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Smart City

Master in Industrial Electronics and Computers Engineering
Embedded Systems

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Acronyms

AI Artificial Intelligence

API Application Programming Interface

CPS Cyber-Physical System

CSI Camera Serial Interface

GPIO General Purpose Input/ Output

GUI Graphical User Interface

HPS High Pressure Sodium

IoT Internet of Things

LED Light-Emitting Diode

PWM Pulse Width Modulation

Chapter 1

Introduction

1.1 Problem Statement

Nowadays, the energy crisis is a constant theme because of the inflated energy prices [2]. Furthermore, huge energy consumption is a burden to the environment, as not all means of energy production are non-polluting. According to "Our World in Data" [3], in 2019, 63,3 % of electrical energy production comes from fossil fuels. It is known that generally, street lamps are continuously switched on at night, most of the time unnecessarily glowing with its full intensity, in the absence of any activities in the street, leading to a great waste of energy. Furthermore, it is in cities where the consequences of using cars are most noticeable. An example of this is the search for a parking space. According to the RAC Foundation [4], in England, an average car is parked 95 % of the time, which explains how hard it can get sometimes when trying to find a parking spot. This struggle leads to an increase in carbon dioxide production as well as fuel and energy consumption.

With that in mind, the main objective of this project is the implementation of Smart City applications, regarding Smart Street Lighting and Smart Parking. The solution will embrace a distributed system, composed by smart street lights capable of turning on only when they detect movement in the surroundings, at night time, and also, capable of detecting available parking spaces in the street post vicinity.

1.2 Problem Statement Analysis

The main purpose of this system is to control a street lamp post, using for this Raspberry Pi 4B [5].

When there is no activity detected in the area, the lamp post is at a predefined minimum light level, whereas when a car or pedestrian is noticed in the area, the light automatically activates at full brightness. Therefore, each street lamp post communicates wirelessly with the neighbor lamp posts, allowing to dynamically turn on the lights of the following poles. To detect movement in the vicinity of the pole, a motion detector is used. Since the lamppost will only light up during the night time, the motion detector will also only work during that period. To ensure this, a luminosity sensor is used, determining the ambient light conditions. In order to facilitate the maintenance of the pole, a system that determines the operating conditions of the lamp is also implemented. When this system verifies that the lamp is not in good working conditions, in other words, that it is broken or burnt, this information is transmitted to the entity responsible for the network of lamp posts, through a mobile app. This is also used by the person in charge, to manage all information on the pole network, such as the location and working conditions of each pole.

In order to detect empty parking spots, this system should only be used in an area where there are parking spaces nearby. For this, the lamp post has a camera, turned on all day, and, after Raspberry Pi processes the acquired information, it will be available on a website, so that a user, a driver, can know where there are empty parking spaces.

Chapter 2

Analysis

2.1 Market Research

Public lighting is essential to the society quality of life, since it allows citizens to enjoy public spaces at night, providing greater security. “In 1417, the Mayor of London ordered all houses to hang lanterns outdoors after dark during the winter months. This marked the first organized public lighting.” [6].

Currently, many countries are replacing the traditional street lights, High Pressure Sodium (HPS) which is a gas-discharge lamp that uses sodium to produce light at a distinctively yellow-orange, monochromatic glow, with the Light-Emitting Diode (LED) street lighting. LED technology has lower maintenance and operation cost than the HPS lamps, and can generate savings of more than 60 percent of energy costs [7], allowing payback of the initial investment. From oil lamps to LED lamps, public lighting has become a more efficient, cheaper and less polluting way of lighting the streets.

2.1.1 Market Definition

Smart Street lighting is a rapidly growing lighting market, boosted by regulatory policies that encourage energy efficiency, Internet of Things (IoT) convergence and the drop of LED prices. This new concept of smart light post is also growing, implementing not only the smart management of street lights, but also features that go from basic LED replacement control, to traffic and video monitoring, environmental monitoring, and others.

Smart street lights represent a strategic infrastructure for smart city development, in particular, for video-surveillance services and autonomous driving. [8]

In figure 2.1, one can see the global growth rate for connected street lighting market, evidencing the high growth rate in Asia, and the largest market in North America.

