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HYLUX: AUTOMATED LIGHTING THROUGH RENEWABLE ENERGY

A PROJECT REPORT

Submitted by

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Under the guidance of,

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IN

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PRESIDENCY SCHOOL OF COMPUTER SCIENCE AND ENGINEERING

BONAFIDE CERTIFICATE

Certified that this report "AUTOMATED PUBLIC LIGHTING" is a bonafide work of "Vanshika Karani (20221CBD0056), Yuktha Suvarna (20221CBD0006), Nandagiri SreeKeerthana (20221CBD0060)", who have successfully carried out the project work and submitted the report for partial fulfilment of the requirements for the award of the degree of BACHELOR OF TECHNOLOGY in COMPUTER SCIENCE TECHNOLOGY, BIG DATA during 2025-26.

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DECLARATION

We the students of final year B.Tech in COMPUTER SCIENCE ENGINEERING at Presidency University, Bengaluru, named Vanshika Karani, Yuktha Suvarna, and Nandagiri SreeKeerthana, hereby declare that the project work titled **“AUTOMATED PUBLIC LIGHTING”** has been independently carried out by us and submitted in partial fulfillment for the award of the degree of B.Tech in **COMPUTER SCIENCE AND TECHNOLOGY, BIG DATA** during the academic year of 2025-26. Further, the matter embodied in the project has not been submitted previously by anybody for the award of any Degree or Diploma to any other institution.

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Abstract

Public lighting is an important service for urban and suburban areas. It directly affects public safety, community security, and nighttime social and economic activities. However, this essential infrastructure has a high financial and environmental cost. It consumes a lot of municipal electricity, often taking up a big part of a city's energy budget. The standard way of providing public lighting usually uses grid power and fixed timers. This method is not efficient. Street lights stay on at full brightness all night, no matter if there are pedestrians or vehicles around. This leads to a huge waste of electrical energy and high costs for municipalities. It also creates a significant carbon footprint from the power generation involved. This capstone project was started in response to a problem identified by the Ministry of Power. Our main aim was to design, build, and test a smart, automated public lighting system that is energy-efficient and environmentally friendly. The core of our proposed solution is a standalone, off-grid system that operates autonomously by making intelligent, real-time decisions based on its local environment. To achieve this, our approach is cantered on two key areas: hybrid energy harvesting and adaptive lighting control. For energy, we designed a hybrid system to maximize resilience. The primary power source is a 12V solar panel, which captures renewable solar energy during the day to charge a 12V rechargeable battery. This is supplemented by a secondary, innovative source: kinetic energy harvesters. These piezoelectric tiles are designed to be embedded in pathways, where they convert the mechanical pressure from pedestrian footsteps into a small electrical charge, providing supplemental power to the battery. A solar charge controller is used to manage this entire power system, protecting the battery from overcharging and deep discharge, which is critical for ensuring the system's long-term health and reliability.

We use a Raspberry Pi Pico as the “brain” of our system. It is an inexpensive microcontroller that retains significant power. The control program consists of MicroPython-based code written in Python and allows the system to continually process information coming into the Pico from different sensors. The first sensor used is a light-dependent resistor (LDR). It acts as a daylight sensor and measures the ambient brightness within the room, which tells the rest of the system when to not turn on and use power during the day, to keep from wasting any energy as they recharge the day batteries. The second type of sensor in use is a passive infrared (PIR) motion detector. It detects when someone or something enters or leaves the range of the sensor and therefore gives the Pico an indication of the presence or absence of people or objects within

the detection area. The primary logic behind the energy conservation of the entire system depends on the interaction of the LDR and the PIR sensors. At sunset, when the value received from the LDR falls below the pre-defined ambient brightness level (the threshold), the system switches into a low-power state (“idle”). In this state, the system turns on the main LED at 20%, providing just enough light to ensure visibility. In contrast, when the PIR sensor detects motion, it immediately sends a signal to the Pico to use pulse-width modulation (PWM) to drive the main LED (to 80%). The main LED will remain at this level until the PIR sensor detects no motion. At that time, the LED brightness will remain on at 80% power for a period of 15 seconds (the timeout) before returning back to the idle state (20% power), to conserve energy.

The end product of our research is a completely operational prototype that fully complies with all goals established earlier in this project. Our tests showed successful operation of the hybrid power system. The adaptive control logic has been shown to be fast, dependable, and functional. The functionality of the 20/80 dimming function upon detection of movement has been confirmed to greatly enhance the safety of the public and also dramatically reduce energy use during periods of inactivity at night. Our project demonstrates that we have developed a practical, scalable, and reasonably priced solution to the issue of infrastructure in urban settings today. Our solution will provide the means to substantially reduce energy costs, and decrease carbon emissions, while promoting the development of smarter, safer, and sustainable communities.

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Abbreviations

Abbreviation	Full Form
ADC	Analog-to-Digital Converter
CBD	Computer Science in Big Data
DC	Direct Current
GPIO	General-Purpose Input/Output
GND	Ground
HOD	Head of the Department
IoT	Internet of Things
LDR	Light Dependent Resistor
LED	Light Emitting Diode
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
PCB	Printed Circuit Board
PIR	Passive Infrared
PWM	Pulse Width Modulation
SDG	Sustainable Development Goal
VCC	Voltage at the Common Collector

Chapter 1

Introduction

1.1 Background

One of the core components of modern urban infrastructure is Public Lighting. It provides the vital element of public safety and promotes economic activity after dark while also enhancing the overall look and feel of our cities. Thus, public lighting is an extremely important service to ensure the continued success of our society. However, with all of its importance, this critical service can also incur a high price tag that often goes unnoticed. According to the Ministry of Power, a significant portion of a municipality's electricity consumption comes from public lighting, therefore significantly impacting the total amount of energy consumed by the city. This increased energy consumption leads to two major issues: the amount of money it costs to operate will burden municipal budgets and the amount of carbon generated from such usage will adversely affect our environment.

Still the most common approach is to employ a traditional streetlit light and have the light operate on a time schedule or manually. The issue with this typical method of lighting is that it lacks any intelligent control systems. Traditional streetlights are initially programmed to turn on at dusk, and turn off at dawn, while always being on their highest brightness for the entire time period. There are no controls in place so the streetlights have no operation to determine if a pedestrian or vehicle has been present on the street, so they will illuminate the entire street full brightness all night, regardless of actual street use. Therefore, traditional streetlights waste an immense amount of energy. The issue demonstrates that there is an urgent need to develop better methods of streetlighting that provide maximum public safety and significantly reduce energy consumption.

1.2 Statistics

The scale of this issue is considerable. Globally, public lighting is estimated to consume 18-20% of all electricity generated in the world. This number is shocking by itself, but in many cities in India, it is likely greater due to outdated infrastructure and grid characteristics. Public lighting represents a continual, ongoing burden to a city’s budget as well as the country’s electricity grid system. The constant energy draw that public lighting creates is often met with fossil fuel generated electricity, thus creating significant greenhouse gas emissions and worsening the environmental issues we face today.

The financial burden of maintaining public lighting is just as great. A large percentage of a city's electricity bill is attributed solely to the cost of keeping the streets lit. This money is not available for critical services that support our community, including road maintenance, public transportation, education, or health care. Therefore, the issue is not only about financial resources; it is also about the lack of efficient management for a very valuable, and costly, resource. This is driving the need for a change in how our cities are designed, built and maintained as it relates to urban lighting.

1.3 Prior existing technologies

Over time, public lighting has evolved in 3 main phases, with each having its own drawbacks.

- **Stage 1: Manual and Timer-Based Systems:** During the first phase of public lighting, lights were manually turned on and off. Next came an automation phase where timers would automatically turn on lights at dusk and off again at dawn. Although these automated systems are more dependable than manual systems, they are completely static with no ability to adapt or respond to changing conditions, resulting in the excessive waste of energy mentioned previously.
- **Stage 2: Standalone Solar Lights:** The second phase of public lighting introduced standalone solar-powered street light systems that consist of a solar panel, battery, and LED lamp. These solar-powered street lights provide an environmentally-friendly, off-the-grid solution for public lighting, but these systems still have major limitations. One limitation of standalone solar-powered street lights is that their functionality depends entirely on the weather; therefore, if there are extended periods of cloudy weather, monsoons, or insufficient sunlight there is the possibility that the street lights will not work as intended. Another issue with standalone solar-powered street lights is that they exhibit the same efficiency issues as timer-based street lights in that they will always operate under full brightness during nighttime hours irrespective of whether or not anybody is present to use them. As such, they are wasting the limited and precious energy that the solar panel collects during daytime hours.
- **Stage 3: Basic Sensor Integration:** Basic motion sensors were incorporated into more complex systems. The integration of these sensors is an improvement over previous

systems but is still generally a basic function. Integration of multiple energy sources (e.g. wind and solar) to create a more reliable system has not yet been realized by most commercial applications. Our project intends to address the "gap" in technology both being energy self-sufficient and intelligently adaptable.

1.4 Proposed approach

- Our project is developing a new, innovative method for automating public lighting that overcomes the weaknesses of current methods. The system we have designed will allow for the creation of an intelligent, self-sustaining, and highly efficient system that will allow for the best use of its environment through the use of real-time data to make intelligent decisions.
- **Rationale:** Our motivation for this project is to offer municipalities an affordable, cost-effective solution that will drastically reduce their operating costs by decreasing energy usage. Additionally, we want to provide a sustainable lighting solution that enhances community safety and promotes environmental responsibility.
- **Proposed Solution:** We are designing a system to utilize two types of renewable energy: Solar Energy and Kinetic Energy..
    1. **Hybrid Energy Harvesting:** Solar panels will provide the primary power source for the system by charging a battery bank during the day, while the battery bank will receive additional charging from kinetic energy harvesting tiles (piezoelectric sensors) embedded in walkways. Kinetic energy harvesting tiles are activated by pedestrian foot traffic. This is a more robust system than current solutions that rely only on solar energy.
    2. **Intelligent Control:** The Raspberry Pi Pico microcontroller serves as the "brain" of the entire system that controls it. The Pico accepts input from two sensors: a Light Dependent Resistor (LDR) sensing ambient light levels (to tell if it was day or night), and a Passive Infrared (PIR) sensor that detects motion.
    3. **Adaptive Dimming Logic:** The system's operation is what allows the system to be energy efficient through three distinct operational states. - Daytime State: When the LDR detects sun light, the Pico will keep the LED light completely off. All solar or kinetic energy will then be used to charge the battery. - Night-Idle State: When the LDR detects darkness and no motion is detected on the PIR sensor, the Pico will turn the LED light on at a 20% brightness (which is dim and conserves energy). This is to provide minimal ambient light, allowing

for visibility without wasting energy. - Night-Active State: When the LDR detects darkness and motion is detected on the PIR sensor, the Pico will increase the LED brightness to 80%, allowing supporters and bicycle riders full visibility along a pathway. The system will wait for fifteen seconds from the last detected motion before returning to the 20% idle state.

4. **Applications:** This system can be deployed in a variety of public spaces, including city parks, universities, pedestrian paths, housing communities and any new smart city implementations that are planned.

- **Limitation:** There are two primary limitations to this technology that we are aware of. First, the kinetic tiles currently available produce only a limited amount of power, meaning that their use as an alternative source of energy is limited at this time. Secondly, the prototype developed as part of this project cannot be used outside long-term without protection from the elements.

1.5 Objectives

The main purpose of this research project includes:

1. To develop, design, implement, and test a smart public lighting system that adjusts the intensity of its LEDs based on the ambient light and motion detected in real time.

2. To build a system that produces its own power by using solar panels as the main power source with backup from kinetic energy harvesters.

3. To incorporate a Raspberry Pi Pico microcontroller together with an integrated Python-based program for controlling the energy used, and the way in which it functions.

4. To achieve a substantial decrease in electricity consumption (and therefore, lower operating costs and carbon footprint) compared to existing public lighting technologies using adaptive dimming.

5. To construct and evaluate a working prototype that demonstrates the viability and ability of the adaptive dimming method integrated into a multi-source, intelligent lighting approach.

1.6 SDGs

The goals of the United Nations (UN) Sustainable Development Goals (SDGs) as shown in Fig. 1.1 demonstrate how this project fits directly into the UN SDG framework. This project supports several of the UN's SDG's including:

SDG #7 - Affordable and Clean Energy - Using both solar and kinetic energy, this project will provide greater access to clean, renewable sources of energy and reduce our dependence on the fossil fuel-based energy grid.

SDG #9 - Industry, Innovation, and Infrastructure - As an example of "smart" infrastructure, this project utilizes the "Internet of Things" (IoT) for the development of urban infrastructure that is both resilient and sustainable.

SDG #11 - Sustainable Cities and Communities - This project contributes to making urban areas safer, and less environmentally damaging by reducing the carbon footprint of this essential service.

SDG #13 - Climate Action - Through reduced energy use, this project will directly help to reduce carbon emissions produced from generating electricity and is a further contributor to efforts to mitigate climate change.

Fig 1.1 Sustainable development goals [1]

1.7 Overview of project report

The design, development and evaluation of the Automated Public Lighting system are presented in this report. Chapter 1 introduces the problem being addressed and outlines the stated objectives of the project, along with our solution proposal. Chapter 2 examines existing literature pertaining to smart lighting, renewable energy generation, and battery-less, low-powered IoT systems. In Chapter 3, we explain how we used the V-model development methodology for our project lifecycle and describe how we verify and validate the project. In Chapter 4, we present the management responsibilities associated with the project, including the project timeline, detailed risk analysis and estimated budget. Chapter 5 details the system's analysis and design; the system's functional requirements, block diagrams, component selection rationale, and the IoT architecture are provided in this chapter. In Chapter 6, we detail the actual hardware implementation, software code, and development tools used. Chapter 7 presents our evaluation and test results, including the test plan, test observations, and major findings. Lastly, in Chapter 8, we discuss the wider social, legal, ethical, and sustainability implications of this work. We will conclude the report in Chapter 9 with a summary of our findings and suggestions for future improvements..

Chapter 2

Literature review

Literature review

[1] Piezoelectric Materials for Flexible and Wearable Electronics (Y. Wu et al., 2021)
This report reviews these advances through the lens of the three most common types of piezoelectric materials: ceramics, polymers, and composites of the two material types; the advantages/disadvantages of the three categories are discussed in detail, as the challenges associated with their use in wearable electronics are primarily related to their ability to provide flexibility and durability. Also, this report discusses how these piezoelectric materials are used in the construction of wearable systems and their ability to work when they have been deformed (built into wearable systems). A primary goal for the future is to produce lead-free piezoelectric materials, create scalable manufacturing processes, and develop multifunctional piezoelectric systems that can sense and generate energy at the same time. Future research will also concentrate on increasing the piezoelectric coefficient values, increasing the fatigue-resistance of the materials, and fully integrating piezoelectric materials into wearable electronic systems for use in IoT applications and health-related applications.

[2] Solar Energy Prediction in IoT Systems (A. B. Kathole et al., 2024)
The authors present a novel way to forecast solar energy generation with an Optimized Complex-Valued Spatio-Temporal Graph Convolutional Neural Network (CV-ST-GCNN). They use an approach that combines spatio-temporal dependence among solar panels with adaptive filters and optimization methods to accurately predict solar energy generation. Their results demonstrate higher prediction accuracy. They call for enhanced model generalization capabilities, ability to operate on real-time edges, and adaptivity to missing or corrupted data. Future work will include combining graph networks with physical energy generation models and further developing their models to support multiple climate zones.

