Dynamic Light Intensity Mapping in Sports Centres

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Dedication

To Agustin, my family, friends and the public education institutions in my home country that provided me the tools and strength to be writing this. ...

Summary

The project is focused on dynamically measuring light and developing an application that can be integrated into an autonomous robot. A key aspect of the project is the calibration method, which includes both hardware and software components. This method is crucial for ensuring accurate light measurements and for developing the skills needed to process and present information effectively to users.

One of the main objectives is to measure light intensity in Lux units. To achieve this, the project aims to create a solution that is easy to mount, robust, and economical. This involves testing various sensors to find the most suitable ones for the task.

In addition to the hardware components, the project includes the development of an app to manage the system. This app will feature a graphic interface designed to present the collected data in an accessible and user-friendly manner. Furthermore, the design of the device will prioritize ergonomics, ensuring it is comfortable and practical for users to handle.

Overall, this project not only addresses the technical aspects of light measurement and sensor integration but also focuses on creating a seamless user experience through thoughtful design and effective information presentation.

key words: BPX 43/3, Heat Map, Light Intensity, Luximeter

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Chapter 1

Introduction

The history of football fields is an interesting journey from ancient times to today. In ancient Greece, Rome, and China, people played different ball games on simple fields. These early games led to the modern football we know now. In the 19th century in England, the first official rules for football were made. At that time, games were played on natural grass fields. As football became more popular, the need for better playing conditions and a better experience for spectators led to the creation of specialized football fields. These improvements included new materials and designs to make the game better.

The history of illumination on football fields is an important part of this development. Early football games were played during daylight hours, so there was no need for artificial lighting. As the sport grew in popularity, the desire to play matches in the evening increased. The first football match under artificial light took place in 1878 in Sheffield, England. The lights used were basic and did not provide the best visibility, but they marked the beginning of a new era.

Over time, the technology for lighting sports fields improved significantly. By the mid-20th century, more advanced lighting systems were being installed in major stadiums. These systems used powerful floodlights that provided much better illumination, making it possible to hold night games with good visibility for players and spectators. Today, modern LED lighting systems are used, which are more energy-efficient and provide even better light quality. These lights can be controlled to adjust the brightness and coverage, ensuring optimal conditions for both playing and viewing.

Measuring light intensity on football fields accurately is a big challenge. Light intensity is very important in many places, like hospitals, schools, and sports facilities. In sports venues, especially large football fields, controlling light intensity is necessary to make sure the playing conditions are good and fair. It must consider things like the time of day and the weather.

Measuring light intensity manually in large spaces is difficult. The results can change a lot depending on the height and angle of the measuring device. To solve this problem, a solution is to use a sensor in a robotic system. This robot can go to specific points on the field, record their positions, and measure light intensity in a consistent way. This makes the measurements more accurate and reliable.

The goal is to create a device that can be used both indoors and outdoors. This device will be mounted on a machine and will measure light intensity dynamically. It will show the information to users in a simple and easy-to-understand way. The focus is on using as little electronic hardware as possible, making it efficient, easy to use and low-cost.

Calibrating the sensor is very important to make sure the measurements are correct and consistent. Also, managing the data collected and making sure the user interface is easy to use are key parts of the project.

Good lighting on football fields is important for many reasons. It keeps players and spectators safe by making sure they can see the playing area, boundaries, and any hazards clearly. Good lighting makes the game better because players can see the ball and their surroundings clearly, which helps them play better, in a safer space and fairer conditions.

An overall idea of the project can be observed in figure 1.1. This visual representation offers a concise summary of the concepts and methodologies detailed in this report.

