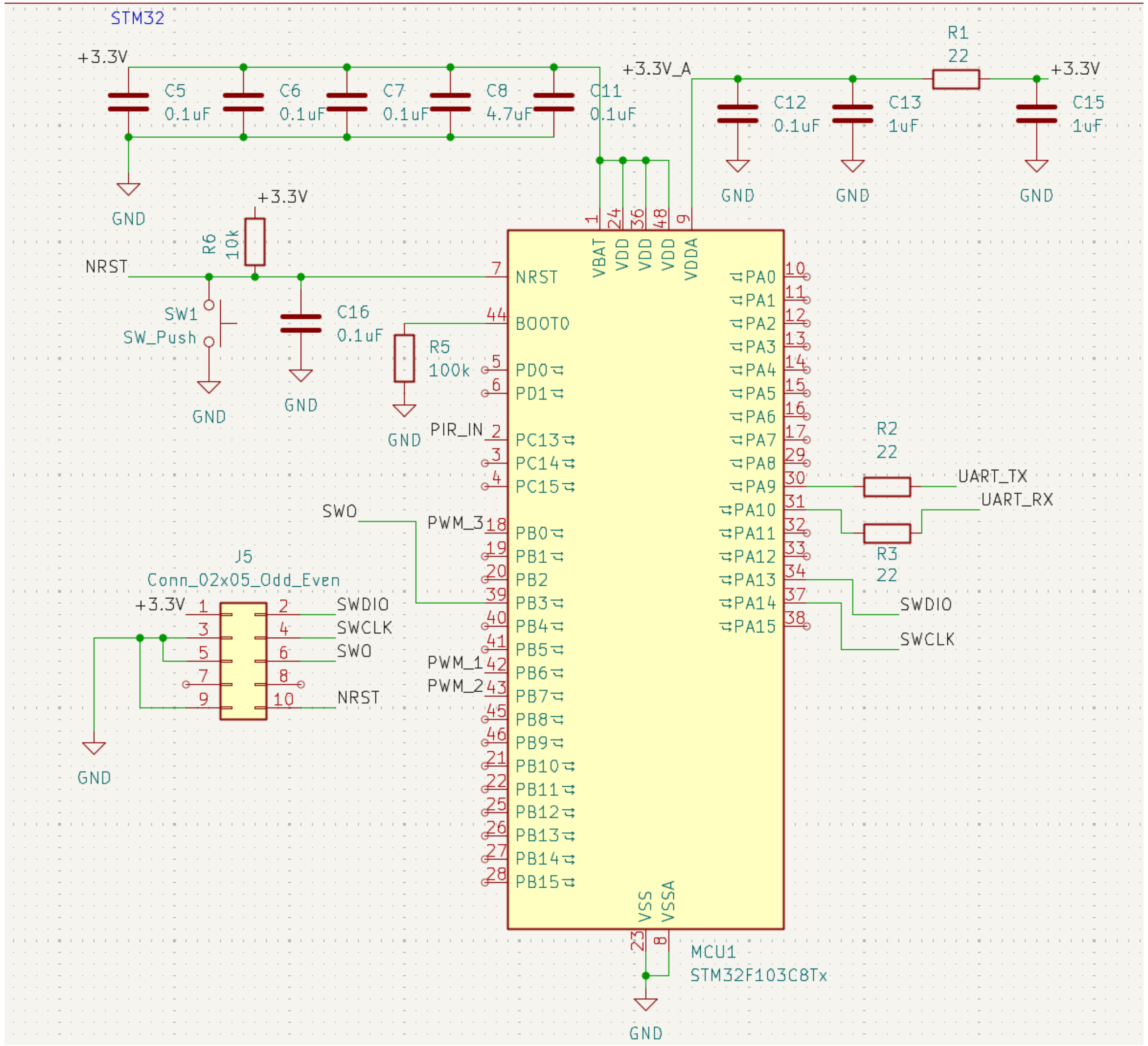
C4001 mmWave Radar

- 24 GHz motion/presence sensing
- Lingering detection, sensing breathing and fidgeting
- Low power, 0.45 W Operating Power
- 25 Meters detection, 100 x 40 degrees