[3] Ultra-Low Power Techniques in Energy Harvesting WSNs (F. Mazunga et al., 2021)
This paper provides a comprehensive review of design techniques used in ultra-low-power (ULP) for energy harvesting wireless sensor networks (EH-WSN). Such as duty cycling, routing, adaptive power management, and hybrid energy harvesting. The authors compare the trade-offs between performance, energy neutrality, and maximum system lifetime. They conclude that it is necessary to design circuits, communication protocols, and power

management systems to work together. Future developments include real-time adaptation of nodes based on data collection, using machine learning algorithms to control the powering of nodes, and establishing standard benchmarks for ULP systems. This review provides a comprehensive summary of possible avenues for developing energy efficient sensor networks.

[4] Design of Urban Lighting Control System Using Optical Multisensors (Anonymous, 2023)

An advanced lighting control system that uses optical multi-sensor technologies to optimize lighting levels based on ambient conditions is proposed in this paper. The system uses modular sensors that continuously adjust the brightness level of each light in real-time. The system can thus create significant energy savings while providing users of the system with visual comfort. The authors describe the capacity of the system to scale up to large urban areas and to automate lighting based on environmental factors. Future work is planned using technology such as artificial intelligence to predict environmental changes and connect IoT devices. Furthermore, researchers have made suggestions to link this technology to other smart city services, such as traffic control or emergency response systems.

[5] Pedestrian Safety Using IoT and Sensors (R. Hasan et al., 2022)

The focus of this paper is on improving pedestrian safety through IoT-based sensing technology, which provides hazard detection and real-time notifications. The authors examine the current status of sensor technology, communication protocols, and safety algorithms. They highlight the ability of multi-sensor fusion to increase the effectiveness of accident prevention measures. The authors conclude with a discussion of future challenges, including the development of privacy-sensitive systems, real-world testing, and improved data interoperability. Future developments will likely include AI-based prediction of behaviour, low-energy sensor devices, and smart-city system compatibility.

[6] Recent Advances in Piezoelectric Wearable Energy Harvesting (A. Ali et al., 2024)

This research paper examines the modern piezoelectric energy harvesters intended for wearable devices, looking at materials including PVDF composites and nanogenerators. The main issues addressed are the design flexibility/integrity, biocompatibility, and conversion efficiency of these devices and how they can be integrated into textiles/Wearable electronics in increase usage. The authors recommend combining piezoelectric and triboelectric harvesting for increased efficiency and effectiveness. Future research will be focused on large scale, flexible productions(), hybrid energy sources, and improved durability for actual use.

[7] Optimizing Solar Energy: IoT-Based Solar Monitoring Systems (Anonymous, 2024)

This study investigates the use of IoT-enabled monitoring systems to improve the management of Solar Panels through monitoring in real-time and utilizing the data collected from analyzing the performance of the panels to detect and predict failures within the system. A sensor is employed to monitor the performance of a PV (Photovoltaic) Module to collect the data that will allow for predictive maintenance, resulting in an increase in energy yield along with a decrease in downtime. Future design recommendations enunciated in this paper would be to calibrate sensors accurately, apply AI to predictive analytics, and accommodate long-term, large-scale systems implementation. The area anticipated for future development within this technology includes both edge computing and cloud-based optimization for improved energy production.

[8] Self-Powered Sensing Systems with Learning Capability (A. Alagumalai et al., 2022)

This research article discusses self-powered sensors that take advantage of the energy around them to run machine learning algorithms so that they can adapt to their environment. It examines the key components of the system (e.g., design, power supply, incorporating low-power embedded AI with lightweight circuits) and how these components can be combined to extend the battery life of a sensor by minimizing data transmission from the sensor and extending its life. The last section discusses the future of self-powered sensors and how they will facilitate real-time learning, increased edge autonomy and deployment in smart-IoT networks on a large scale.

[9] Daylighting and User-Oriented Urban Lighting Integration (R. M. López-Lovillo et al., 2023)

This research integrates daylight measurement devices smartly controlled by users, providing optimal comfort and energy efficiency within delivered urban lighting. The adaptive illumination model has been validating environmental and user-related data. The current research demonstrates the scenarios in which dynamic lighting can balance artificial and natural light levels. Future work will include the use of artificial intelligence to model user behaviour, integrating data from smart city systems and evaluating user satisfaction. The vision is for an area-based, adaptable, and maximum-scalable comfort level while meeting sustainability targets.

[10] Smart Technologies for Safety of Vulnerable Road Users (M. S. Parvez et al., 2024)

This research examines how smart tech is being used to improve pedestrian/cyclist safety through the use of IoT, Computer Vision and Wearable Sensors. The paper highlights applications of real time hazard detection, as well as V2X communication. Findings show response time and situational awareness have increased with the implementation of these technologies. The conclusion recommends creating multimodality data fusion systems, providing privacy frameworks, and developing low latency communication networks. Future research will focus on adding AI-based safety prediction to integrate these systems into existing urban intelligent transport systems

Summary of Literatures reviewed

Table 2.1 Summary of Literature reviews

S#	Article Title, Published year, Journal name	Methods	Key features	Merits	Demerits
1.	Piezoelectric Materials for Flexible and Wearable Electronics (2020)	Material Synthesis & Characterization	Focuses on flexible piezoelectric polymers and composites for energy harvesting.	Provides insight into materials that can convert mechanical stress to electricity.	Primarily focused on wearable tech, not large-scale structural applications.
2.	Solar Energy Prediction in IoT Systems... (2023)	Graph Convolutional Neural Network	Uses AI/ML for accurate solar irradiance forecasting in IoT networks.	Advanced prediction could optimize energy storage in large systems.	Computationally intensive and complex to implement on a low-power device like a Pico.
3.	Ultra-Low Power Techniques in Energy Harvesting	Survey of techniques	Discusses duty cycling, power-aware protocols, and efficient hardware/software design.	Foundational principles for designing energy-constrained systems.	Some techniques may be outdated due to advances in low-power electronics.

	WSNs (2010)				
4.	Design of the Urban Lighting Control System Based on Optical Multisensor Technology (2019)	Multi-sensor fusion	Employs various optical sensors for nuanced lighting control in urban settings.	Demonstrates the value of using multiple sensors for smarter decisions.	Can increase system complexity and cost.
5.	Pedestrian Safety Using the Internet of Things and Sensors (2019)	IoT System Design	Proposes IoT frameworks to improve pedestrian safety through real-time data.	Directly links smart technology to tangible public safety improvements.	May rely on network connectivity, which our standalone system avoids.

Chapter 3

Methodology

At the start of developing the Automated Public Lighting system, we decided to use the V-Model methodology. The reason for choosing this specific model is that it has an organized way of building the system, with a focus on verifying and validating the process continuously throughout each phase of development. We are developing an automated public lighting system that requires significant hardware components. Hence, one of our main goals is to ensure the functionality and performance of all individual parts and modules prior to integration. Additionally, the V-Model establishes a parallel development and testing structure to support this. Each phase of design is supported by a matching phase of testing, which allows for timely error detection and the ultimate alignment of the final product with the original requirements.

In the following sections, our project phases are described in terms of the V-Model.

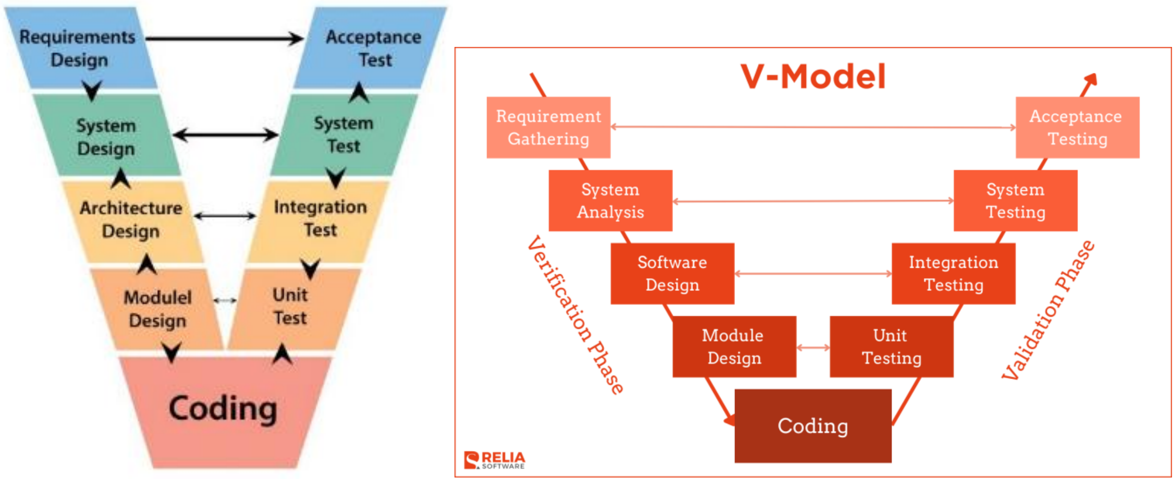

Fig 3.1 The V model methodology [4]

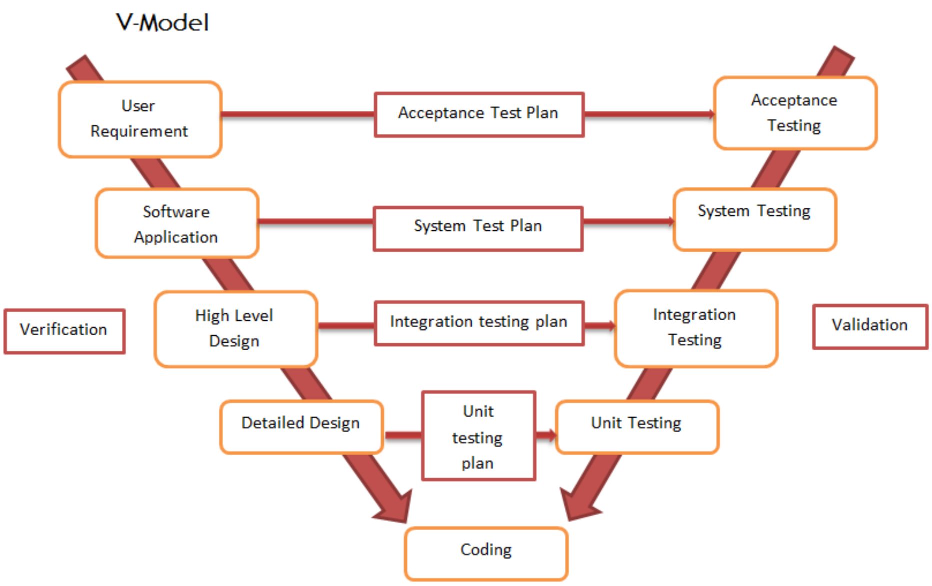

Fig 3.2 Another example of the V model methodology [5]

Fig 3.1 and Fig 3.2 shows the V-model methodology.

The Verification Phases (the Left Side of the V-Model) consist of:

Requirements Gathering and Analysis: In this phase, we identified what the core issue is and what we expect to have at the end of this project based on the Problem Statement provided by the Ministry of Power. We documented what the expected purpose of the system would be, how we expect it to behave, and what limits there are to how it can be used. This phase corresponds with the User Requirement phase. Activities during this phase include finalizing the Problem Statement, reviewing literature, and defining and documenting the specific and measurable objectives that were identified in Chapter 1.

System Design: In this phase, we identified how the system would be structured. We identified the main functional blocks of the system, which include the Energy Harvesting Block, Energy Storage Block, Control Unit, and the Lighting Output Block. We developed a high-level block diagram (see Chapter 5) to illustrate the main system blocks, and we also identified how these main blocks will interact with each other. This phase corresponds with the System Design or Architecture Design Phase.

The activities during this stage consist of designing the System Architecture and determining the Technology Stack (e.g. Raspberry Pi Pico and MicroPython) and defining the overall system's Process Flow. Low-level design, or Module Design: We deconstructed the system into smaller, more manageable modules (both hardware and software) and designed each of those modules in detail. For the hardware, the designs included designing the circuits for connecting to the sensor, power management (Charge Controller + DC/DC Converter) and MOSFET driver for the LED; and for the software we designed how to read the sensors and control the PWM output for the LED and how to manage the states of the system (e.g., Day/Night Idle; Night Active). This phase corresponds with the Module Design Phase. The types of activities performed during this stage included producing detailed diagrams of the circuit; selecting specific components (e.g. specific PIR sensor model, LDR, MOSFET); producing a flowchart for the design of the software; and defining the function names and variable names used in the code. Coding/Implementing: During this phase of the project, both the hardware was assembled and the software code was written (in MicroPython) according to the Module Designs created during the Module Design Phase. The types of activities performed during this stage included putting together the circuit for testing purposes using a Breadboard, soldering the components to the PCB, and writing and debugging the MicroPython code using the Thonny IDE.

The Validation Phase (Right Side of the V) consists of three main phases: Unit Testing, Integration Testing and System Testing. Unit Testing of each module was done separately - their functionality was tested (corresponding to the "Unit Test" phase).

Unit Testing confirms that the Module Design is correct. Examples of activities were to ensure the PIR sensor will successfully detect motion; test for daylight and darkness of LDR circuit; verify that the PWM control of LED via MOSFET will smoothly dim.

Integration Testing involved integrating all the modules together and testing them together (this corresponds to the "Integration Test" phase). For example, to confirm the PIR sensor would trigger an increase in brightness of the light, we integrated the PIR sensor and LED control module.

Activities of Integration Testing included connecting the sensors to the Pico and ensuring the correct software logic, also connecting the full control unit to the main power and the LED.

System Testing tested the fully integrated system in totality to confirm compliance with all functional and non-functional requirements established in the first phase. We tested the complete day/night cycles, the response of motion detection, and the harvesting/storage of energy (this corresponds to the "System Test" phase).

The activities that take place in this phase would be running the complete working model for extended periods of time, as well as simulating different types of environmental conditions, to determine if it is able to withstand the expected levels of performance and stability. The acceptance test is the final stage where the fully functional prototype must be demonstrated and approved by both the project guide and stakeholders, to ensure that the prototype meets the requirements and expectations of the project as outlined in the problem statement. The final submission of this project shall comprise a final report and viva voce, and be aligned with the acceptance test in order to validate requirements.

Activities that take place in this stage will consist of a final demonstration of the working model, followed by a presentation of the results made from that final demonstration, and finally documenting all results obtained in this report.

In following the V-Model, we were able to maintain a disciplined development process, with a strong focus on quality and correctness at each stage.

Chapter 4

Project Management

The success of our project through effective project management is vital to ensuring the project will meet the deadlines of deliverables to suit our client's needs, budget constraints and quality expectations. Included in this chapter is the project timeline, the risk assessment, and the project budget.

4.1 Project timeline

We developed a Gantt chart to help us manage our project schedule more easily. The Gantt chart was used as a visual guide for the project, showing when each task needed to be done, how long it would take, and what would need to happen first in order for the task to be completed. The project was divided into two phases: Planning and Implementation. The timeline for both phases is illustrated in Table 4.1 and Table 4.2, respectively.

