Universidade do Minho
Escola de Engenharia

Smart Street Lighting

Master in Industrial Eletronics and Computers Engeneering

Embedded Systems

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Acronyms

API Application Programming Interface

CPS Cyber-Physical System

HPS High Pressure Sodium

IoT Internet of Things

LED Light-Emitting Diode

RTOS Real-Time Operating System

Chapter 1

Introduction

1.1 Problem Statement

Nowadays, the energy crisis is a constant theme because of the inflated energy prices [1]. 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"[2], in 2019, 63,3% of eletrical energy production comes from fossil fuels. It is known that, in cities, 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. This leads to a great waste of energy, also contributing to the increase in light pollution. As claimed by National Geographic [3], 83% of world population lives under light-polluted skies. This is a problem since it alters the biochemical rhythms that normally flow with natural light levels and also endangers ecosystems by harming animals whose life cycles depend on dark.

With that in mind, the main objective of this project is the creation of a distributed system, composed by smart street lights capable of turning on only when they detect movement in the surroundings, at night time.

1.2 Problem Statement Analysis

The main purpose of this system is to control a street lamp, using Raspberry Pi 4B, turning the lamp on when movement in the surroundings is detected, only at night time.

Para a deteção do movimento, pode ser usada uma camera que, ao contrário de outros detetores de movimento, por exemplo os Passive Infrared (PIR), não é propensa a falsas deteções pois não são sensiveis a mudanças ambientais, como o fluxo de ar quente ou frio. Além disso, a camara permite a deteção de movimento nas redondezas de mais que um poste, diminuindo o número de sensores a utilizar. Por exemplo, se uma camera for capaz de detetar movimento nas redondezas de dois postes de luz, então seria necessário apenas uma camara, ao passo que, com sensores, seria necessária a sua colocação em todos os postes. Esta deteção deve ser realizada apenas de noite, sendo, para isso, necessário determinar as condiçoes de luminusidade do ambiente através de um sensor de luminusidade. De modo a facilitar a manutenção do poste, deve ser implementado um sistema que apura as condições de funcionamento da lâmpada. Quando este sistema verificar que a lâmpada não está em boas condiçoes de funcionamento, ou seja, que está partida ou fundida, esta informação deve ser transmitida à entidade responsável pela rede de postes de iluminação numa mensagem, enviada através de um modulo Global System for Mobile Communications (GSM).

The system consists of a monitoring device, which communicates with various controllers. Each controller manages a single light pole, ensuring that its lamp lights up whenever motion is detected, through its sensors. The monitoring device receives and sends data to a database, which contains information about all lamp posts, and communicates with a mobile application. A responsible person for the lamp posts network, the operator, uses the application to obtain knowledge about this network. In addition, the monitoring device can also request each controller to turn on their lamp, regardless of whether or not there is movement in the vicinity of this pole.

Each street lamp post must communicate wirelessly with the neighbor lamp posts, allowing to dynamically turn on the lights of the following poles. Also, each smart street light must evaluate if its lamp is in good conditions and, when not verified, report to the responsible authority.

Chapter 2

Analysis

2.1 Market Research

2.1.1 Market Definition

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.” [4]. From oil lamps to Light-Emitting Diode (LED) lamps, public lighting has become a more efficient, cheaper and less polluting way of lighting the streets.

Currently, most of the lamps used in public lighting are High Pressure Sodium (HPS). This is a gas-discharge lamp that uses sodium to produce light, at a distinctively yellow-orange, monochromatic glow. These are more efficient than the older incandescent lights, have a cheaper price and have a higher lumen efficiency than older street light types. However, these have a higher maintenance cost and operation cost than the LED lamps. Also, HPS lamps doesn’t have the advantage of being a directional light, like LED does, meaning that HPS light gets emitted in various directions, contributing to light pollution. [5]

The market is driven by several factors, among which are regulatory policies, Internet of Things (IoT) convergence, and LED price, in addition to the culture and morphology of each area. LED technology can generate savings of more than 60 percent of energy costs [3], allowing payback of the initial investment. But, on the other hand, it comes with hidden costs: people tend to overuse it and over-illuminate areas, wasting energy unnecessarily by casting large amounts of light in all directions, emitting bluelight wavelengths that bounce around in the atmosphere, badly affecting animals, including humans.

2.1.2 Market Dimension and Growth

Cities are looking at smart infrastructure to reduce costs, improve sustainability, and provide better services to residents. Nowadays, Telensa is the market share leader in smart street lighting with more than ten years of experience. 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. 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 [6].

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 [7]. Using the existing infrastructure, this solution saves money and transforms the existing distribution level network into an intelligent infrastructure of the future. 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.