mmWave vs Other Sensors

mmWave Radar (C4001)	Other Sensors (PIR, Ultrasonic, Camera, etc.)
Detects presence + micro motions	PIR Detects Motion Only
Works through plastic/other materials (not line of sight)	PIR & Camera Require clear line of sight, potential privacy concern with Camera
Stable under various lighting, temperatures, etc.	PIR: heat/sunlight errors Ultrasonic: airflow Issues
Provides UART presence classification	Most Sensors give 1 bit motion signal
Good 3-9 meter indoor detection range	Ultrasonic: Unreliable Range PIR: Small motions unreliable at longer ranges

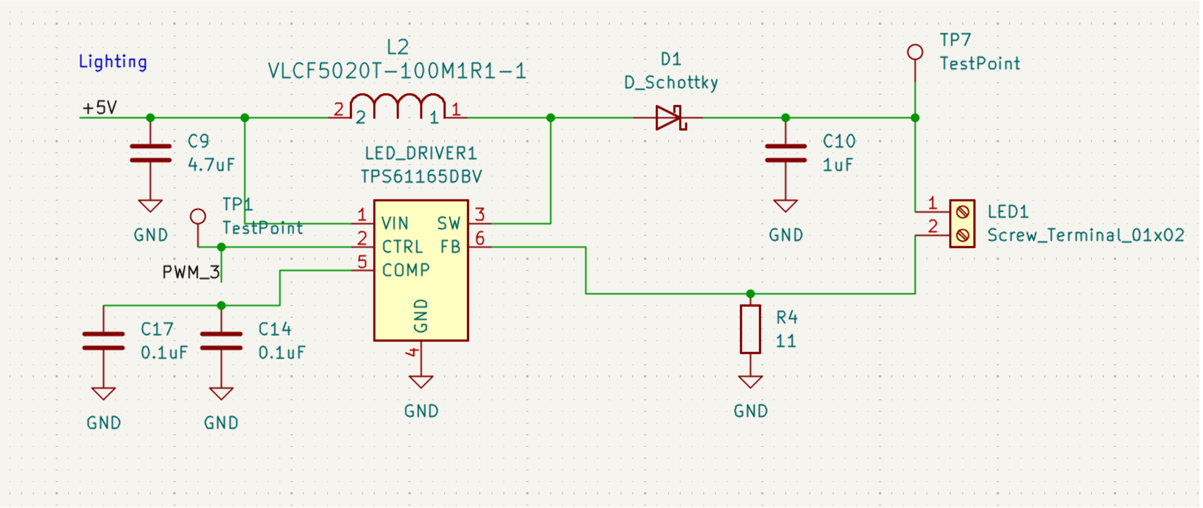
Microcontroller Subsystem



STM32F103C8 Microcontroller

- Multiple timers for servo PWM + LED Driver, UART RX/TX for the mmWave Sensor, GPIO for PIR Sensor
- 64 KB Flash and 20 KB SRAM with low power draw

Lighting Subsystem



TPS61165 LED Driver

- TPS61165 LED driver
- PWM-dimmable “CTRL” pin
- Integrated protections for a safer LED channel

Circuit Details

- FB Set to 0.2V
- Internal MOSFET changes Duty Cycle based on sensed V_FB
- 20 mA LEDs
- R4 = 10 Ω (11 Ω best through shop)
- Duty Cycle at CTRL sets Brightness

Requirements and Verification

High Level Requirements

Requirement #	Description
1	The light must begin to illuminate when someone enters a room, stay on for 30 minutes with someone being in the room, and begin to turn off after a full motor sweep.
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 30 degrees vertically. The pan and tilt motors must stop for enough time at each increment to detect motion (as moving servos causes the mmWave to detect motion).