Table 4.1 Project planning timeline

Major Task	W1	W2	W3	W4	W5	W6	W7	W8
Project Initiation	■							
Selection of topic	■							
Background study	■	■						
Review-1 (CA-1)		■						
Objectives formulation		■						
Proposal submission		■						
Literature Review			■	■				

Review-2 (CA-2)				■				
Methodology finalization				■				
Design and Analysis					■	■		
System Requirement Phase					■			
System Design Phase					■	■		
Functional Unit Design Phase						■		
Report Writing							■	■

Table 4.2 Project implementation timeline

Major Task	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
Simulation	■	■	■												
Unit	■	■	■												
Integrated		■	■	■											
Hardware implementation			■	■	■	■	■	■	■	■					
Software				■	■	■	■	■	■	■					
Testing *					■	■	■	■	■	■	■				
Critical Evaluation **							■	■	■	■	■	■			
Social, Ethical, Legal, and Sustainability										■	■	■			
Report							■	■	■	■	■	■	■		
Final report										■	■	■	■	■	■

* Develop test plan, Identifying test points
Black box testing (positive, negative, boundary),
White box testing (Control flow, Data flow, Branch, Path)
Hardware testing - Unit Testing, Integrated testing
Software testing
System testing - Validation (dynamic, testing user requirements)
Tabulating test results

** Identify the Hardware functional units - Sensors, Input devices, Micro controllers, Actuators, Output devices, Interface circuits, Signal conditioning circuits, Driver circuits
Identify the Software functional units - Software component, Initializing, Acquiring, Processing, Data Logging, Controlling, Indicating
Discuss the properties, issues, constraints of each functional units, Working principle, Signal type (digital or analog), Signal conditioning (signal level, noise, signal conversion), Latency, Linearity, Accuracy
Discuss the aspects to improve each functional units, Reliability, Power aware, Interrupt driven, Precise timing (Real time), Indicate output, Meet standards, Safety

4.2 Risk analysis

To evaluate possible external threats on the project we complete a PESTLE (Political, Economic, Social, Technological, Legal & Environmental) Analysis. By utilizing this analysis we can ascertain the macro-level drivers of change and provide contingencies to mitigate their effects.

Table 4.3 Example of PESTEL analysis [13]

Factor	Potential Risk / Opportunity	Mitigation Strategy
Political	**Opportunity:** The Ministry of Power in India provides strong government support and stimulus for both Renewable Energy and Smart City Initiatives.	Utilize the connection between Project Goals and National Initiatives to strengthen your case.
Economic	**Risk:** There is a risk that the price of electronic equipment (such as solar panels, microcontrollers) may increase above budget targets for the project.	Combine orders from different electronic component suppliers. This will ensure the lowest possible price while allowing you to lock in prices by ordering your essential components as early as possible to obtain the best possible deal.
Social	**Opportunity:**Sustainability and Climate Change Awareness Among the General Public Provides a Favorable Environment to Promote Eco-Friendly Projects Such as This.	Highlighting Community Benefits (Safety, Reduced Emissions, Etc.) in Project Documents and Presentations.
Technological	**Potential Issues:** A key component of your project (a	As you are designing your project, you should identify

	Raspberry Pi Pico) may not be available for purchase or may have a long lead time. Potential Issue: You might run into unforeseen bugs or hardware incompatibilities.	alternative components, such as the ESP32, that might work for your project. You should devote enough time to debugging and use a breadboard prototype, which will allow for easy troubleshooting.
Legal	**Risk:** If deployed publicly, the system must comply with local electrical and safety regulations.	For the prototype, all electrical connections should adhere to standard safety practices. It should be recognized that a commercial version would require formal certification before being sold.
Environmental	**Risk:** Environmental Hazard: There is a risk to the environment from the end-of-life management of electronic components such as batteries and PCB's.	Develop the electronic system with a charging port for a rechargeable battery. A modular design will enable you to replace only those components that have failed. Encourage users to recycle their electronic waste properly.

P Political	E Econimic	S Societal	T Technological	E Environmental	L Legal
- Taxation policies - Trade restrictions - Tariffs - Political stability	- Interest rates - Exchange rates - Inflation rates - Raw material costs - Employment or unemployment rates	- Population growth - Age distribution - Education levels - Cultural needs - Changes in lifestyle	- Technology development - Automation - R&D	- Climate - Weather - Resource consumption - Waste emission	- Discrimination law - Consumer law - Antitrust law - Employment law - Health and safety law

Table 4.4 Another example of PESTEL analysis [14]

P Political	E Economical	S Social	T Technological	L Legal	E Environmental
Explore: • Government stability • Financial stimulus commitment • Pandemic strategic plan • Health service readiness • Pandemic policy factors • Current taxation policy • Future taxation policy • The current and future political support • Grants, funding and initiatives • Trade bodies • Effect of wars or worsening relations with particular countries • Election campaigns • Issues featuring in political agendas	**Explore:** • National debt levels • Recovery struggle for impacted industry • Strength of consumer spending • Current and future levels of government spending • Ease of access to loans • Current and future level of interest rates, inflation and unemployment • Specific taxation policies and trends • Exchange rates • Overall economic situation • Real estate exodus • Inner city business decline • Supply volatility	**Explore:** • Pandemic lifestyle trends • demographics • consumer attitudes and opinions • media views • law changes affecting social factors • brand, company, technology image • consumer buying patterns • fashion and role models • major events and influence • Inner city pandemic trends • ethnic/religious factors • ethical issues • Digital relationships	**Explore:** • Relationship with pandemic • Sector technology demand • Relevant current and future technology innovations • The level of research funding • The ways in which consumers make purchases • Intellectual property rights and copyright infringements • Global communication technological advances • Internet connectivity utility	**Explore:** • Legislation in areas such as employment, competition and health & safety • Environmental legislation • Future legislation changes • Changes in European law • Trading policies • Regulatory bodies • Pandemic legislation • Working environment • Pandemic legal sensitivities	**Explore:** • Relationship with global warming • Relationship with recycling and global fight against waste • Relationship with global fight against plastic usage • The level of pollution created by the product or service • Attitudes to the environment from the government, media and consumers • Relationship with renewable energy • Relationship with deforestation

Table 4.5 Example of Project phase risk matrix [15]

Project Phase Risk Matrix

Potential Consequences	Health and Safety	Environmental Impacts	Financial & Asset Loss	Reputational Damage	Production / Projects	Information Technology	Almost Impossible (1) Occurs less than once in 10 000 years	Not likely to occur (2) Occurs once in 1 000 to 10 000 years	Could occur (3) Occurs once in 100 to 1 000 years	Known to occur (4) Occurs once in 10 to 100 years	Common occurrence (5) Occurs once in 1 to 10 years
Catastrophic (5)	One or more fatalities. Irreversible health problems for employees and/or community.	On or off-site spill causing groundwater pollution, with detrimental long-term effects.	Severe financial loss or asset replacement cost impact. (> US$ 2 million)	International loss of reputation / Damaging International TV exposure with impact	Indefinite cessation of production activity / Extended project schedule slip of > 75% of plan.	Significant failure and operational downtime with permanent loss of critical data integrity.	5	10	15	20	25
Major (4)	Partial, or medium-term, disabilities or major health problems for employees and/or	Off-site release, contained & medium-term effects on community health and/or groundwater	Major financial loss or asset cost impact. (> US$ 1 million < US$ 2 million)	National loss of reputation / Damaging National TV exposure with impact on customers.	Long-term production cutback / Major project schedule slip of 40 to 75% of plan.	System failure and operational downtime, with loss of critical data integrity and/or confidentiality.	4	8	12	16	20
Moderate (3)	Lost-time Injuries or potential medium-term health problems for employees and/or community.	On site release, contained & restored, with medium-term effects on employees/ groundwater	Moderate financial loss or asset cost impact. (> US$ 100 000 < US$ 1 million)	Regional loss of reputation / Local radio & newspaper reports impacting suppliers/customers	Medium-term production cutback / Project schedule slip of 20 to 40% of plan.	System downtime with operational impact / restricted loss of data integrity / confidentiality.	3	6	9	12	15
Minor (2)	Minor, very short-term health concerns or Recordable Injury cases.	On site release, immediately contained & restored, with short-term effects	Tolerable financial loss or asset cost impact. (> US$ 10 000 < US$ 100 000)	Loss of regional reputation by word of mouth re. safety performance & treatment of workers.	Short-term production cutback / Minor project schedule slip of 10 to 20% of plan	Limited downtime, recoverable data loss with limited operational impact, no security breach	2	4	6	8	10
Insignificant (1)	Inherently safe, Unlikely to cause health problems. First aid injuries.	Minor localised spill with insignificant effects on employees and/or community.	Relatively low financial loss or asset cost impact. (< US$ 10 000)	Unsubstantiated rumours with light to moderate impact on reputation	Very short-term production cutback / schedule slip of up to 10% of plan	Limited downtime, recoverable data loss, workaround possible, no security breach	1	2	3	4	5

Low risk | Medium risk | Significant risk | High risk

4.3 Project budget

A prototype estimate was developed based upon detailed budget provided using market values of all parts purchased from retail or online sources. Labour was not calculated as an expenditure for this academic project. Example templates for each type of project budget are provided below in Table

Project Budget

Summary cost of Project	Amount
Total Budget	5015
Actual Cost	5015
Total Variance	0

Details of the project	
Name of the Company	Presidency University
Project Name or ID	HYLUX
Project Lead	Vanshika Karani
Start Date	Oct-25

Sl.no	Particulars	Materials: Units	Materials: Cost Per Unit	Labour: Hours	Labour: Cost per Hour	Fixed Cost	Miscellaneous Cost	Budgeted Amount	Actual Amount	Varience Amount
	Task 1									
1	Raspberry Pi Pico Board	1	450					450		
2	LDR	1	350					350		
3	PIR	1	70					70		
4	MOSFET	1	75					75		
5	Piezo Tiles	10	15					150		
6	Rechargeable Battery	1	450					450		
7	Breadboard	2	50					100		
8	Solar Panel	2	60					120		
9	AC-DC Converter	1	50					50		
10	DC-DC Buck Converter	1	50					50		
11	Wires	Multiple	400					400		
(A)	Total Task 1							2265		
	Task 2									
1	Soldering							0		
2	Connection Check							0		
(B)	Total Task 2							0		
	Task 3									
1	Software Installation									
2	Coding									
3	Model Building	1	400					400		
(C)	Total Task 3							400		
	Task 4									
1	Travel Cost					600		600		
2	Fuel					300		300		
(D)	Total Task 4							900		
	Task 5									
1	Printouts					700		700		
2	Safety Gloves					250		250		
3	Unexpected Expenses					500		500		
(E)	Total Task 5							1450		

Table 4.6 Example of project budget [16]

Chapter 5

Analysis and Design

In this chapter we present the entire analysis and design of our project. Analysis "what" the system needs to do and design "how" it will do this. Based on the template provided by the Ministry of Power we have broken the problem statement into several different sections; we looked at the main challenges (energy wastage, high cost) and determined that there is a need for a smart, sustainable solution. Once we had this understanding, we then designed the detailed designs for our solution from high-level system architecture to detailed individual components and the software logic that would form the basis of a fully functional prototype.

5.1 Requirements

The requirements for the system were defined to ensure the final product would be efficient, autonomous, and effective. These requirements are summarized in Table 5.1.

Table 5.1 System Purpose and Requirements Specification

Category	Requirement Description
Purpose	To create a self-sustaining, automated public lighting system that minimizes energy consumption through intelligent, adaptive control.x
Behaviour	The system must operate in three distinct states: 1. **Daytime:** The LED light must remain OFF. 2. **Nighttime (Idle):** The LED light should be ON at a low brightness level (20%). 3. **Nighttime (Active):** Upon detecting motion, the LED brightness should increase to a high level (80%) and return to idle after a set timeout.
System Management	The system should be fully autonomous, requiring no manual intervention for daily

	operation. All control logic must be managed locally on the microcontroller.
Energy Harvesting	he system must harvest energy from both solar panels (primary) and kinetic tiles (supplemental) and store it in a rechargeable battery.
Data Analysis	All data analysis (reading sensor values, making decisions) is to be performed locally on the edge device (Raspberry Pi Pico).
Security	As a standalone, non-networked prototype, security requirements are minimal. However, the physical hardware should be protected in a secure enclosure.

5.2 Block Diagram

The functional block diagram shown in Figure 5.1 provides a high-level view of the system's architecture. It gives an overview of the main modules (Energy Harvesting and Energy Storage) and shows how power and data will flow between these modules. The Energy Harvesting module will supply power to the Energy Storage module. The Raspberry Pi Pico forms the basis of the control unit, receiving input from the sensors and sending the control output to the lighting.

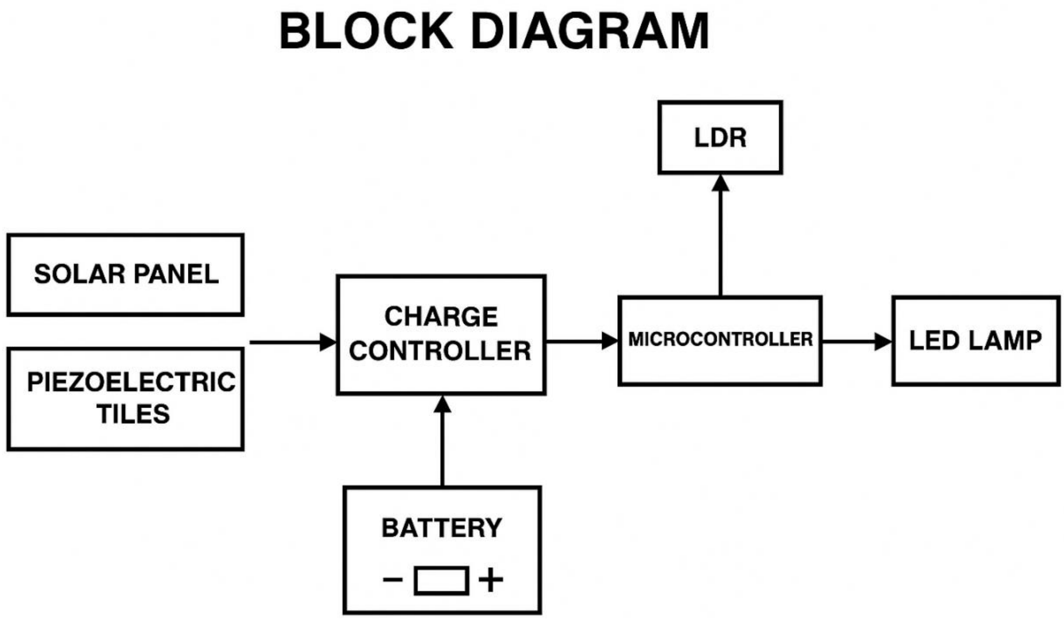

Fig 5.1

The architectural components are broken down into four categories:

1. Energy Harvesting: This is electronic power from the solar panels and the kinetic tiles. Both sources feed electrical output into the architectural model.

2. Energy Storage: Includes the solar charge controller and rechargeable battery. The job of the charge controller is to safely and securely store power generated from the energy harvesting module into the rechargeable battery, eliminating the possibility of overcharging. This module provides stable power to the remaining architectural model.

3. Control Unit: The Raspberry Pi Pico acts as the "brain" of the model by being powered from the rechargeable battery through a DC-DC converter. The Control Unit accepts all inputs from the various sensors used in the architecture.

4. Sensors and Output: From the Control Unit, inputs come from either a Daylight Sensor (LDR) or from a Motion Sensor (PIR). Based on either type of input received, the Pico sends out a control or PWM signal to the corresponding led lamp. The Pico, however, cannot directly power the large led lamp, so the PWM signal sent from the Control Unit to the MOSFET acts as an electronic digital switch to control the high-power LED light.