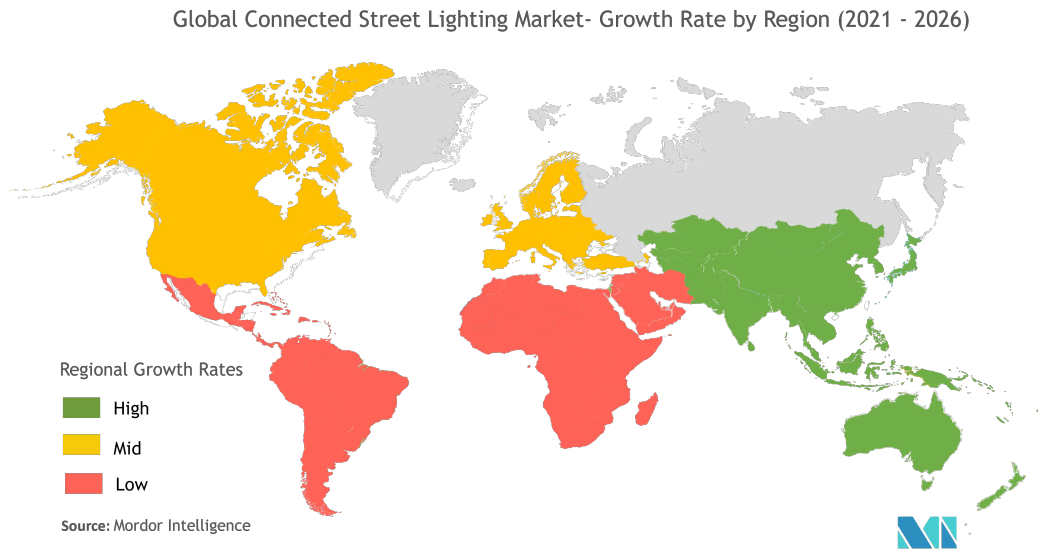


Figure 2.1: Global Connected Street Lighting Market - Growth Rate by Region [1].

2.1.2 Scope

In this project, it will be implemented a street lighting solution for residential areas and public spaces, with the creation of smart light pole technology, feasible of being installed in existent lamp posts, requiring minimum changes to the original infrastructure. This technology comprises sensors, a video-camera, a controller, and wireless connection to the smart street light network. This solution provides cost reduction and improved maintenance quality associated with street lighting, and also supports the deployment of smart city applications, through the use of the video-camera to detect available parking spaces.

2.1.3 Similar products

Telensa - PLANet

Nowadays, Telensa is the market share leader in smart street lighting with more than ten years of experience.[9] PLANet is an intelligent street lighting system, consisting of wireless nodes connecting individual lights, a dedicated network owned by the city and a central management application, seen in figure 2.2. This system reduces energy and maintenance costs associated with street lighting and also improves quality of maintenance through automatic fault reporting.

Doncaster, the largest metropolitan borough in England, houses over 45,000 smart Telensa streetlights, covering 220 square miles, achieving energy savings of approximately 1,5 million euros annually, with potential to increase this in the future.

Telensa is also developing a new generation of light pole sensor devices featuring smartphone Artificial Intelligence (AI) technology, enabling detailed real-time insights on traffic mix, pedestrian movements and others.

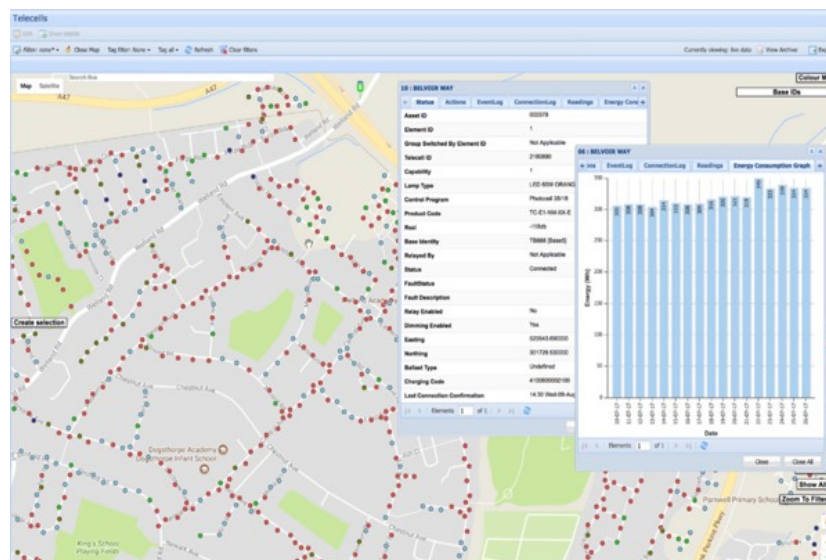


Figure 2.2: Telcells - PLANet's Central Management System.