Requirement 1

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% during peak current draw.

Verification

Result:

<u>Largest:</u> 5.01 [V]
<u>Lowest:</u> 4.94 [V]

Requirement 2

The power subsystem must be able to accept 5V (±5%) and output 3.3V with a tolerance of ±5% through the LDO during peak current draw.

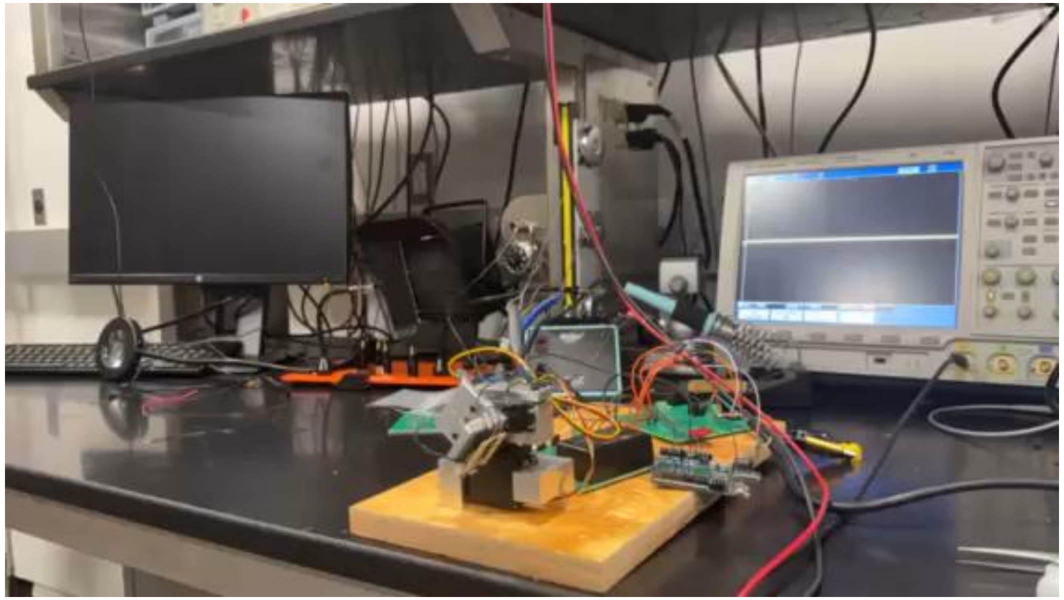
Verification

Result:

Largest: 3.32 [V]
Lowest: 3.28 [V]

Requirement 1

The pan motor must be able to rotate 180 degrees (±5 degrees) through mcu programming, and the tilt motor must be able to rotate 30 degrees (±3 degrees).



Verification

Result:

Test Number	Starting Angle (Vertical)	Ending Angle (Vertical)
1	-31°	-1°
2	-31°	-2°
3	-32°	-2°

Test Number	Starting Angle (Horizontal)	Ending Angle (Horizontal)
1	-2°	178°
2	-2°	179°
3	-1°	178°

Motor specs & Movement Capabilities:
Travel per μs = 0.095°/μs
Deadband width = 5 μs
Smallest step = 0.095 x 5 = 0.475°= ~0.5°

Requirements and Verifications - Motor

Requirement 2

Both the pan and tilt motors must be able to start in the same position (within ±5 degrees).