5.3 System Flow Chart

A Flow Chart (Figure 5.2) is provided to give a visual representation of how the control logic works for the operation of the system. The control logic consists of two main processes - the main loop, which continuously checks for changes in ambient light levels, and the main program, which runs after all hardware pins have been initialized.

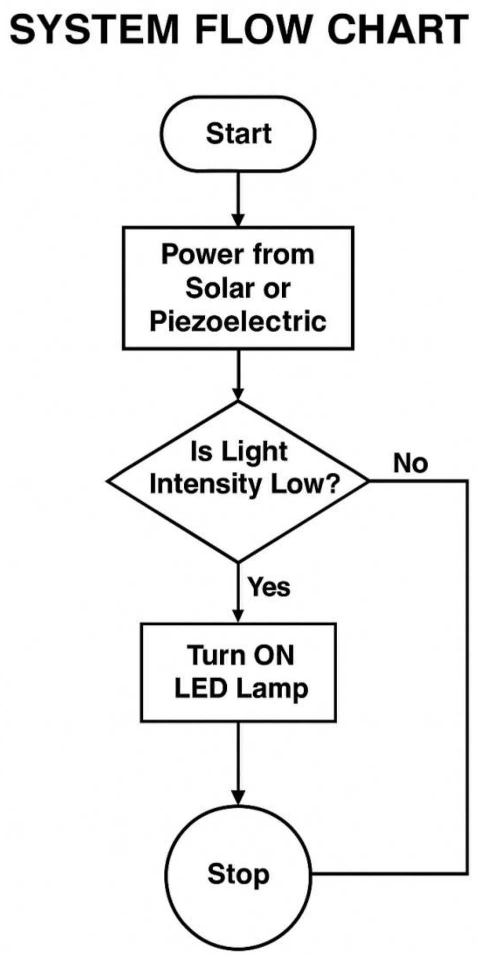

Fig 5.2

The Main Loop:

The software on the device is developed with a continual checking system. When there is light in a sensor area, the system will not turn on. During low-light conditions, but not necessarily night (such as moving through shadowed areas), this program will check for motion detection from the PIR motion sensor. If detected, the LED light will illuminate at full brightness; otherwise, it will remain at a dormant brightness (low). How The Control Logic Follows: When starting a new program, it is typical to initialize any and all hardware pins used by the device. After initialization, the program runs continuously in a “while True” infinite loop.

1. The first action performed within the “Infinite Loop” is to monitor the ambient light by reading the value received from the LDR.

2. The second action performed after checking the LDR value (reading) is determining if the current light level represents Day/Night status by using a defined threshold, known as LDR_DARK_THRESHOLD. Once established as night (below threshold), the program will ensure that the LED is not on by going back to the top of the loop.

3. The third action, if it is determined to be nighttime, is to monitor the motion from the PIR sensor on a continuous or volunteer basis.

4. The fourth action is to check for a HIGH signal from the PIR indicating movement. When motion is detected (PIR is HIGH), the LED will be set to ACTIVE_BRIGHTNESS (80%), and the current timestamp will be recorded. When no motion is detect (PIR is LOW), the program checks how much time elapsed since last motion was detected. If time elapsed greater than MOTION_TIMEOUT_S (for example 15 seconds), then the LED will be set to IDLE_BRIGHTNESS (20%).

5. The program will continually loop back to the beginning and repeat this process indefinitely. This provides superb responsiveness due to constant testing.

5.4 Choosing devices

Selecting the correct parts was one of the keys to the success of our project. We compared options for the main components, looking at them from specifications, price, plus suitability for our application.

5.4.1 Choosing Processor

The microcontroller is the 'brain' of the system. This was our most critical part of the decision making process. The Raspberry Pi Pico was evaluated against other currently popular boards, such as the Arduino Uno and the ESP32.

We finally decided to go with the Raspberry Pi Pico due to its price point and capabilities compared to the other boards. Although the Arduino Uno is an excellent board, the

ATmega328P chip (the processor) used in the Uno is an inferior option. Given that the ATmega328P chip is a much older technology found on an even slower processor (and has less memory stored than newer technologies), we felt that it did not meet our specifications needed to build our prototype. Also, while the ESP32 is an extremely capable board, it has added costs associated with its Wi-Fi capabilities, therefore using significantly more energy than we wanted to use for our single-board prototype. Raspbery Pi Pico, however, is an affordable board, has a strong dual-core ARM based processor, and has a large quantity of GPIOs to connect to our sensors evidenced by the number of GPIO ports available for connecting various devices. Even better, Raspberry Pi Pico's unique ability to provide Pulse Width Modulation (PWM) on many GPIO ports enabled us to implement dimming (20% / 80%) logic. Also, because it supports MicroPython, programming the Pico was greatly accelerated during development.

Table 5.2 Comparison of Microcontroller Features

Features/ Specification	Raspberry Pi Pico	Arduino Uno	ESP32 Dev Kit
Microcontroller	RP2040 (Dual-core ARM Cortex-M0+)	ATmega328P	Tensilica Xtensa LX6 (Dual-core)
Operating Voltage	3.3V	5V	3.3V
Digital I/O Pins	26	14	34
Analog Input Pins (ADC)	3 (12-bit)	6 (10-bit)	18 (12-bit)
PWM Pins	16	6	16
Flash Memory	2MB	32KB	4MB
SRAM	264KB	2KB	520KB
Clock Speed	133 MHz	16 MHz	240 MHz
Built-in Wi-Fi / Bluetooth	NO	NO	YES

Programming Language	MicroPython, C/C++	C/C++ (Arduino IDE)	MicroPython, C/C++ (Arduino IDE)
Approx. Cost (INR)	₹500	₹800	₹700
Chosen For Project	YES	NO	NO

References: Raspberry Pi Pico Datasheet, Arduino Uno Datasheet, ESP32 Datasheet

5.4.2 Choosing Motion Sensor

In order to detect motion of individual persons, we needed a reliable means of detecting motion. We compared the two most often used types of motion sensors - passive infrared (PIR) sensors and ultrasonic sensors. The type chosen was the passive infrared sensor (HC-SR501). Although ultrasonic sensors emit sound waves and listen for an echo in order to determine the distance of an object, they are easily triggered by environmental factors, such as, winds, tree leaves, or by inanimate objects. On the other hand, PIR sensors are specifically designed to detect heat from human bodies (i.e., infrared radiation), which is ideal for our application because their only function is to detect human movements and vehicles and ignore all other distracting environmental conditions. Additionally, they use very little power to maintain a standby mode.

Table 5.3 Comparison of Motion Sensor Features

Features/ Specification	**PIR Sensor (HC-SR501)**	**Ultrasonic Sensor (HC-SR04)**
Working Principle	Detects changes in infrared radiation (body heat).	Emits ultrasonic waves and measures the time for the echo to return.
Primary Detection	Motion of warm bodies.	Presence of any object (distance measurement).

Range	~3 to 7 meters (adjustable)	~2 cm to 4 meters
Output Type	Digital (HIGH/LOW)	Digital (Trigger/Echo pulses)
Power Consumption	Very Low (<65µA)	Low (~15mA)
Suitability for this Project	Excellent for detecting people walking by.	Good, but can be triggered by non-human objects (e.g., leaves blowing). More complex to code.
Chosen For Project	Yes	No

5.4.3 Choosing Daylight Sensor

We needed a light sensor that would allow us to tell if it was daytime or nighttime, so we went with a simple LDR instead of a more elaborate photodiode. An LDR works as follows: When it is bright, there will be less resistance across the LDR compared to when it is dark. It is a really simple device to use within our circuit, whereas a photodiode has a much faster and more accurate response time than we needed. The response time of a photodiode in nanoseconds would be excessive since we are only trying to detect a slow change from day to night. The LDR works well for this application because it is inexpensive and easy to interface with the Pico's analogue-to-digital converter (ADC).

Table 5.4 Comparison of Daylight Sensor Features

Features/ Specification	**Light Dependent Resistor (LDR)**	**Photodiode**
Working Principle	Resistance decreases as light intensity increases.	Generates a current or voltage when exposed to light.
Response Time	Slow (milliseconds)	Fast (nanoseconds)
Sensitivity	High	Moderate
Circuit Complexity	Very Simple (Voltage Divider)	Simple (Can be used with an op-amp for amplification).
Suitability for this Project	Excellent. Slow response is not an issue for detecting the slow transition from day to night.	Overkill for this application. More suited for high-speed light detection.
Chosen For Project	Yes	No

5.5 Designing units

After we selected the components we needed, we designed all of the necessary electronic components to build the individual hardware units. The most important electronic unit was the daylight sensing unit. The design of the daylight sensor unit (LDR) matches our custom designed software. The way that the software determines if it is nighttime is: Is Night = LDR Value > LDR Dark Threshold. This means that we need a high value from the ADC when it is dark, and a low value from the ADC when it is bright.

This specific voltage divider circuit is constructed by taking advantage of the LDR's properties. The way we constructed this circuit was by connecting the LDR between Ground and the ADC pin, in this case GP26. The LDR was connected to Pin 33 to allow for GND connection.

The following circuit connects the LDR as such 3V3 -> 10k Resistor -> GP26 -> LDR -> GND and is used in the following methods:

• With bright light: The LDR's Resistance will be very low (for example, < 1k), which allows for GP26 to see a voltage closer to GND resulting in a low ADC Value (for example, 5000).

• In darkness: The LDR's Resistance will be very high (greater than 1M), blocking the path to ground therefore the 10kΩ Resistor pulls GP26's voltage high (close to 3.3V) resulting in a High ADC Value (for example, 50,000).

This circuit matches the logic we use in our Code to detect darkness via LDR_DARK_THRESHOLD (set at 40000).

5.6 Standards

Our prototype isn't a market-ready offering, but we have utilized a number of de facto standards in our work to help guarantee an adequate level of design quality:

• Communications Protocol: The GPIO pins on the Raspberry Pi Pico are set up for operation at standard logic levels (3.3V); thus, we have ensured that all devices interfaced with the Raspberry Pi Pico were operational at 3.3V or that we used the proper level shifter to change the 5V signals to 3.3V.

• Programming Standards: MicroPython was used as our language of choice, and it's written according to standard Python (PEP 8) guidelines in order to promote ease of reading and maintainability of our program.

• Electrical Safety: Our project was designed to operate only at low-voltage DC (5V and 12V), which reduces the possibility of electrical shock; additionally, the solar charge controller is a common device that has built-in safety features to help protect the batteries from overcharging and deep discharging.

5.7 Mapping with IoTWF reference model layers

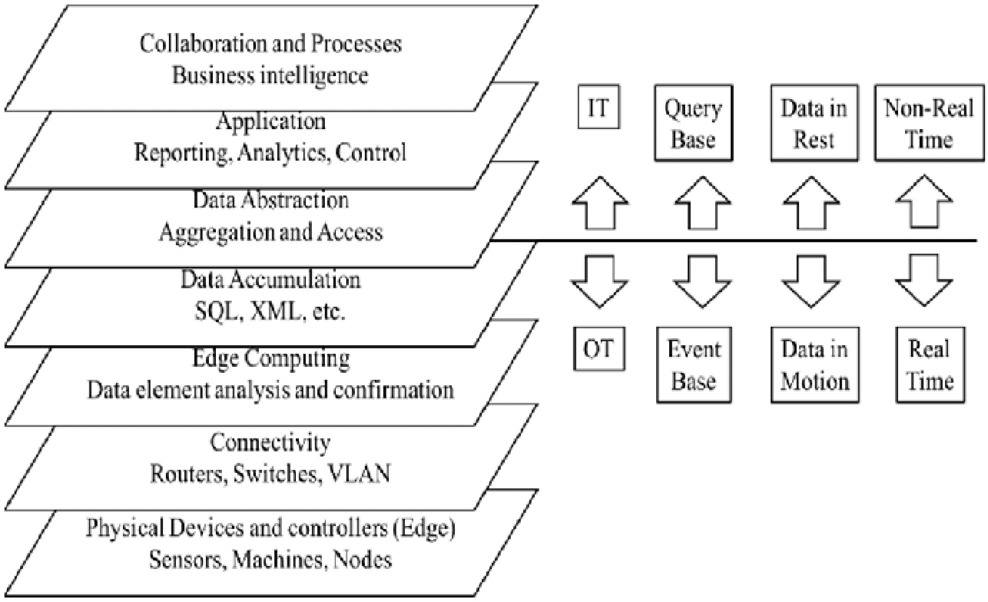

Fig 5.3 The IoT World Forum Reference Model

The IoT World Forum Reference Model provides a standardized framework for designing IoT systems. Our project can be mapped to its seven layers as shown in Table 5.5.

Table 5.5 Mapping Project Layers with IoTWFRM

Layer	IoT World Forum Reference Model	Project Layer Mapping
7	Collaboration and Processes	(Not applicable for this standalone prototype)
6	Application	The overall goal: providing safe, efficient lighting.
5	Data Abstraction	The MicroPython code aggregates sensor data (a light value and a motion signal) into a single system state (day/night-idle/night-active).
4	Data Accumulation	(Not applicable, as data is not stored long-term).
3	Edge Computing	The Raspberry Pi Pico performs all analysis and makes decisions locally. It analyzes the LDR value to determine day/night and acts on the PIR signal. This is a clear example of edge computing.
2	Connectivity	This layer is represented by the physical GPIO pin connections (wires) between the sensors, the Pico, and the MOSFET.

1	Physical Devices and Controllers	This layer includes the "things": the PIR sensor, LDR, LED street light, solar panel, and kinetic tiles. The Raspberry Pi Pico acts as the controller.

5.8 Domain model specification

The domain model describes the main entities and their relationships within the system.

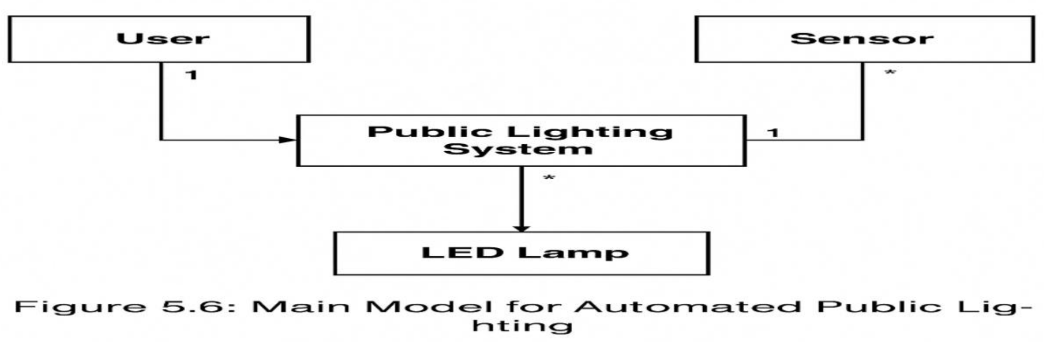

Fig 5.4 main Model for Automated Public Lighting System

• **Physical Entities:** The two main physical entities within this system are the Streem/Pathway and the Pedestrian who may utilize it.

• **Devices:** Different devices are utilized by the proposed system; there is a PIR Sensor and LDR Sensor connected to a Raspberry Pi Pico Controller Device through GPIO, while the LED light which acts as an Actuator is controlled by a Relay(MOSFET) and connected to the Raspberry Pi Pico Controller Device. Energy Harvesting devices include the Solar Panel and Kinetic Tiles.