FLASHNET - inteliLIGHT

FLASHNET is a company focused on developing intelligent systems for smarter cities and better infrastructures and have created a solution that provides the right amount of light where and when needed to lighten the streets, the inteliLIGHT [10].

Using the existing infrastructure, this solution saves money and transforms the existing distribution level network into an intelligent infrastructure of the future, as shown in figure 2.3. Furthermore, the system is integrated with major IoT platforms and provides Application Programming Interface (API) connectivity with City Management applications, ensuring compatibility with existing smart lighting and smart city initiatives.

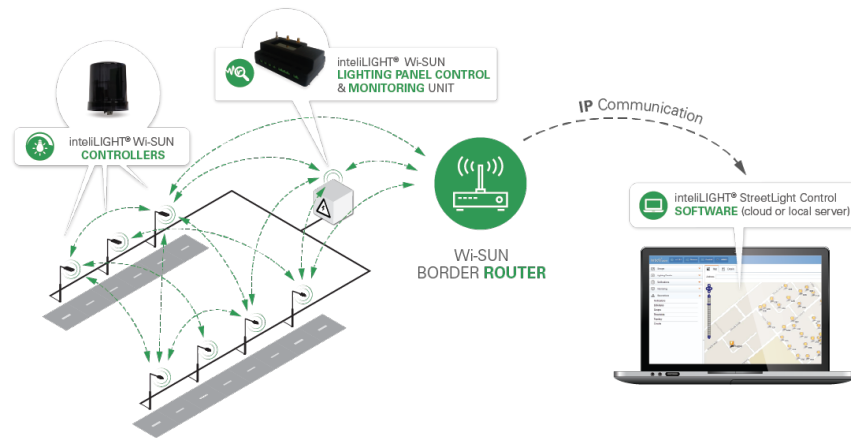


Figure 2.3: inteliLIGHT Communication Technology.

intuVision - intuVision VA Parking

Regarding only to the detection of available parking spaces, there is a solution, by intuVision, named intuVision VA Parking, which provides parking lot analytics to determine vehicle count and security, and monitor parking space availability at all times, both for cities and for private parking lots, as one can see in the figure 2.4. [11]



Figure 2.4: intuVision Parking Lot Demonstration.

2.1.4 Why choose our product

This product aims to decrease power consumption associated with the traditional street light network, and also, using that infrastructure, contribute to the development of a smart city, detecting available parking spaces in the streets. It is a very scalable product, since each street lamp post connects to the rest of the network, via wireless. Besides the utilization in residential areas or public spaces, this can also be used in a large outdoor parking lot. Aside the parking spaces availability detection, this product can have the ability to monitor and to process various areas of interest using the camera built in, like for example, security purposes.

2.2 System Overview

Through the system overview diagram, in figure 2.5, it is possible to identify the main modules of the system to be developed, and how they interact. We can divide the system into two subsystems: the local system, which represents a lamp post, and the remote system, that allows interaction with the system users.