Note that smart street light is an emerging technology that, despite being established in the market, is still relatively uncommon in cities due to the initial investment it entails. However, it is clear that in the long run it is compensatory and now, as the consequences of light pollution tiptoe from the shadows and into the spotlight, cities, regulatory agencies, and conservation groups are agitating for solutions.

2.2 System

2.2.1 System Overview

Through the system overview diagram, in figure 2.1, 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 monitoring device, which can monitor a network of lamp posts.

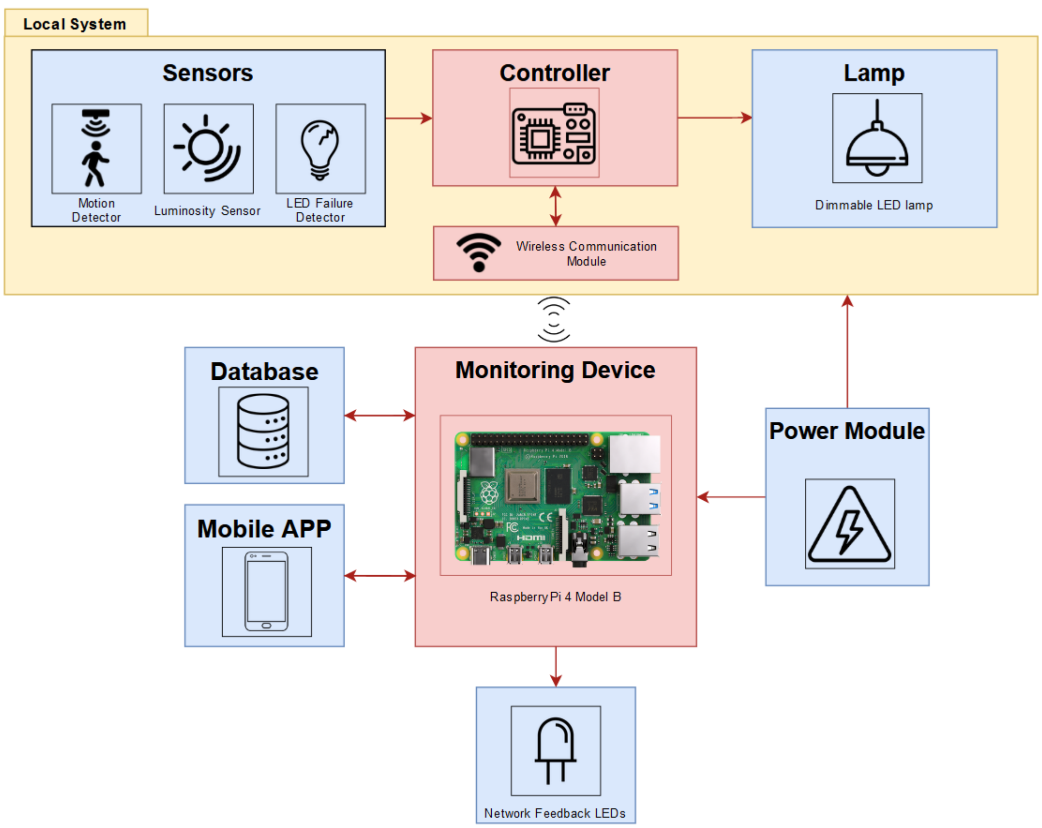

Figure 2.1: System Overview Diagram.

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 light sensor, to detect the light conditions of the pole's surroundings, and a LED state sensor to know if the LED lamp is working. The controller, through sensors information, controls the luminosity of the lamp and communicates via wireless with the monitoring device. The monitoring device exchanges data with a database, recording all information relating to each local system. This information can also be viewed and managed by a mobile application, which can be accessed by a person responsible for the street lamp network. The monitoring device can also control a series of LEDs regarding network state. Knowing that the public lighting network is directly related to the electrical network, this will be used to power local systems, such as the monitoring device.

2.2.2 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 detector
- Control of a street lamp
- Control a network of street poles
- Wireless communication
- Access system information through a mobile application

Non-Functional Requirements

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

Technical Constraints

- Buildroot
- C/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

2.3 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.

2.3.1 Hardware Architecture

In figure 2.2, one can see the diagram that represents the physical connections of the system. The power of most system components will be the output of the DC/DC converter, powering the controller and its associated sensors. In order to power the lamp and at the same time control its brightness, a driver must be used, taking the controller output and system power as inputs. The Raspberry Pi, despite not belonging to the local system, is powered similarly to the controller, via a DC/DC converter. Furthermore, it communicates with the controller wirelessly through its wireless interface, with the controller's wireless communication module.