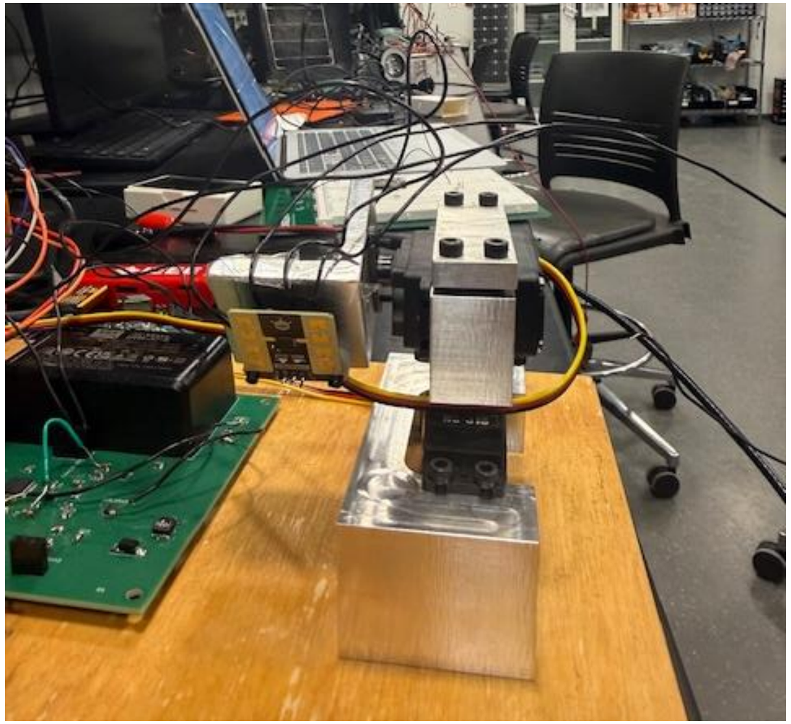
Requirement 3

For both servos (pan and tilt), the settled angle at each endpoint shall vary by no more than 5.0 degrees across repeated commands.

Motor specs & Movement Capabilities:
Travel per μs = 0.095°/μs
Deadband width = 5 μs
Smallest step = 0.095 x 5 = 0.475°= ~0.5°

Verification

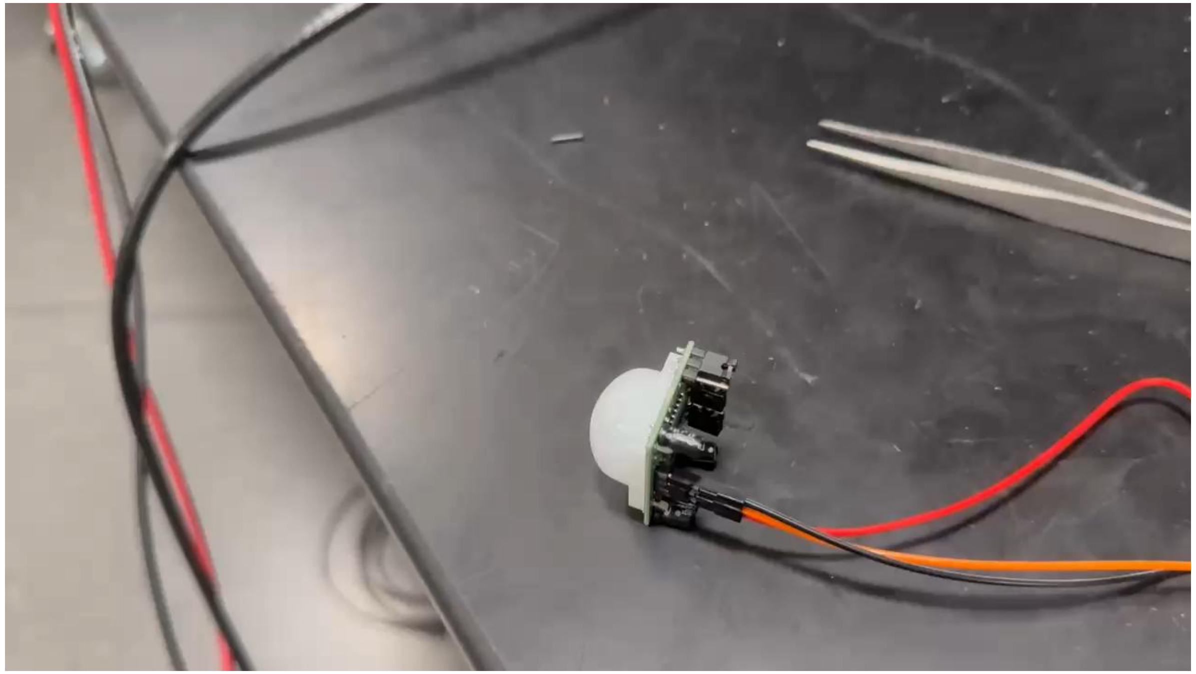
Test Number	Starting Angle (Horizontal, Vertical)	Ending Angle (Horizontal, Vertical)
1	-2°, -31°	178°, -31°
2	-2°, -31°	179°, -31°
3	-1°, -31°	178°, -32°