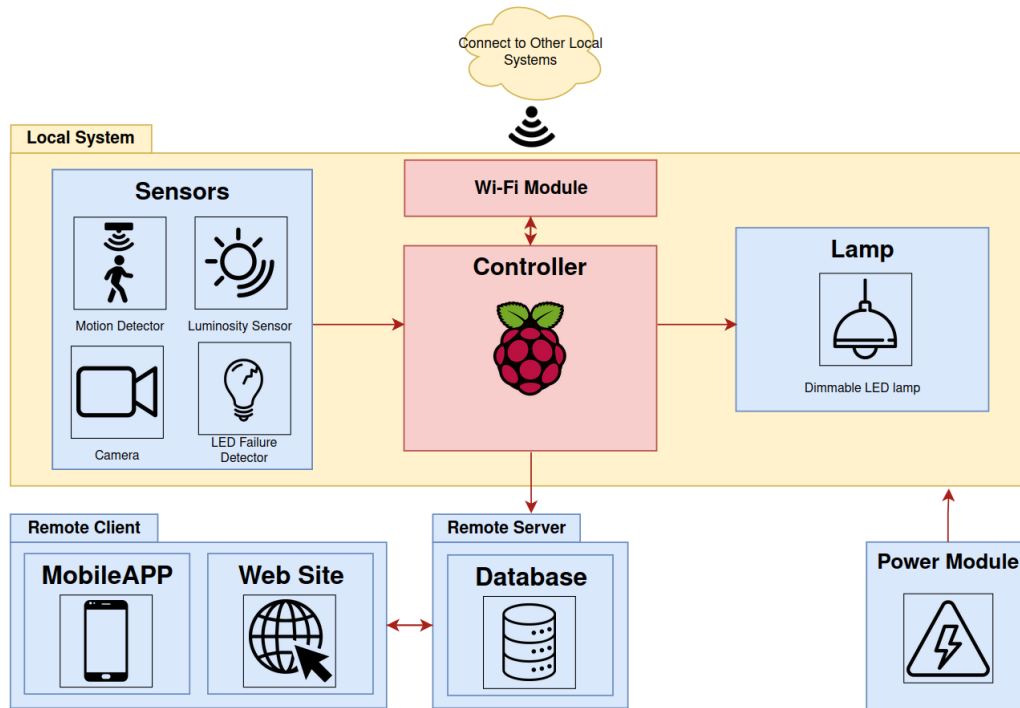


Figure 2.5: System Overview Diagram.

The local system is composed of sensors, a controller and a lamp. Regarding the sensors, there will be a motion detector, to allow the detection of movement in the vicinity of the pole, a luminosity sensor, to detect the light conditions of the pole's surroundings, a camera to find empty parking spots and a LED failure detector to know if the LED lamp is working. The controller, the Raspberry Pi, through sensors information, controls the luminosity of the lamp and communicates through the internet with a remote server, using the Wi-Fi module. Each lamp post communicates with the neighbor posts to turn on the lights dynamically, so the local system

communicates with other local systems, also through the Wi-Fi module.

The remote system is composed by the remote server and the remote client. The remote server consists of a database that stores all information about each lamp post location and operating status. This information can be accessed through a mobile application by the operator responsible for the street lights network, in order to carry out the necessary maintenance of the lamp of each pole. Furthermore, the operator when installing a new lamp post can add its location to the database, using the mobile application. In addition, the database stores information on available parking spaces. When a user, a car driver, wants to know where there are empty parking places, he can access a website that informs him of the location of the empty parking spaces.

Knowing that the public lighting network is directly related to the electrical network, this will be used to power each local system.

2.3 System Requirements and Constraints

In order for the system to have the desired performance, these requirements and constraints must be respected:

Functional Requirements

- Sensors data acquisition
- Motion detection
- Control of a street lamp
- Wi-Fi communication
- Empty parking spots detection
- Manage system information through a mobile application
- Add lamp post location through a mobile application
- Access available parking spots location through a web site

Non-Functional Requirements

- User friendly mobile application and web site
- Ambient luminosity sensing
- Lower power consumption than actual street lights
- Soft Real-Time Embedded System

Technical Constraints

- Buildroot
- C and C++
- Device Drivers
- Linux
- Raspberry Pi
- Cyber-Physical System (CPS)
- Makefiles
- Pthreads

Non-Technical Constraints

- Two members team
- Project deadline at the end of the semester
- Low budget

2.4 System Architecture

Using the system overview diagram information, one can describe the system in two different architectures. Hardware architecture, as how the hardware modules interfaces with itself, and what are the physical components of the system, and software architecture, which details how the information is processed among different software layers.

2.4.1 Hardware Architecture

In figure 2.6, one can see the diagram that represents the physical connections of the system. The Raspberry Pi is the main component in the system, processing all the information given by the sensors, via General Purpose Input/ Output (GPIO) pins and Camera Serial Interface (CSI) for the camera. The communication with the Wi-Fi module is straightforward since its built-in into the Raspberry-Pi.

The power of all system components comes from the power grid and, through an AC/DC converter, will power the Raspberry Pi and its associated sensors.