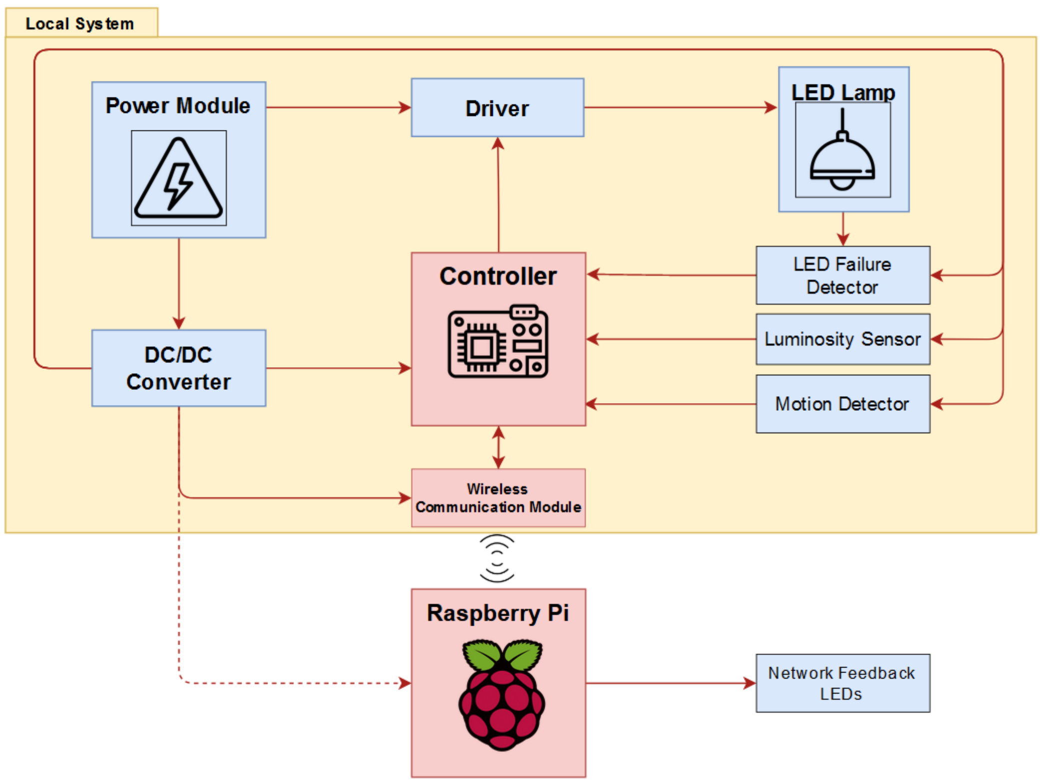

Figure 2.2: Hardware Architecture Diagram.

2.3.2 Software Architecture

As seen previously, the system is divided into two subsystems: the local system and the monitoring system. Their software architectures are 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.

Regarding the local system, shown in figure 2.3, the operating system layer is composed by the sensor drivers, such as the LED Failure Sensor, the Luminosity Sensor, the Motion Detector Sensor and also the Wireless Communication driver. As this system will acquire data from the environment through the mentioned sensors, at a low rate, and communicate this data to the monitoring device, multitasking will not be necessary, so this system will be bare metal, that is, it won't have an operating system. In the middleware layer are the tools needed to acquire data from sensors and communicate wirelessly with the monitoring system. Finally, the communication between the different devices is managed in the application layer.