Requirements and Verifications - Sensing

Requirement 1

The PIR sensor must be able to detect human presence at a distance of 20 ft. or less. (90% of the time)



Verification

Distance from Target	Drop Rate (Out of 20 Trials)
5 ft	0%
10 ft	0%
15 ft	5%
20 ft	10%

Requirement 2

The mmWave sensor must be able to detect human presence at a distance of 32ft or less. (90% of the time)

Verification

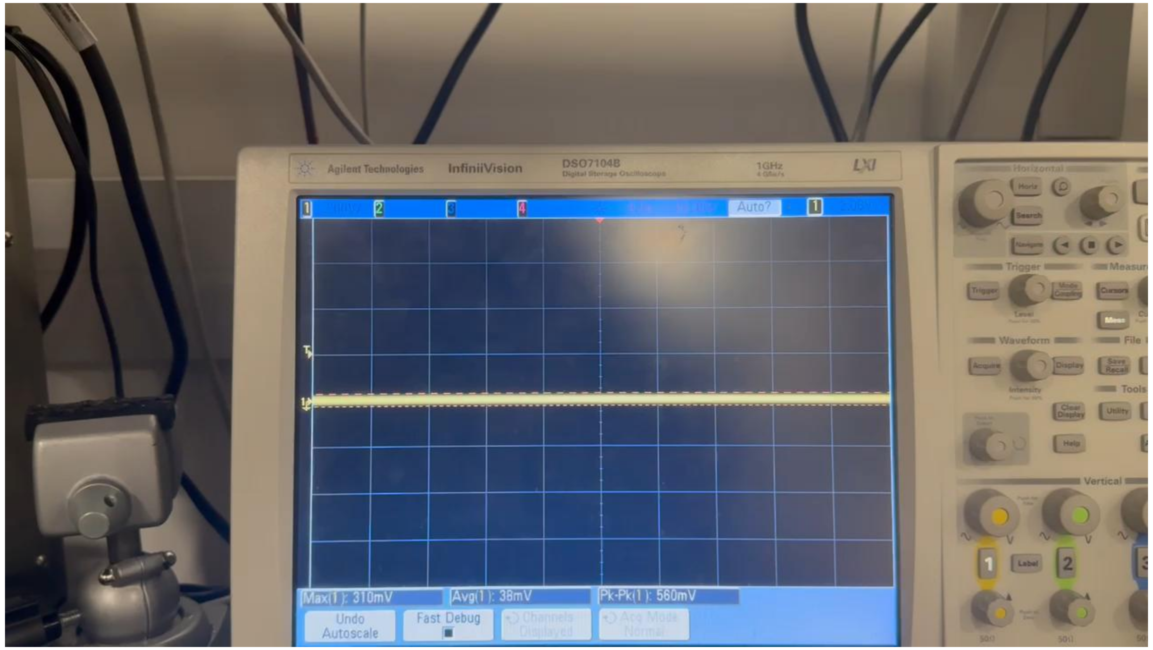
- Unable to be verified
- Very poor accuracy at long distances
- Poor accuracy even at shorter distances
- Motor Vibration

Distance from Target	False Positive Rate (Out of 20 Trials)
10 ft	25%
20 ft	25%
25 ft	35%
32 ft	40%

Requirement 1

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 gradual illumination stage.