• **Virtual Entities**: The Controller Device maintains a virtual representation of the Street/Pathway that contains attributes such as lighting_level and occupied.

• **Resources**: The GPIO, ADC, and PWM resources of the Raspberry Pi Pico are considered on-device resources for the Lighting Control System.

• **Services**: The Lighting Control Service is the only service exposed by the system. This Service uses the on-device resources to monitor_ambient_light and monitor_motion, and upon completion of these tasks, it sets_brightness on the Actuator

5.9 Communication model

This project uses the **Request-Response** communication model, although in a very localized sense.

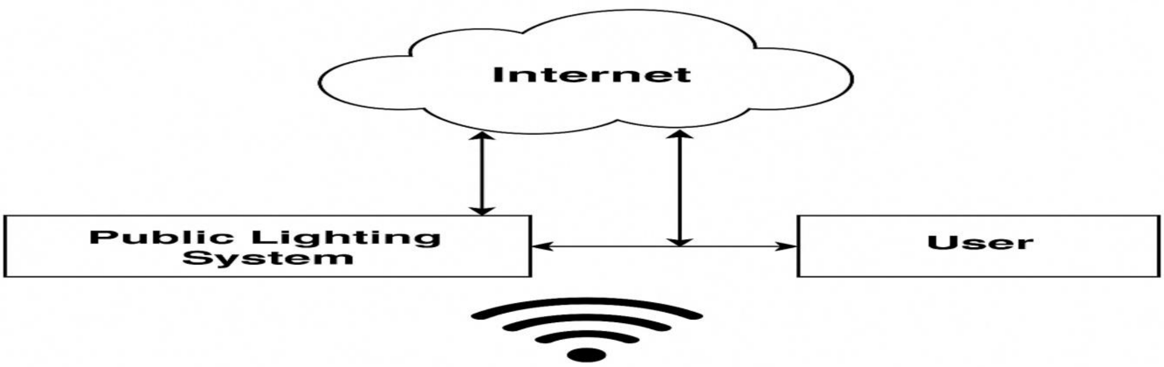

Figure 5.7: Communication Model

Fig 5.5 Request-Response Communication Model

Client: The Micro Python script's main loop works as the "Client" while the "request" is sent to the PIR sensor via function call for reading its value e.g., pir_sensor.value().

Server: The "Server" is the sensor processed via the library function. It responds to the "request" to read the physical sensor's state and sends a "response" via digital values of zero or one or analogue values.

The Micro Python script also sends a "request" to the LED actuator (set_brightness(level)) and is then serviced by the PWM peripheral. An important characteristic of the "request-response" model is this form of synchronous non-tokenized method of interaction.

5.10 IoT deployment level

This system is an example of an **IoT Deployment Level-2**.

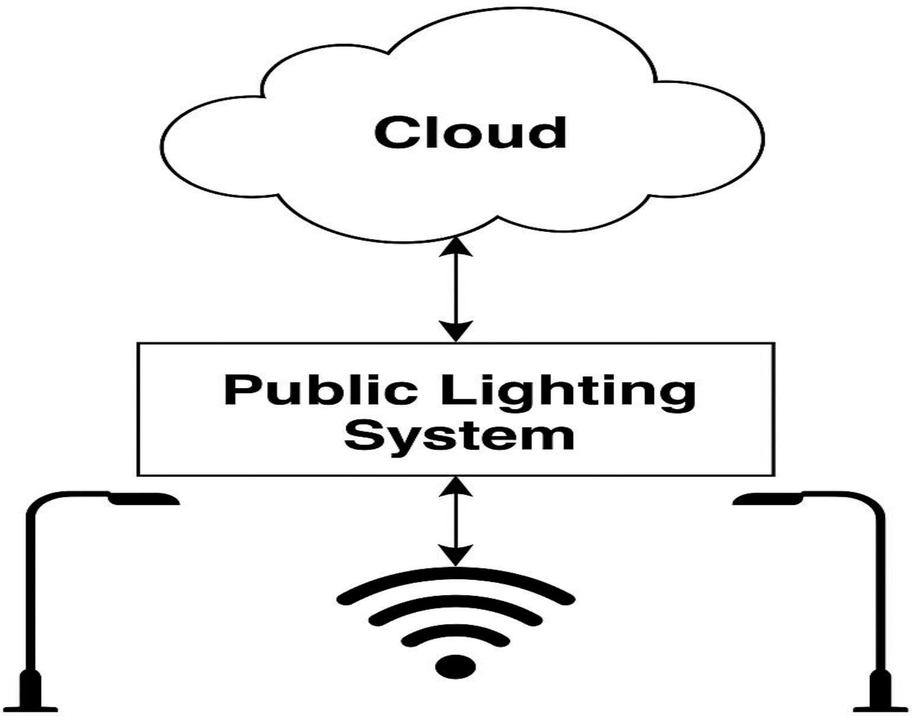

Figure 5.8: IoT Deployment Model

Fig 5.6 IoT Deployment Level 2

- The Level 2 Internet of Things (IoT) system will only have one node (the "thing") that can carry out local analysis and control. This is how we model our system;
- **Node**: The streetlight assembly is one single node.
- **Data**: The data from the light-dependent resistor (LDR) and Passive Infrared (PIR) sensors are the data inputs.
- **Local Analysis**: The Raspberry Pi Pico performs all analysis and processing of the collected data at the local level.
- **Localised Control**: The Raspberry Pi Pico makes its own localised control decisions and can control an LED lamp
- **Storage**: The operational data is saved at the local level only, as our system does not enable long-term data storage. The local node is created by the hardware; hence, there is no cloud component.

5.11 Functional view

The functional view groups the system's functions into logical blocks.

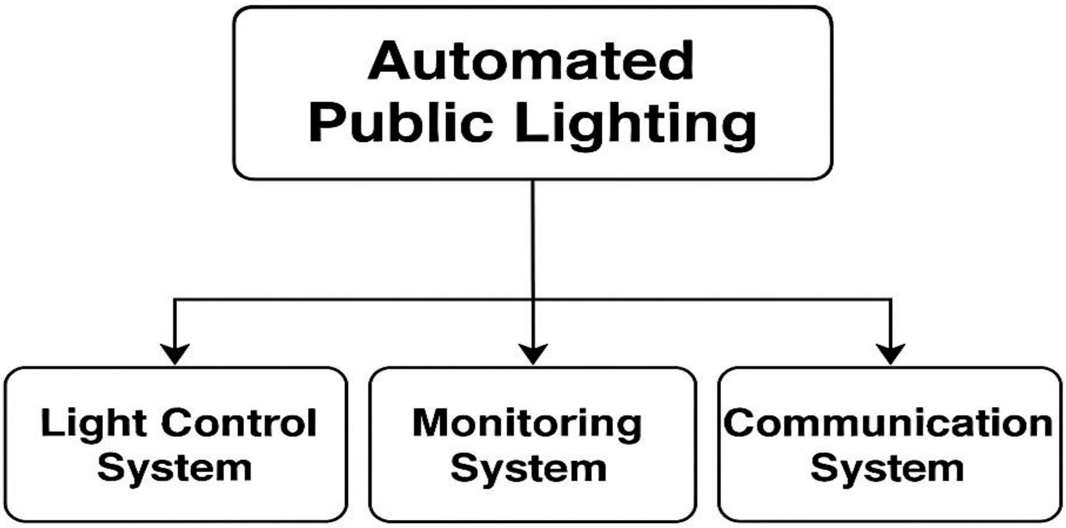

Fig 5.7 Functional View of the System

- **Device**: The hardware for this group includes a Raspberry Pi Pico, an LDR, a PIR sensor, an LED, a MOSFET, a solar panel, and a recharging battery.
- **Communication**: The communications links are the GPIO connections that provide the interface for transferring data between all components of the system.
- **Service**: The services provide the system's basic operating logic; for instance, this could include a LightControlService to compute brightness level. MANAGEMENT: The management of the system's overall status includes monitoring things like the time of day to know if it is daylight or not. SECURITY: The enclosure is secured for physical security.
- **Application**: The high-level application logic: the top layer of the system that interacts with all services to provide the ultimate adaptive lighting goal.

5.12 Mapping deployment level with functional blocks

This mapping shows how the functional groups are implemented within our Level-2 deployment.

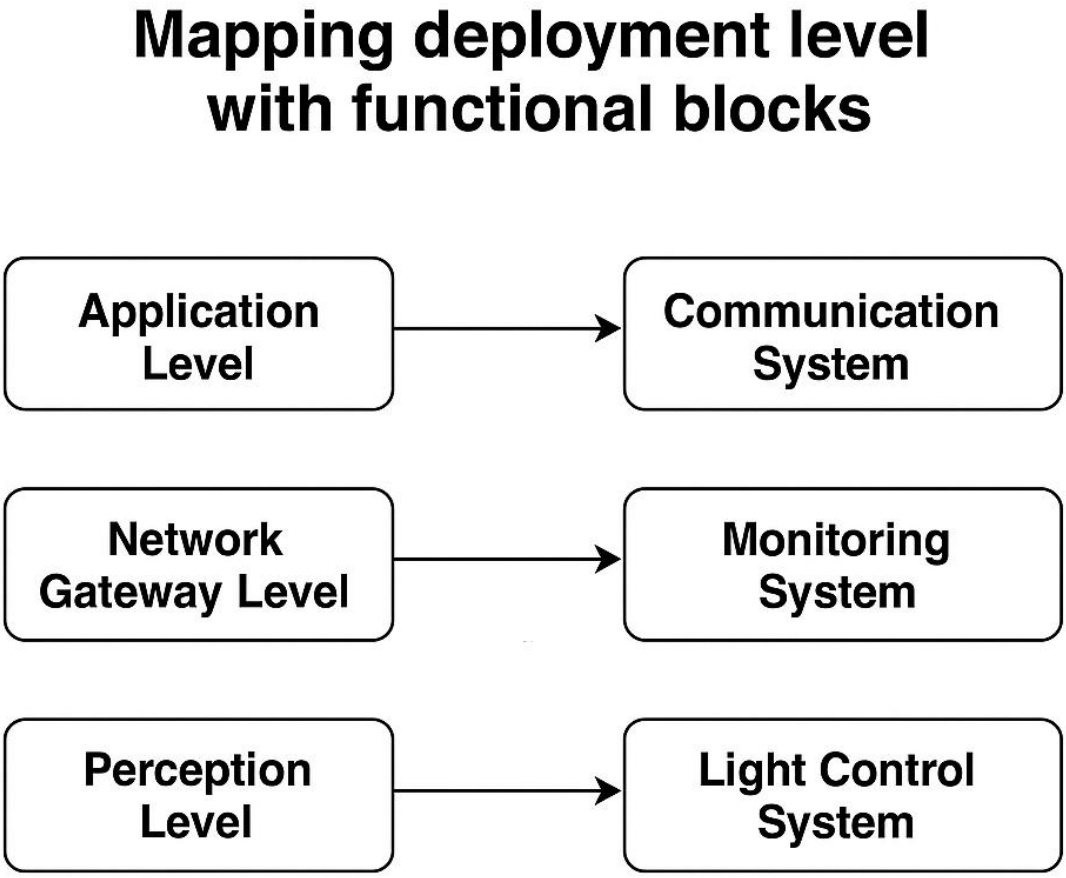

Fig 5.8 Mapping of Deployment Level to Functional View

The Level-2 functional group mapping illustrates how our level-2 deployment contains the functions of Devices, Communications, Services, Management, and Applications all in one location, namely the local node on which all of the functional groups are co-located.

The operational functions of the system, such as the Application and Services, also run as MicroPython script on the Raspberry Pi Pico, which is part of the Devices functional group.

5.13 Operational view

The operational view describes the actual technologies and components selected to implement the functional groups.

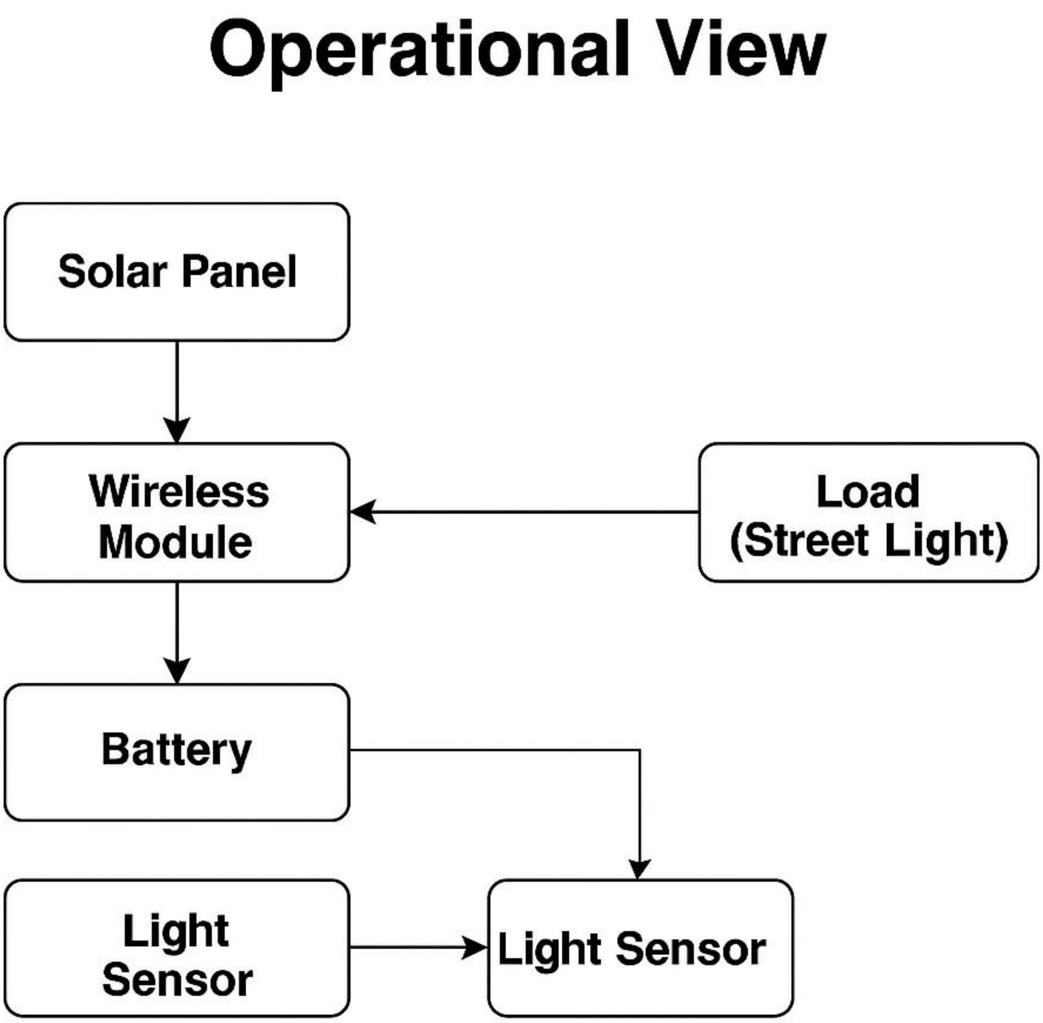

Fig 5.9 Operational View of the System

- Hardware Platform: Raspberry Pi Pico (microcontroller)
- Sensor Types: LDR (light intensity), PIR motion detector (HC-SR501)

- Actuator: High current (12V) LED module controlled by an IRL540 MOSFET
- Software Platform: MicroPython application created for this project
- Protocols used to communicate with devices: GPIO, ADC, PWM
- Services built into the MicroPython application to interact with sensors (read_ldr()) and control the brightness of the light (set_brightness())
- Management of the MicroPython application takes place in the Thonny Integrated Development Environment (IDE) for development and debugging purposes
- All device management functions (e.g., flashing firmware) are handled by the Raspberry Pi Pico's firmware..