1.1 Motivation

The motivation for this project comes from a genuine desire to enhance the efficiency and quality of sports activities through an affordable and easy to implement solution. The idea

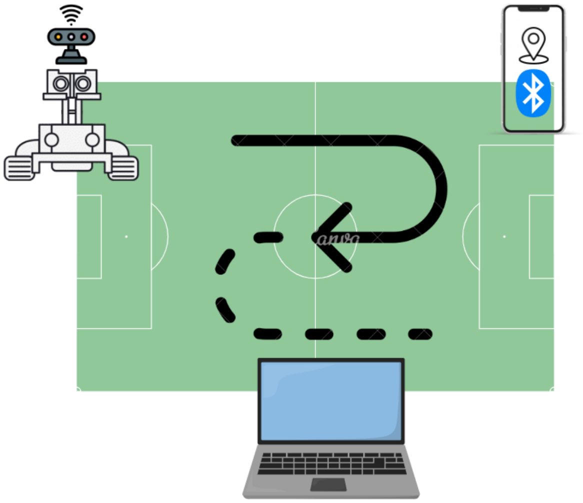


Figure 1.1: Block Diagram

is to design a tool that ensures optimal lighting conditions on football fields, improving performance and safety for athletes. This idea drove the development of a system that is not only practical for sports but also versatile enough to be used in various other fields.

Creating a project that involves multiple areas of engineering is both challenging and exciting. The idea of developing a device that integrates hardware and software, involves designing electronic circuits, creating a mobile application, and managing data storage, presents an incredible opportunity for learning and growth. This multidisciplinary approach is not only intellectually stimulating but also crucial in preparing for a professional career in engineering.

A great motivation is to create a device whose affordability and simplicity make it accessible for widespread use. It's not just about the high-tech functionality but also about creating a solution that can be easily adopted and utilized in different scenarios. Whether it's optimizing lighting for sports, enhancing agricultural practices, or improving urban planning, the potential applications are vast and impactful. This will be taken in considereation when it comes to the developing, always designing a solution that can be easily re-adapted.

Also, a motivation behind this project is to push the boundaries of what is possible to do with easy to access materials, embrace the challenge of integrating diverse technologies, and create a practical tool that can make a significant difference.

1.2 Document Structure

This thesis will be structured in several key sections to ensure a thorough exploration of the topic.

The first section will focus on the magnitude to be sensed, providing a comprehensive review of the physical properties of light intensity. By understanding this groundwork, it will be gained a solid foundation in the fundamental concepts necessary for the rest of the inform.

Following this, there will be an extensive literature review. This section will involve a deep dive into existing projects and technologies related to light intensity measurement. By examining the work that has already been done in this field, the review will highlight the strengths and weaknesses of current methods, providing a clear picture of the state of the art and identifying areas where improvements can be made.

Next, it will be presented an experimental analysis and development. It is on this part, that various experiments will be performed to evaluate different sensing devices and calibration methods. The analysis will not only test the effectiveness of these devices but also explore practical strategies for achieving optimal calibration. Emphasis will be placed on user-friendliness, ensuring that the proposed solutions are not only accurate but also easy to use in real world applications. This section will include detailed descriptions of the experimental setups, methodologies, and results.

The final section will offer a conclusion and future work. This will summarize the key findings from the previous sections, discussing the implications of the results and how they contribute to the field of light intensity measurement. Additionally, this section will propose potential directions for future research, identifying promising areas for further research and development.

By addressing each of these components in detail, the project aims to develop a robust and effective solution for dynamically measuring light intensity in various settings.

Chapter 2

State of the Art and Study of tools

When it comes to sports centers lighting, the fusion of new technologies and the pursuit of optimized athletic performance has sparked a keen interest in the innovative domain of dynamic light intensity mapping. From an electrical engineering point of view, this thesis explores the implications, technological advancements, and uncharted potentials of light mapping technologies within sports facilities. Electrical engineers face diverse challenges in implementing dynamic light mapping technologies. These challenges span technological intricacies, cost-effectiveness, standardized protocols, safety compliance, and long-term performance optimization. The unexplored territories show the need for precise engineering solutions, precise control systems, and the seamless integration of lighting technologies within the framework of sports. This thesis aims to provide an analysis, examination, and innovation within the realm of light mapping technologies applied in sports centers.