Verification



Requirements and Verifications – Microcontroller

Requirement 2

The MCU shall be able to dim and turn off an LED if no motion is detected after a full sweep. It should dim after 1 full sweep, and turn off after another full sweep.

Requirement 3

The MCU shall be able to hold its Bright state for at least 30 minutes with people being in a room.

Verification

- Unable to be verified
- Requirement 2 works if mimicking mmWave signal
- mmWave vibrates too much, sees motion

Requirement 1

When CTRL is held HIGH (100% duty), the LED current should be 18.18 mA ±10%.
(16.362 mA to 20mA)

Verification

Result:

<u>Largest:</u> 0.205 [V]
<u>Lowest:</u> 0.193 [V]

0.205 [V] → 18.6 [mA]
0.193 [V] → 17.54 [mA]

Requirements and Verifications – Lighting

Requirement 2

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, 0.5*I, 0.9*I respectively.

Verification

TARGETS:
10%: 1.818 mA to 2 mA
50%: 8.18 mA to 10 mA
90%: 14.726 mA to 18 mA

Duty Cycle	Voltage (Average)	Current
10%	0.022 V	2 mA
50%	0.106 V	9.63 mA
90%	0.185 V	16.82 mA

Requirement 3

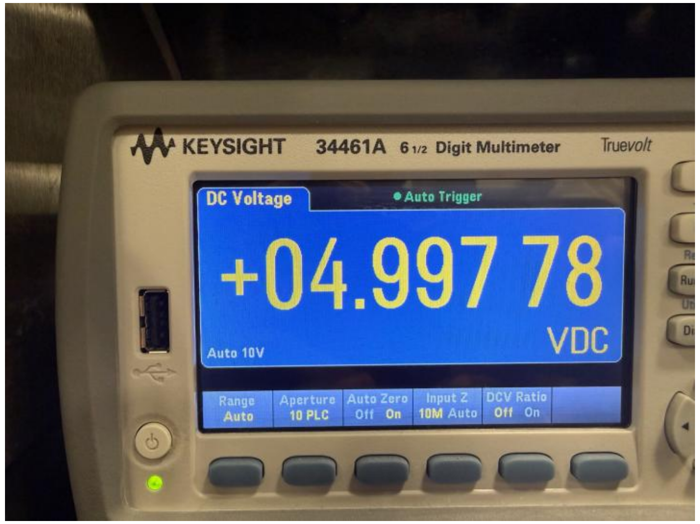
With CTRL = 100% and the normal load attached:

- The LED current ripple must be ≤ 20% peak-to-peak of the targeted LED current I.

- The input-pin ripple (VIN at the IC) must be ≤ 100 mV peak-to-peak.

Verification

Max VIN: 5.042 [V]
Min VIN: 4.983 [V]
(Very Similar to VIN from AC/DC Output)



(Repeated from requirement 1 test)
Largest VFB: 0.205 [V]
Lowest VFB: 0.193 [V]

0.205 [V] → 18.6 [mA]
0.193 [V] → 17.54 [mA]

Successes, Challenges

Successes

- Stable, correct power
- LED State Machine Creation
- Debugging and understanding Issues with implementation
- LED Driver implementation

Challenges

- Initial Flashing of Microcontroller
- mmWave Sensing
- LED Choice (Dim)

Conclusion

Lessons Learned

- Exposure to the complete engineering design process
  - Including problem identification, part selection, PCB design, assembly, hardware debugging, testing
- Adaptability
- Responsibility Division
- Lab Equipment Skills
  - Measurement devices, soldering, microcontroller programming, etc.

Future Work and Improvements

- MmWave improvement and implementation
- Improved part selection
- Scaled down Enclosure Design
- Digital Logic Power Shutoff Mechanism for Servo Motors

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