In order to power the lamp and at the same time control its brightness, a driver is used, taking the controller output, a Pulse Width Modulation (PWM) signal, and system power as inputs.

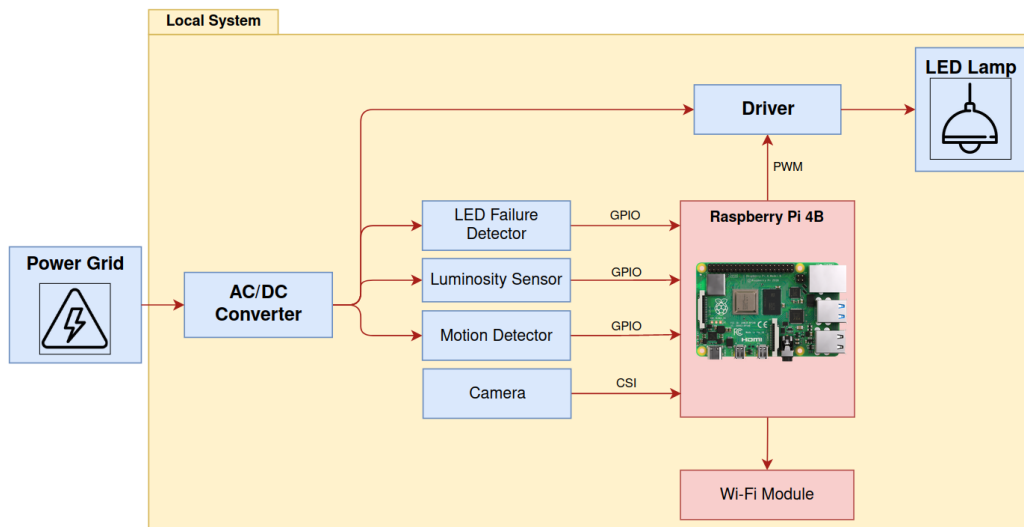


Figure 2.6: Hardware Architecture Diagram.

2.4.2 Software Architecture

The software architecture is divided into three layers:

- The **Operating System** layer, which is composed by the Operating System drivers and Board Support Packages;

- The **Middleware** layer, which includes software for abstracting the lower level layer packages. It works as a pipe since it links two applications, in different layers, so that data can be easily transmitted;
- The **Application** layer, where the core functionality of the program is built, with a resource for the API's in the lower level layers.

As shown in figure 2.7, the operating system layer is composed by the sensor drivers, such as the LED Failure Sensor, the Luminosity Sensor, the Motion Detector which uses GPIO drivers, the camera, that uses CSI drivers and also the Wi-Fi Communication driver. In the middleware layer are the tools needed to process the images from the camera, to multitasking, using PThreads execution model, to acquire data from sensors and to communicate via Wi-Fi with the remote server. Finally, the application layer manages the system database, as well as the Graphical User Interface (GUI), that is the mobile application and the web site, and also all communications with the neighbor street poles.

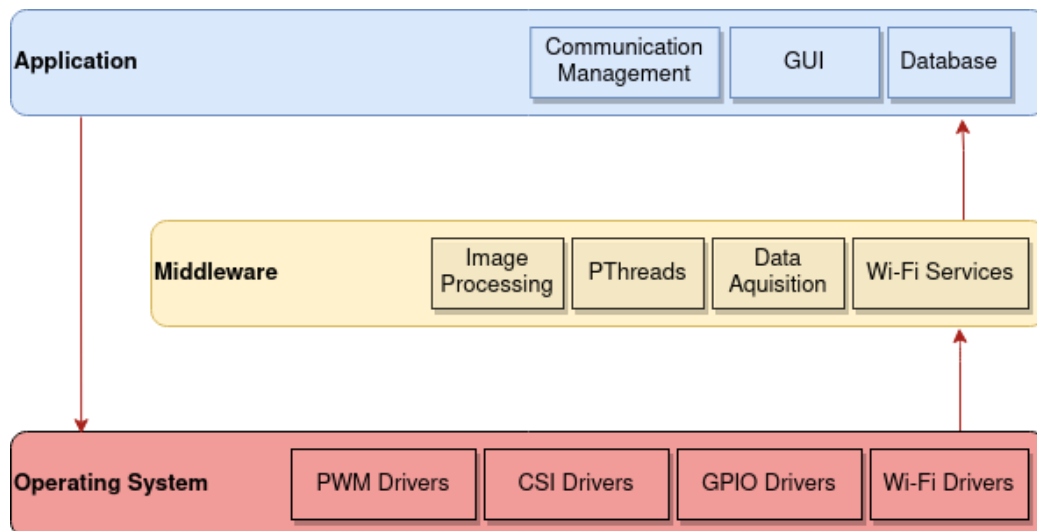


Figure 2.7: Software Architecture Diagram.