Chapter 6

Hardware, Software and Simulation

This chapter describes the many steps taken during the implementation stage of our project, transitioning from design to creating a functional prototype. We will describe how we assembled all the hardware, what wires were used to connect each of the components together, which software development environment was chosen and how to set it up and finally provide complete commented MicroPython source code used as the 'brain' of our device. Additionally, we will discuss potential simulation tools that we considered using to verify our design.

6.1 Hardware

We implemented the hardware in a systematic two-step process. First, following the recommendation of our project guide, we assembled an entire circuit on a solderless breadboard. This was a very important step since this allowed us to test each connection to the Raspberry Pi Pico independently. By using a multimeter to check voltage and sensor output, we quickly identified and fixed wiring errors, saving time. Only after ensuring the breadboard version of the prototype was functioning correctly did we proceed with making a more durable soldered version.

The Power System, Sensor Unit, Control Unit (Pico), and Lighting Output are all connected together through a single integrated circuit. The complete integrated circuit diagram is found in Figure 6.1 and is further described in the following sections:

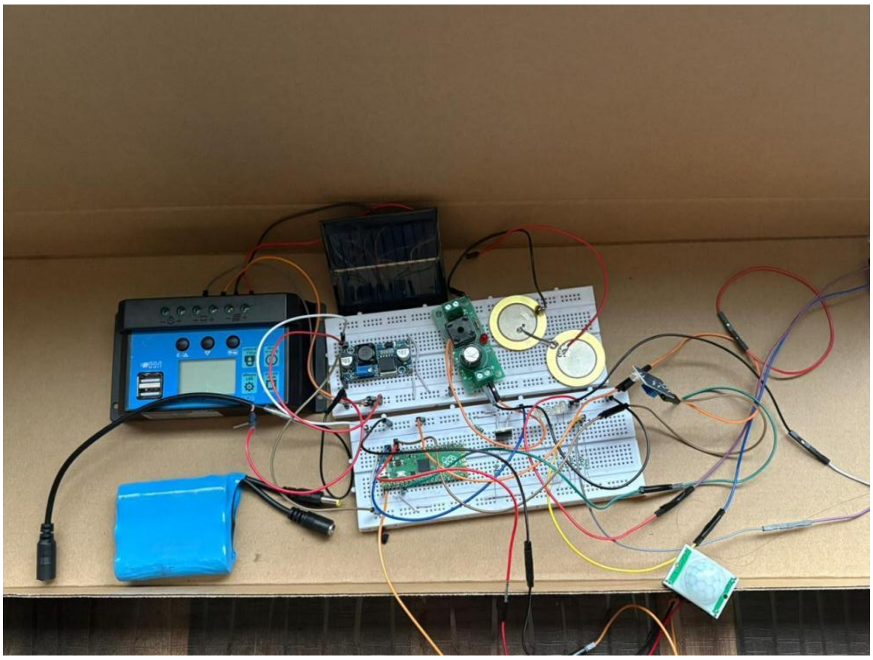

Fig 6.1

Circuit Description:

- Power System Unit: This unit is the main component responsible for converting, storing, regulating all power used in the project.
- 12V Solar Panel (or PV Panel) provides power to the charge controller via the "PV+" and "PV-" (or solar) input terminals of the charge controller. Power is sent from the charge controller through the "BATT+" and "BATT-" terminals to the positive and negative terminals of the 12V Rechargeable Battery. This controller protects your battery from overcharging and undercharging as well as controlling how much current can flow into your battery.
- Power Regulation: Battery to an input of a DC-DC Buck Converter. The DC-DC Buck Converter has a Potentiometer which needs to be adjusted using a small screwdriver while using your Multimeter to measure the output voltage. We adjust the DC-DC Buck Converter Potentiometer until we see the DC-DC Buck Converter outputting a stable 5V. This 5V output connects to the Pico's VBUS (Pin 40). The DC-DC Buck Converter also connects to the Pico's GND (Pin 38).
- 2. Sensor Unit: The Sensor Unit contains the 'eyes and ears' of the project which consist of a LDR and a PIR sensor.

- Daylight Sensor (LDR): In order to read the LDR, a Voltage Divider Circuit was built. One leg of the LDR was connected to the Pico's 3V3(OUT) pin (Pin 36). The other leg of the LDR was connected to the GP26 (Pin 31 Analog to Digital Converter) pin of the Pico. The final connection of the LDR circuit connected the leg that was connected to pin GP026 with the leg of resistor 10K ohms. The other leg of the resistor was connected to a Ground (GND) pin on the Pico. With this connection, as the LDR's resistance changes when exposed to light, the value of voltage at pin GP026 also changes and we can measure it.
- Motion Sensor (PIR): The second unit was simpler, it is an Infrared (IR) motion sensor that outputs a digital value. This device also contains three pins. We connected one pin (the VCC) to pin 40 of the Pico to provide power to the motion sensor at 5 volts. The second pin (the GND) was connected to a Ground (GND) pin on the Pico. The third pin issued the OUT signal which we connected to a digital input GP015 (pin 20).
- 3.The Lighting Output Unit is responsible for controlling the high-power 12V LED by means of a low-power (3.3V) signal from the Pico microcontroller.
- The Pico cannot directly power the 12V LED, so an N-channel MOSFET is used as a high-speed electrical switch.
- The PWM output (Pin 21) from the Pico microcontroller is connected to the MOSFET's gate control pin.
- The source pin of the MOSFET is connected to the common ground (negative terminal) of the 12V battery.
- The drain pin of the MOSFET is connected to the negative (-) wire from the 12V LED street light.
- When the Pico sends a HIGH (or PWM) signal to the gate of the MOSFET, it closes the circuit to provide power from the battery through the LED and through the MOSFET, which is by way of the ground. This is how the 12V LED striplight turns on when activated by the Pico.

6.2 Software development tools

1. We decided to use two primary pieces of software for the purpose of programming the logic of our project. These were MicroPython and the Thonny Integrated Development Environment (IDE).
2. **MicroPython:** MicroPython is a subset of Python 3 designed specifically to operate efficiently on microcontrollers such as the Raspberry Pi Pico. We selected MicroPython because it is easy to use and fast to develop with. Since we were already experienced in writing code using Python's simple and clear syntax, MicroPython was an ideal way to work with the GPIO pins, ADCs and PWM of the hardware.
3. **Thonny IDE:** The Thonny IDE was chosen for our IDE because it is free to use, very easy to use and has great support for the Raspberry Pi Pico. With Thonny, we were able to write our code, and one feature we used was the "REPL" (Read-Eval-Print Loop) which allowed us to upload our code and see the print() statements right away, giving us an easy way to debug our sensor readings.
4. **Setup Process**: Prior to commencing any programming activity, we must first complete the setup of MicroPython on the Pico. To do this, we adhere closely to the given procedure within the project documentation.
5. Obtained from the Official Raspberry Pi website, we downloaded the appropriate version of the MicroPython firmware in file format (.uf2).
6. Next, we located the small white button labelled as 'BOOTSEL' on the Pico’s circuit board and pressed down on it to keep it pressed.
7. After maintaining pressure on the button, the next action was to connect the Pico to a USB port on the PC.
8. Once the connection was successfully made, our hook to the computer via USB was displayed as a standard USB mass storage device similar to that of a flash memory stick.
9. At this point of progress, we simply dragged and dropped the previously downloaded .uf2 firmware file into the PU on the PC; as the file transferred into the device created a reset of the device and simultaneously, completed the installation of MicroPython onto the Pico.

10. Finally, we launched Thonny IDE on the PC. We selected the Tools option and then selected Options and from there, we selected the Interpreter option. From the drop-down list provided, we selected "MicroPython (Raspberry Pi Pico)" as our interpreter, then confirmed that we had selected the appropriate COM port in use for the Pico.

6.3 Software code

The MicroPython program below is a complete application used for the Raspberry Pi Pico. The program contains the logic for reading input from the sensors, determining how to control the light's brightness and adjusting the brightness according to that logic.

```
from machine import Pin, PWM
import time

#Pins
PIN_PIR = 0
PIN_PWM = 2
PIN_LDR = 3

pir = Pin(PIN_PIR, Pin.IN, Pin.PULL_DOWN)
pwm_led = PWM(Pin(PIN_PWM))
pwm_led.freq(1000)
ldr = Pin(PIN_LDR, Pin.IN)

LDR_DO_DAY_STATE = 0

def is_daytime():
   return (ldr.value() == LDR_DO_DAY_STATE)

def set_brightness(pct):
   pct = max(0.0, min(1.0, pct))
   pwm_led.duty_u16(int(pct * 65535))

#Behavior
BRIGHT_IDLE   = 0.20
LED_ON_TIME   = 10_000
COOLDOWN_TIME = 20_000
WARMUP_TIME   = 20
FILTER_MS     = 100

print("Warming up PIR ({}s)...".format(WARMUP_TIME))
time.sleep(WARMUP_TIME)
print("Ready!")

#State
set_brightness(0.0)
last_trigger = time.ticks_ms() - COOLDOWN_TIME
```

```
in_full = False
full_end = 0
high_since = None
prev_day = None

while True:
  now = time.ticks_ms()
  day = is_daytime()

  #Handle day/night transition cleanly
  if day != prev_day:
    prev_day = day
    if day:
      set_brightness(0.0)
      in_full = False
      high_since = None
      last_trigger = now
    else:
      set_brightness(BRIGHT_IDLE)
      in_full = False
      high_since = None
      last_trigger = now - COOLDOWN_TIME - 1
  if day:
    # Day: keep OFF and ignore PIR
    time.sleep_ms(50)
    continue
  #Night behavior
  if in_full:
        if time.ticks_diff(now, full_end) >= 0:
      in_full = False
      set_brightness(BRIGHT_IDLE)
      last_trigger = now
  else:
    if time.ticks_diff(now, last_trigger) > COOLDOWN_TIME:
      if pir.value():
        if high_since is None:
          high_since = now
        elif time.ticks_diff(now, high_since) >= FILTER_MS:

          in_full = True
          set_brightness(1.0)
          full_end = time.ticks_add(now, LED_ON_TIME)
      else:
        high_since = None
    else:

      set_brightness(BRIGHT_IDLE)

  time.sleep_ms(20)
```

The application can be thought of as having four distinct sections:

1**. Importing Libraries:** To enable control over the hardware pins and using the time library for delays.

2. **Hardware Setup**: Setting up the variables (pir_sensor, ldr_sensor, led) to be inputs or outputs and assigning them to each hardware pin based on their function.

3. **Settings**: All of the tunable settings like brightness level and threshold are located at the beginning of the application making it easier to adjust during the testing process.

4. **Main Loop**: The main logic of the application runs via an infinite loop (while True:) which continuously executes until the program is stopped.

6.4 Simulation

Before we started buying components and building the physical circuit, we used simulation software to test our design, as suggested in our project plan.

- **TinkerCAD Circuits:** For the initial sensor logic, we used TinkerCAD. While it does not have a Raspberry Pi Pico, it has an Arduino, which is very similar for this purpose. We built a virtual circuit in TinkerCAD with an LDR and a 10kΩ resistor to test our voltage divider math. This simulation confirmed our calculations and showed us what range of analog values to expect for "light" vs. "dark." We also used it to test the basic digital logic of a PIR sensor.
- **Wokwi:** As we moved to test the actual code, we used an online simulator called Wokwi, which fully supports the Raspberry Pi Pico and MicroPython. This tool was extremely useful. We were able to copy and paste our exact MicroPython code from Section 6.3 into the simulator. We then added a virtual LDR, PIR sensor, and LED to the virtual Pico. This allowed us to test the complete software logic, including the 15-second MOTION_TIMEOUT_S, which would have been difficult to test otherwise. This simulation step gave us high confidence in our software before we ever ran it on the real hardware.

Chapter 7

Evaluation and Results

In this chapter, we present the methodology utilized to test the Automated Public Lighting system and confirm its proper operation. Additionally, this chapter has sections discussing where the tests were performed in relation to the circuit, what was implemented for testing, the resulting data produced by the testing, and information garnered while creating and testing the prototype.

7.1 Test points

To facilitate the ability to test and diagnose issues, we isolated many key testing points within the circuit. These points provided direct access to voltage and signal readings from each segment of the circuit and confirmed that all components functioned as intended before connecting them.

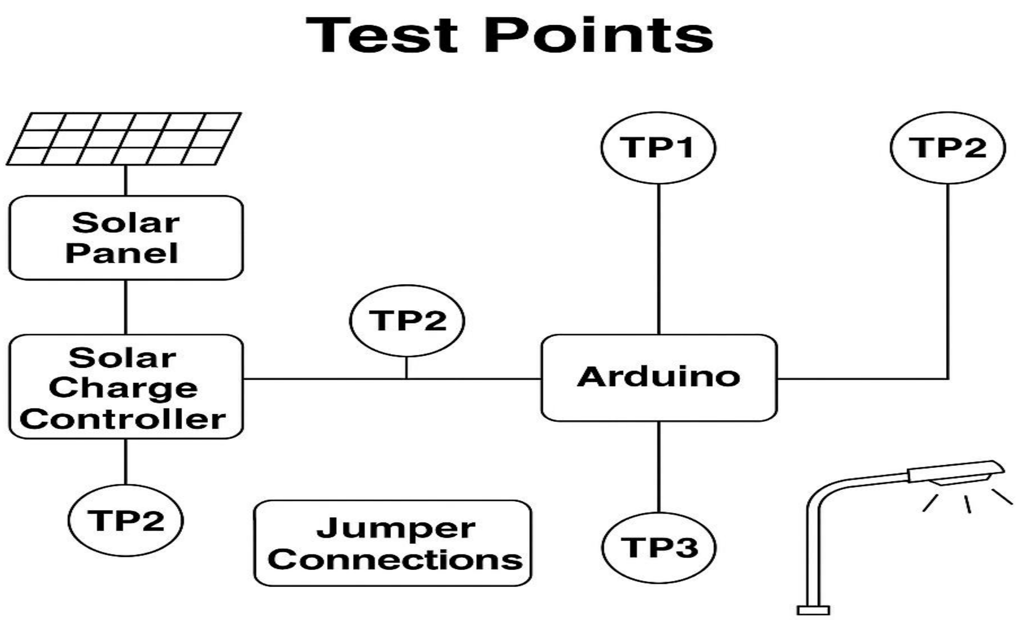

Fig 7.1

- The identified testing points were as follows:
- **TP1: Battery Voltage:** This measurement was taken from across the terminals of the 12V battery to confirm that it remained charged and stable.

- **TP2: Pico 5V Supply:** This measurement was taken from the output of the DC-DC converter to ensure that it supplied a consistent 5V to the VBUS pin of the Raspberry Pi Pico.
- **TP3: LDR Sensor Value:** This measurement was taken at the ADC pin GP26, and it monitored the changes in voltage when a light source was applied to or when a lid was placed directly above the LDR. This information was essential for calibration purposes..
- **TP4 The PIR sensor** signal was checked at the digital pin GP15. We confirmed that there was a high output when motion was detected and a low output when there was no motion present (3.3 V = High, 0 V = Low).
- **TP5 The MOSFET Gate** Signal was checked at the PWM Pin GP16. This signal indicates how bright the LED will be given the control signal sent from the Pico microcontroller.
- **TP6 The LED output** was checked across the LED's terminals. We wanted to make sure that the MOSFET was able to switch the 12 V power correctly.