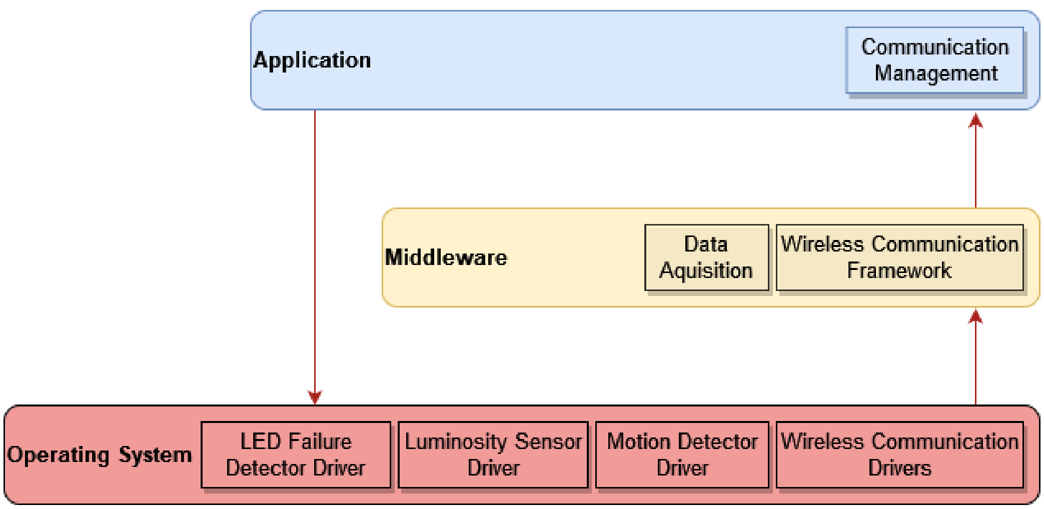

Figure 2.3: Software Architecture Diagram - Local System.

Regarding the monitoring system, represented in figure 2.4, the operating system layer is responsible for the network feedback LED drivers and for the wireless communication driver. This operating system will be a Real-Time Operating System (RTOS), due to the need to respond to events in a certain period of time and also multitasking. In the middleware layer, there will be the PThreads execution model, for multitasking, as well as the wireless communication and data acquisition frameworks. The application layer manages the system database, as well as the graphical user interface and all communications with local systems.

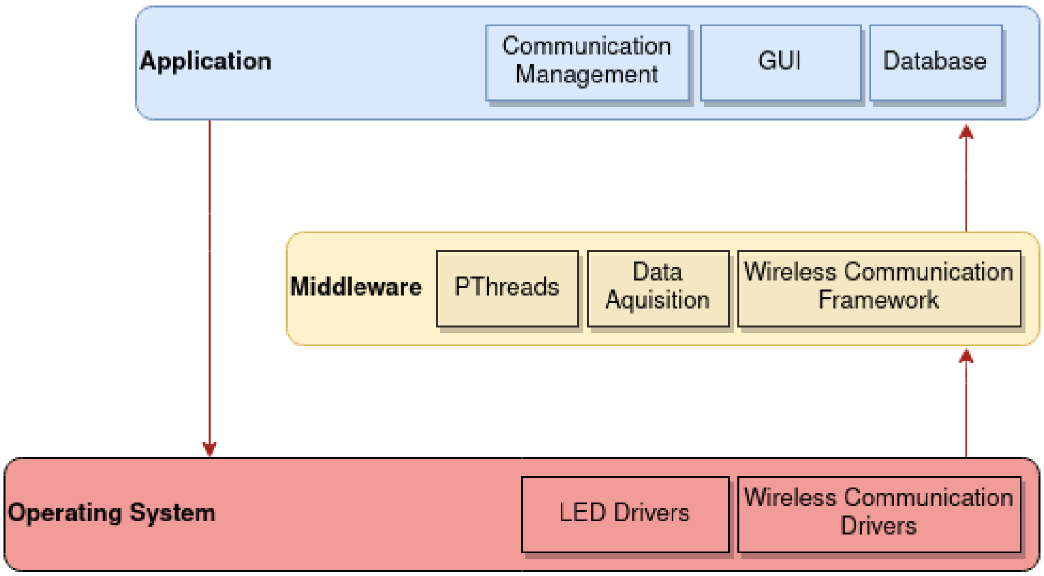

Figure 2.4: Software Architecture Diagram - Monitoring System.

2.4 Task Division and Gantt Chart

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

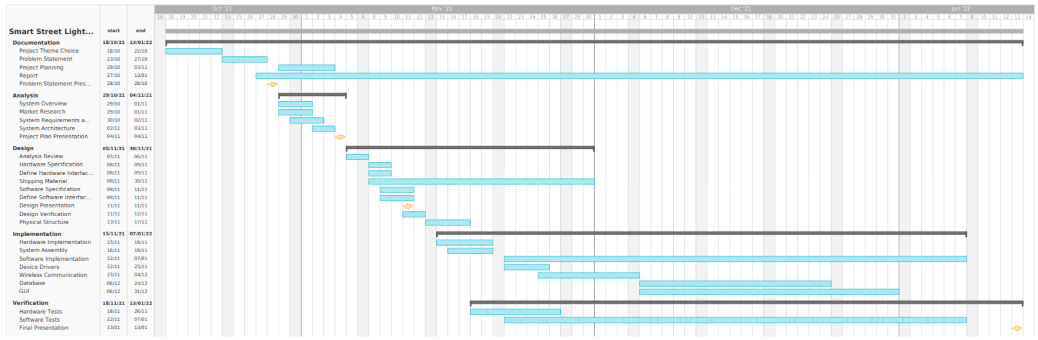

Figure 2.5: Gantt chart.

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