| Event | System Response | Source | Type |
|-------------------------------|----------------------------|--------------|--------------|
| Luminosity detector OFF | Power the lamp | Environment | Asynchronous |
| LED failure detector ON | Notify remote system | Local system | Asynchronous |
| Motion detected | Turn on the lamp | User | Asynchronous |
| Requested to turn on the lamp | Turn on the lamp | Local system | Asynchronous |
| Camera sample | Image processing | Timer | Synchronous |
| Update system information | Send data to remote system | Local system | Asynchronous |

Table 2.1: Base station events.

| Event | System Response | Source | Type |
|--------------------|---|---------------|--------------|
| Login | Show application main screen if successful | Operator | Asynchronous |
| Obtain geolocation | Request device geolocation | Mobile device | Asynchronous |
| App notification | Notifies the operator about the lamppost status | Remote Server | Asynchronous |
| Register operator | Add operator information to databas | Operator | Asynchronous |
| Modify lamppost | Update lamppost information to database | Operator | Asynchronous |
| Register lamppost | Add lamppost information to database | Operator | Asynchronous |
| Insert location | Show parking spots | User | Asynchronous |
| Obtain geolocation | Request device geolocation | Mobile Device | Asynchronous |

Table 2.2: Remote system events.

| Product | Price (€) |
|------------------------------|-----------|
| Raspberry Pi 4B | 63,50 |
| Industrial power supply 12 V | 5,00 |
| Video camera | 8,86 |
| Motion detector | 4,60 |
| Luminosity sensor | 1,69 |
| LED lamp 12 V | 3,63 |
| Driver (MOSFET) | 1,00 |
| Basic Eletronic Components | 5,00 |

Table 2.3: Estimated budget.

2.5 Task Division and Gantt Chart

In figure 2.8, is represented the Smart Street Lighting project schedule in form of a Gantt chart.

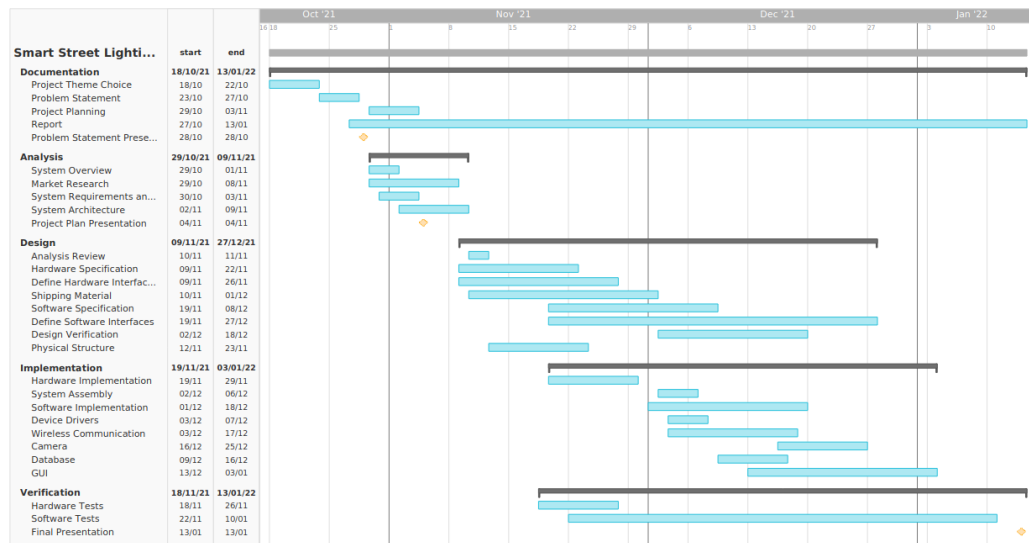


Figure 2.8: Gantt chart.

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