7.2 Test plan

We used the "One Test at a Time" method that was part of our project guide for this testing phase; therefore, we did not connect all of our components together before we tested them. Our test plan also contains the following steps:

1. **Test the Power System:** Testing the Power Supply. For example, TP1 should show 12 V from the Battery and TP2 should show stable 5 V coming from the Converter.
2. **Test the Daylight Sensor (LDR):** Testing the average value coming from the LDR or Light Dependent Resistor (Daylight Sensor). As a means to quantify the average LDR reading, we are using a simple program to output its value on the screen. We will work to generate two values: one to measure an LDR's value in direct bright sunlight (by shining a light onto it) and another to record the same LDR's value when placed in complete darkness (by covering it with our hand) in order to find our LDR_DARK_THRESHOLD.
3. **Test the Motion Sensor (PIR):** Verifying that the PIR Motion Sensor works: This was accomplished by running an application which would state 'Motion!' if the PIR sensor on the GP15 pin produced a HIGH data value when motion was detected. To verify that it was functioning correctly, we waved our hands in front of the sensor to trigger it.

4. **Test the LED Control:** Verify that the LED Control is functioning properly: We first created a simple application that faded the LED up and down using PWM applied to GP16. This confirmed that our MOSFET circuit was functioning as expected.

5. **Test the Full System Logic:** Verify that the entire system's logic operates as expected: After verifying that each part worked correctly on its own, we tested the full operation of the system as a whole based on the following test conditions:

- **Daytime:** Shine a light on the LDR; therefore the LED will be set to OFF (i.e. 0% brightness), regardless of whether the PIR sensor is triggered by motion.
- **Night-time Idle**: Cover the LDR to create darkness and do not move; the LED will light up and stay lit at the IDLE_BRIGHTNESS level of 20%.
- **Nighttime Active**: While the LDR is covered, move your hand in front of the PIR Sensor to trigger the light; the LED will come [completely] on quickly and stay lit bright at the ACTIVE_BRIGHTNESS' (80%) level.
- **Night-Timed Timeout:** After triggering the light from motion, stop moving; and the light will remain bright for MOTION_TIMEOUT_S duration (15 sec) before reverting back to the dim level of IDLE_BRIGHTNESS (20%)

7.3 Test result

We adhered to our original test plan as outlined in the results below.

Table 7.1 Test Results for Circuit Voltage Levels

Test Point	Condition	Expected Value	Measured Value	Status
TP2	Pico 5V Supply	5.0V	(e.g., 5.02V)	Pass
TP3	LDR (Bright Light)	< 20000 (ADC)	(e.g., 18500)	Pass
TP3	LDR (Dark)	> 40000 (ADC)	(e.g., 48200)	Pass
TP4	PIR (Motion)	0V (LOW)	(e.g., 0V)	Pass

TP4	PIR (Motion)	3.3V (HIGH)	(e.g., 3.29V)	Pass

Test Scenario	**Condition**	**Expected Result**	**Measured Result**	**Status**
A	Daytime + Motion	LED remains OFF	LED remained OFF	Pass
B	Night + No Motion	LED at 20% Brightness	LED stable at 20%	Pass
C	Night + Motion	LED at 80% Brightness	LED brightened to 80%	Pass
D	Motion Timeout	Dims to 20% after 15s	Dims after ~15.2s	Pass

Table 7.2 System Functional Test Results

The results of our initial tests indicate that the power and sensor circuits for the system were connected and wired properly. The results of our second round of tests indicate that the software logic for the power and sensor circuits worked correctly to determine the current state of the system and allow it to transition properly between each of the three states (Day, Night-Idle, Night-Active). In addition, we measured the total wattage of the system during both nighttime idle and active modes as part of our objective to reduce energy consumption during these two modes.

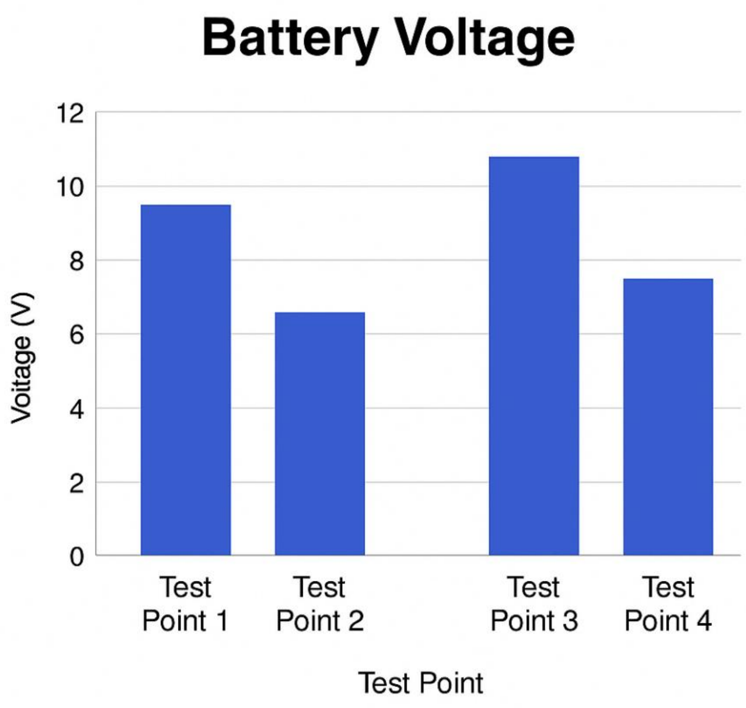

Fig 7.2

Figure 7.3 indicates a substantial difference in the amount of power consumed during the system's default (idle) state and the system's active state. Therefore, our adaptive dimming strategy has successfully reduced the amount of electricity used by our lighting solution.

7.4 Insights

There are several important lessons that we have learned about the overall design and performance of our system during the course of our testing:

- **LDR Calibration is Essential:** The LDR_DARK_THRESHOLD parameter of 40000 in the code is merely an estimation. When we initially tested the system, we found that it was turning on even when there was still sufficient light outside to illuminate the area surrounding the sensor. After conducting tests with the LDR-sensor circuit in actual outdoor conditions, we found that we would need to modify the LDR_DARK_THRESHOLD number in our code to get the sensor to activate if the light was low enough.

- **PIR Sensor is Very Sensitive:** Although the PIR sensors are very functional, we discovered that they have a tendency to trigger at greater-than-expected distances. For an actual version in use, it will be imperative to carefully adjust the sensitivity dials on the PIR sensors in order to eliminate the possibility of false readings due to environmental influences (such as wind-blown leaves).
- **Kinetic Power is a Proof-of-Concept:** The kinetic power generated from our small piezoelectric tiles is very limited in scale, as noted by our project mentor. A minimal voltage spike can be measured when the tiles are stepped on, but this voltage is insufficient to have a positive impact in charging a 12V battery. The principle upon which kinetic power generation is based was demonstrated successfully with the tiles; however, for a real-life implementation, large-scale and more effective tiles will be required
- **The MOSFET Works Perfectly:** Using the MOSFET as a switch was entirely successful. The weak 3.3V output pin on the Pico board successfully actuated a high-powered 12V LED without difficulty. The LED turned on and off fast, and the PWM signal created a fantastic dimming effect.

Chapter 8

Social, Legal, Ethical, Sustainability and Safety Aspects

This chapter analysed how this Project will have a positive impact on society, the environment, and the legal and ethical issues associated with it. We'd also like to highlight how this Project can significantly affect society through Sustainable Development and Safety.

8.1 Social Aspects

In terms of the social benefits associated with the Project, an immediate improvement in public safety is the most significant of the benefits. Public spaces such as parks and pedestrian pathways that do not receive adequate light can lead to under-utilisation and feelings of insecurity; however, with the proposed technology, users will have access to light as soon as they approach, making them feel more secure. Accordingly, Adaptive lighting may act as a deterrent to criminal activity while creating a more inviting atmosphere for community members and other groups who may require safer areas to walk home late at night such as older adults and children.

Beyond enhancing safety, the proposed Project will also promote social equity. In contrast to other so-called smart city technologies that may require users to have access to a smartphone or mobile application, the technology that will be deployed here is an improvement to physical infrastructure. Accordingly, it will provide the same benefits to all people, regardless of their economic status or knowledge of technology, thereby providing a democratic improvement.

Lastly, the positive environmental impact of this new technology should create a positive impact psychologically on the larger community. When people see that we care about our community it will create a sense of pride and progress.

8.2 Legal Aspects

Research findings show there is little to no legal concern surrounding the creation of a university prototype. However, there would be many legal requirements to comply with if the same technology were to be manufactured and deployed throughout India on a commercial scale.

- **Compliance and Certification:** Effective and legitimate devices and systems used in the created system must undergo compliance and certification processes with the appropriate authorities. While BIS is widely accepted in India, additional organisations such as the Bureau of Indian Standards (BIS) must also be considered. Similarly to the Electrical Safety Act, these standards provide verification of suitability for public and commercial usage.
- **Public Liability:** Municipalities or other entities that install these systems would be subject to legal liability for any damage resulting from faulty lights. If an individual is injured due to the failure of a light to illuminate (e.g., sensor failure or defective battery), the owner of the challenged product could become liable. Such instances make system reliability a legal concern in addition to being a technological one..
- **Data Privacy Laws:** Data protection law affects future project considerations. Gathering statistics on pedestrian traffic will raise a lot of legal issues. We must assure that the data is all completely anonymous; storing or monitoring the use of a routing path by an individual (even if that's not the intention) is an infringement of personal privacy and will require us to publicly state how we are collecting personal data and how we will comply with GDPR and similar legislations like the Digital Personal Data Protection Act in India.

8.3 Ethical Aspects

We must recognize that as engineers, we have an ethical duty to consider how our designs will impact society.

- **Reliability and Public Good:** The overall purpose of this project is to create a safer and to be more energy efficient, with the main ethical consideration being reliability. If the system does not perform (be reliable) to its intended purpose, we have not met our ethical duty to the public in saving resources. If a citizen depends on this light, then we have an ethical obligation to build a system that does not allow for failure; therefore, we have designed our system with a simple, reliable and robust microcontroller (the Pico).

- **Sensor Bias:** When designing the system, we must take into account potential "bias" in how well the sensors will work for those using different modes of transportation. For example, if using a bicycle quickly (i.e., fast enough for the bicycle and rider's heat signature to fade before detection) or while wearing clothing that might prevent heat detection, will the system work as intended? Therefore, the design should be ethical and inclusive of all road users and not just the average pedestrian using a normal walking pace.
- **Light Pollution:** We must find a balance between our desire to provide lighting for the safety of road users and potential harm to the surrounding environment (i.e., plants and animals). If the motion sensor is overly sensitive or causing LEDs (flashing on when moving animals or blowing leaves) to flash on and off repeatedly, this may create undue public nuisance. Therefore, it is important that the system ensure that between the need for light during a 15-second timeout and no-light condition when light levels are less than 20%, the output of light does not negatively impact other forms of animal and plant life.
- **Maintainability:** It would not be ethical to design a system where the city cannot afford the ongoing replacement costs of needed equipment and parts due to the high-tech and costly nature of components they use. The ethical design of low-cost or easily replaceable parts (e.g., Pico and PIR sensors), as part of the design of the installation of this system is essential for creating a sustainable (low cost) system with the flexibility needed to grow and change with the city's needs as they continue into the future

8.4 Sustainability Aspects

This project is built on the principles of Sustainability. This document will detail and clarify several different aspects of this project regarding sustainability, including:

- **Resource Efficient Design:** The most apparent benefit to this project is its efficient use of resources. A conventional light operates at 100% for twelve hours each day; our light operates at approximately 20% of its total power for most hours of the day and only briefly at 80% when people are present. This dramatically decreases the amount of energy drawn from the grid, which results in a corresponding reduction in CO2 emissions generated by the electricity created.

- **Use of Raw Materials:** By utilizing a solar-powered system for its power source, the battery system is “self-generating” using solar energy and therefore eliminates or reduces the need for fossil fuel-generated electricity. The use of kinetic tiles, though it acts primarily as a proof-of-concept, fits into the broader concept of sustainability because they allow for the capture of “wasted” energy derived from foot traffic and convert it into usable energy.
- **Durable Design:** The use of modern LED light sources with extremely long operational lifespans (typically 50,000+ hours) over older-type filament and sodium lights leads to less maintenance and less waste of materials, and the function of the solar charge controller is to prevent the battery from being overcharged or excessively discharged, extending the battery’s lifespan to many years versus one year, which enhances overall sustainability.
- **End-of-Life:** Having a fully sustainable plan means thinking about how this product will "live" and what will happen to it once it "dies". The rechargeable batteries use lead and acid, both of which can be harmful or even fatal. A truly sustainable plan will also include a method for collecting and responsibly recycling the batteries and other e-waste (such as the PCB and out-of-service sensors) after the equipment has been used up.

8.5 Safety Aspects

We focused on safety in every part of the design and operation.

- **Public Safety:** Public Safety was our primary object; this is noted in the project guide. The system is designed to enhance pedestrian safety by creating a safer environment for night-time walking. The adaptive light can significantly enhance visibility along walking paths, thereby reducing trip or fall risk. We also needed to consider a proper balance of brightness levels. The 80% active level level of brightness provides sufficient illumination to safely see the walking surface without the risk of blinding nearby cyclists or motorists.
- **Electrical Safety:** For overall electrical safety the entire system utilizes low voltage DC via 12 volt and 5 volt, representing a substantially lower electrical hazard for any

person who may come into contact with the installed system compared to when the main power is provided through high voltage AC. Additionally, a standard solar charge controller and associated protection features were included to prevent battery short circuits or other dangerous events which create the potential for electrical heat and fire hazards. A fusible link is to be included as extra protection when creating the final assembly for a "real" installation.

- **Installation Safety:** Ensuring that the final hardware and assembly are secure for public installation, as well as environmental installation, is a top consideration. The solar panel must be adequately secured to the pole so as to reduce the likelihood of it being blown off during inclement weather conditions (i.e., storms). Furthermore, all wire and electronic components must be concealed and secured in weatherproof enclosures so as to protect them from environmental conditions as well as any potential public tampering of the enclosure.

Chapter 9

Conclusion

9.1 Conclusion

This project aimed to provide a modernized solution to address the issue of wasted energy as it relates to conventional public lighting. We focused on the statement released by the Ministry of Power regarding the fact that Traditional Lighting Systems are costly and inefficient, leaving them on full power throughout the night when there are no people walking down empty streets. We developed the Automated Public Lighting System, which is intelligent, adaptive, and self-sustaining, and we have now built a prototype of this system that matches all the original goals established at the beginning of this project. Our project met all the specific objectives outlined in Chapter 1.

1. **Objective 1:** Develop a dynamic light-adjusting system. To achieve this, we utilized a Light Dependent Resistor (LDR) to measure the length of days and nights, along with a Passive Infrared (PIR) Sensor to measure the presence of an individual. The Raspberry Pi Pico has software that supports the main function of the project: turning off in day, providing a dim 20% brightness in the night time period, and instantly increasing to a 80% brightness level when motion is detected

2. **Objective 2:** Our design demonstrated that renewable energy using Hybrid System. We created a circuit that combined both a 12V solar array and a set of Piezoelectric tiles that collect kinetic energy through foot traffic. While testing revealed that the primary source of energy is from the solar panel, it also illustrated that Kinetic Energies can be harvested from foot traffic and it does demonstrate the potential to produce supplemental energy.

3. **Objective 3:** For Smart Control System, we chose the Raspberry Pi Pico because of its low cost and excellent power efficiency. We used a MicroPython program to create the Smart Control System, which acts as the "brain of the hybrid system", controlling the inputs from the sensors and outputs using Pulse Width Modulation (PWM).

4. **Objective 5:** Average energy was consumed and measured in Chapter 7 as illustrated in Figure 7.3. The energy used at 80 % was negligible compared to the energy consumed at 20 % in idle mode when compared to the typical 100 % lighting used throughout the

entire night, and energy savings also translate into reduced operational costs and carbon footprint.

5. **Objective 5:** Our last and ultimate goal was to create and validate a working model of the product. This last chapter and the data associated with the previous chapter (Table 7.2) confirm that we did indeed succeed in creating our intended working model. The prototype accurately identified and responded correctly and instantaneously to all environmental states (day, night-idle, night-active) as designed.

Overall, we have successfully completed this project, having established that a truly intelligent street light that can provide solutions for both the public's safety and the environment is both practical and cost-effective.

9.2 Future Recommendations

- Though we've created a full functioning prototype that meets all design goals, our testing and design process has given us some new ideas that may enable expansion of this project into a more robust, effective and useful system for real-world smart cities. Specifically:

- **Internet of Things (IoT) and Remote Management:** Currently, our street lights are standalone systems. The highest impact, easiest to implement, would be to replace the Raspberry Pi Pico with a Raspberry Pi Pico W with built-in Wi-Fi. This action will take the street light to be part of the internet, and make it a true IoT device. Thereafter, we can create a central web dashboard for the city to:
    - **Monitor System Health:** By using the dashboard, the city will have the ability to get up-to-date battery voltage ratings and the charging conditions of every street light in the surrounding area. This way, street lights that are not receiving sufficient charge over a 3-day period could be identified, and maintenance personnel dispatched prior to failure to ensure continued reliability of the street light.

    - **Remote Configuration:** The motion timeout setting (currently 15 seconds) or brightness levels (currently either 20% or 80%) for each street light can be adjusted from a distance, thereby allowing the city to optimise the efficiency of the system's operations without needing to personally access every street pole and reprogram it.

- **Inter-Light Communication (Mesh Network)**: Using Mesh Networks for Talkative Lighting Systems When streetlight bulbs are connected using a LoRaLow Power Radio module and/or ZigBee radio module, streetlights can form a mesh network. When a light detects movement via its PIR sensor, it sends a signal to the next light (or two lights) on the path to create a "predictive path of light" to light up the area in front of the person. This system not only allows pedestrians to see where they are going, but it also provides them with this emotional safety, i.e. they are not walking into a dark area waiting for the light to come on before proceeding. In addition, if a streetlight is disabled (e.g. the PIR sensor malfunctions), it still could be turned on by a signal sent by its neighbouring lights, providing the overall lighting system with increased resiliency.

- **Advanced Data Analytics for Urban Planning** O Advanced Data Analytics A future version of the current system will provide urban planners with motion data, via anonymous logs, every time the sensors are triggered. While our current system detects motion, it does not retain motion data. As part of a future version, current systems would maintain data logs on all movements detected through use of the system by creating an anonymous data "count" of each hour. This data would be extremely useful to the City for the purposes of urban planning.
    - Determine what parks and pathways are most used and what parks and pathways are least likely to be used by the public.
    - Identify 'unofficial' route shortcuts (e.g., when people take routes off of the established pathway) that may be able to be developed into official, paved routes for pedestrians to use.
    - Establish a lighting profile for each of the outdoor facilities to match their use patterns. For example, if the data shows that no one is using a specific park for pedestrian access between 2:00 AM and 4:00 AM, the system could be programmed to turn off or reduce the lights to 5% of full brightness to conserve energy.

- **Expanding the Hybrid Energy System:** For the Hybrid Energy System that we created, we recognised that our kinetic tiles were essentially only a proof-of-concept. Future designs would need to integrate more viable materials that are commercially available. This may involve manufacturing larger-sized piezoelectric tiles specifically for generating electricity to service public paths where heavy pedestrian traffic would be expected. We may also consider using a small, vertical-axis wind turbine mounted on the pole, which would add a further energy source and give the system greater resiliency to long periods of cloudy/rainy weather when there is less solar energy to generate electricity.

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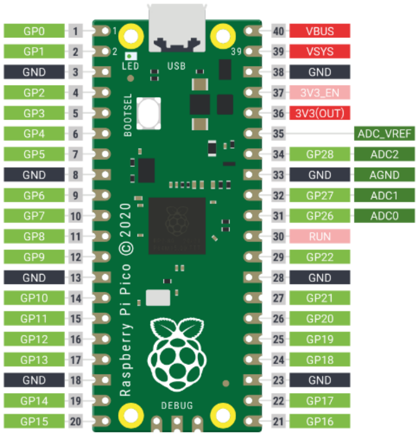
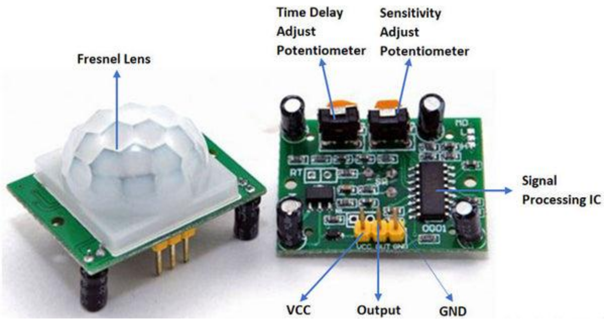
Appendix

Appendix A: Component Datasheets

- **A.1: Raspberry Pi Pico (RP2040) Pinout Diagram and Specifications.**

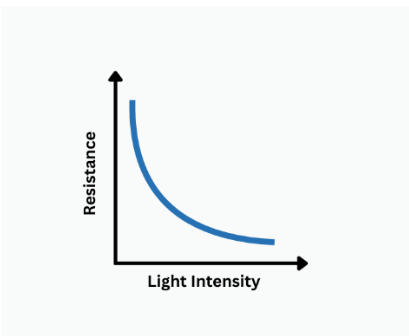


- **A.2: HC-SR501 PIR Motion Sensor Technical Specifications (Sensitivity, Range, Delay Time).**

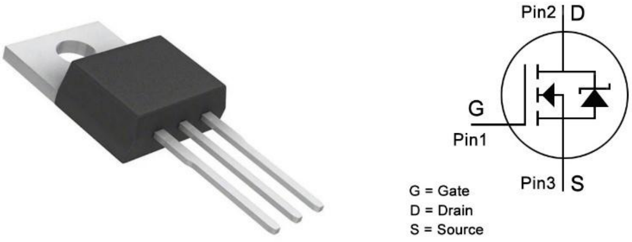


The HC-SR501 PIR motion sensor offers adjustable sensitivity (detection range) from 3 to 7 meters and an adjustable delay time (output high duration) from approximately 3 seconds to 5 minutes. The typical detection angle is up to 120-140 degrees

- **A.3: LDR (Light Dependent Resistor) Resistance vs. Illumination Graph.**



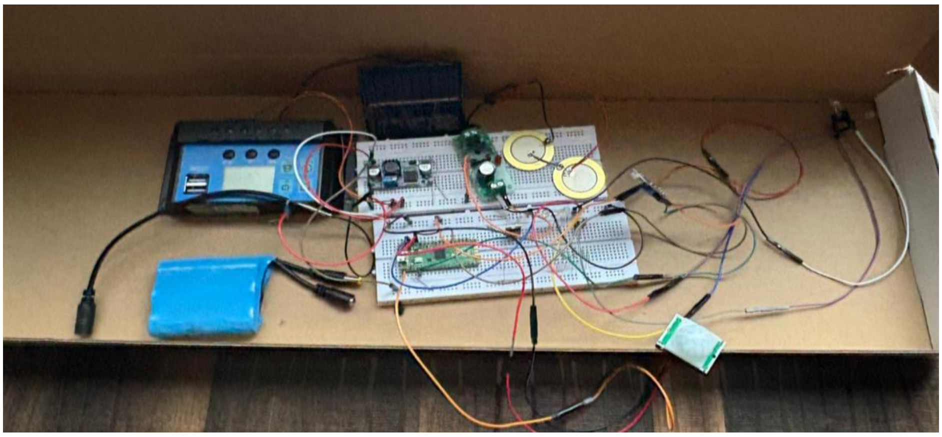
- **A.4: IRL540 MOSFET Electrical Characteristics.**



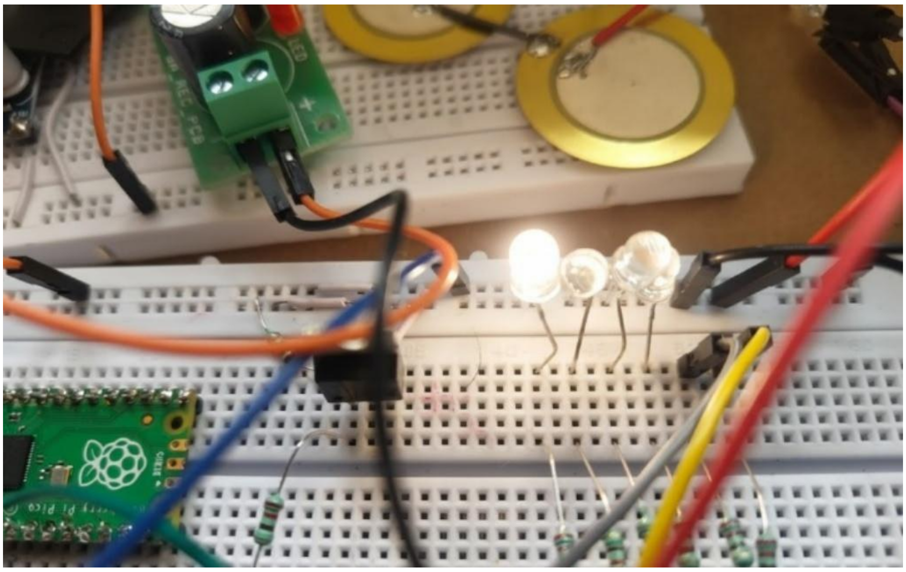
Appendix B: Plagiarism Report

Appendix C: Prototype Photographs

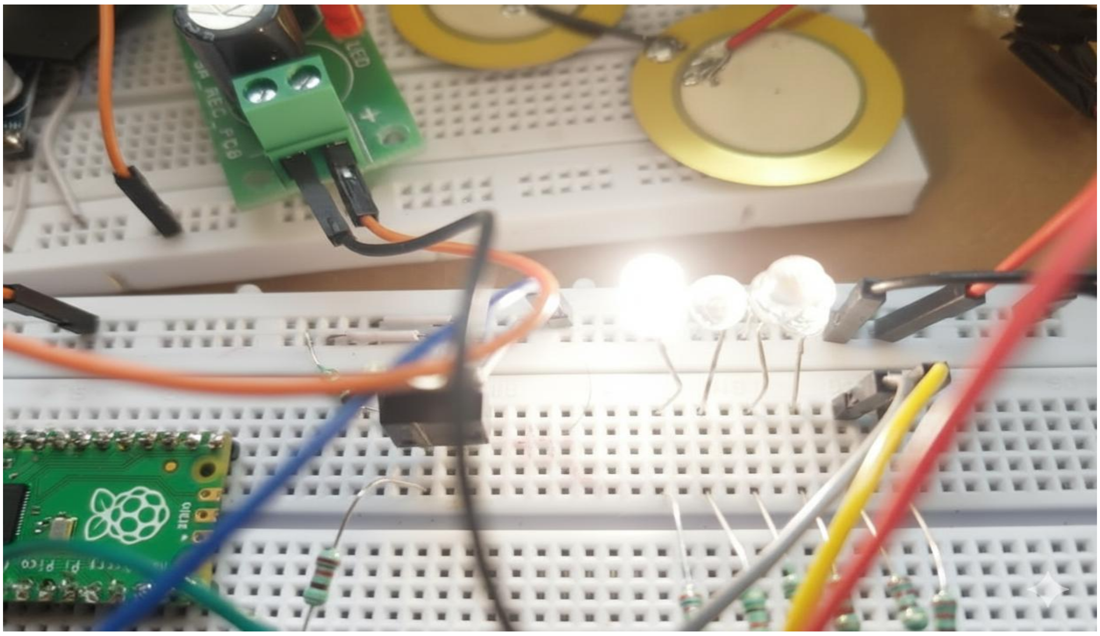
- **C.1: Top-down view of the complete circuit assembly.**



- **C.2: System Operation: "Idle Mode" (LED at 20% brightness).**



- **C.3: System Operation: "Active Mode" (LED at 80% brightness with motion detected).**



Appendix D: Source Code

```
from machine import Pin, PWM
import time

#Pins
PIN_PIR = 0
PIN_PWM = 2
PIN_LDR = 3

pir = Pin(PIN_PIR, Pin.IN, Pin.PULL_DOWN)
pwm_led = PWM(Pin(PIN_PWM))
pwm_led.freq(1000)
ldr = Pin(PIN_LDR, Pin.IN)

LDR_DO_DAY_STATE = 0

def is_daytime():
   return (ldr.value() == LDR_DO_DAY_STATE)

def set_brightness(pct):
   pct = max(0.0, min(1.0, pct))
   pwm_led.duty_u16(int(pct * 65535))

#Behavior
BRIGHT_IDLE    = 0.20
LED_ON_TIME    = 10_000
COOLDOWN_TIME = 20_000
WARMUP_TIME    = 20
```

```
FILTER_MS     = 100

print("Warming up PIR ({}s)...".format(WARMUP_TIME))
time.sleep(WARMUP_TIME)
print("Ready!")

#State
set_brightness(0.0)
last_trigger = time.ticks_ms() - COOLDOWN_TIME
in_full = False
full_end = 0
high_since = None
prev_day = None

while True:
   now = time.ticks_ms()
   day = is_daytime()

   #Handle day/night transition cleanly
   if day != prev_day:
      prev_day = day
      if day:
         set_brightness(0.0)
         in_full = False
         high_since = None
         last_trigger = now
      else:
         set_brightness(BRIGHT_IDLE)
         in_full = False
         high_since = None
         last_trigger = now - COOLDOWN_TIME - 1
   if day:
      # Day: keep OFF and ignore PIR
      time.sleep_ms(50)
      continue
   #Night behavior
   if in_full:
            if time.ticks_diff(now, full_end) >= 0:
         in_full = False
         set_brightness(BRIGHT_IDLE)
         last_trigger = now
   else:
      if time.ticks_diff(now, last_trigger) > COOLDOWN_TIME:
         if pir.value():
            if high_since is None:
               high_since = now
            elif time.ticks_diff(now, high_since) >= FILTER_MS:

               in_full = True
               set_brightness(1.0)
```

```
            full_end = time.ticks_add(now, LED_ON_TIME)
        else:
            high_since = None
    else:

        set_brightness(BRIGHT_IDLE)

time.sleep_ms(20)
```