Lighting plays a critical role in various domains, including sports centers, where dynamic light intensity mapping is essential for ensuring optimal visibility and performance. Recent advancements in light measurement techniques have paved the way for innovative approaches in this area. One method involves using the BPX43-3 phototransistor paired with a collector resistor to take voltage measurements that gauge light intensity. Integrated with an ESP32 microcontroller, this method provides a reliable means of quantifying light levels in various environments.

Sensor's development and calibration are crucial for ensuring accurate measurements. A sophisticated algorithm determines the conversion rate based on the resistor value used within a given range, enabling the conversion of raw sensor readings into precise lux units. Integration with IoT and mobile platforms further enhances the functionality and accessibility of light intensity mapping systems. For instance, an Android application developed using MIT App Inventor facilitates the reception of GPS coordinates from a smartphone paired with the sensor. This seamless connection via Bluetooth allows for real time data transmission and storage.

The data collected is efficiently managed and analyzed using Python, enabling comprehensive insights into light intensity variations across different spatial locations within sports centers. Data analysis and visualization play a crucial role in extracting insights, identifying patterns, and making informed decisions based on the collected data. These processes involve analyzing raw data, deriving meaningful information, and presenting it in a visually comprehensible manner, which is essential for optimizing lighting performance, identifying areas for improvement, and ensuring optimal energy usage.

The complete project will be outlined through five distinct approaches, each developed in detail as follows. All the information presented in these approaches is based on extensive research, with proper references provided for all sources.

2.1 Light Definition

Light is a form of electromagnetic radiation that is visible to the human eye. It travels in waves and can be described in terms of wavelength or frequency. The visible spectrum of light ranges from about 380 to 750 nanometers in wavelength, encompassing the different colors we see from violet to red.

Light intensity, is measured in units called lux. Lux quantifies the amount of light that hits a surface per unit area. One lux is equivalent to one lumen per square meter. Lumens measure the total amount of visible light emitted by a source, while lux measures how much of that light illuminates a given area.

Measuring light intensity in lux is important for various applications, such as ensuring adequate lighting in workspaces, designing lighting for public areas, and even in photography. Devices like light meters or sensors use photodetectors to measure the amount of light hitting their surface and convert that measurement into a lux value. This allows for precise and standardized assessment of light conditions, ensuring environments are well-lit and safe.

2.2 Light Measurement Techniques

Light measurement techniques play an important role in ensuring accurate assessment and control of light intensity, which is essential for various applications, including football fields. By employing some measurement methodologies, it is possible to precisely quantify light levels, ensuring optimal visibility for players and spectators.

One significant aspect of light measurement techniques involves the calculation of cylindrical illuminance, which pertains to the illumination of cylindrical surfaces. This is particularly relevant in football fields where uniform lighting distribution is crucial for player visibility and performance. The study on uncertainty analysis of cylindrical illuminance approximation explores different approaches for calculating it, emphasizing the importance of in-field measurement methods for accurate light modeling. By implementing these techniques, it is possible to assess lighting conditions across the entire playing field, ensuring consistent illumination levels to minimize glare and shadows, thereby enhancing player visibility and safety [1].

Moreover, the comparison of low-cost commercial sensors with professional ones in the context of solar illuminance measurement demonstrates the potential of cost-effective solutions for natural illumination measurement. This is particularly relevant for football fields, where natural light can significantly impact gameplay and spectator experience. By utilizing affordable yet reliable sensors, it is possible to monitor natural light levels on the field, allowing for effective management of artificial lighting systems to maintain optimal visibility and minimize energy consumption [2].

Additionally, the development of low-cost pyranometers for measuring solar irradiance offers insights into affordable yet reliable light measurement solutions. In the context of football fields, solar irradiance measurement is essential for understanding the impact of sunlight on playing conditions, such as glare and heat buildup. Deploying pyranometers, seems to provide accurately quantified solar irradiance levels on the field, enabling them to implement appropriate shading solutions or adjust artificial lighting systems to mitigate the effects of sunlight on player performance and spectator comfort [3]. It is interesting to have look on the types of irradiance schema on figure 2.1.

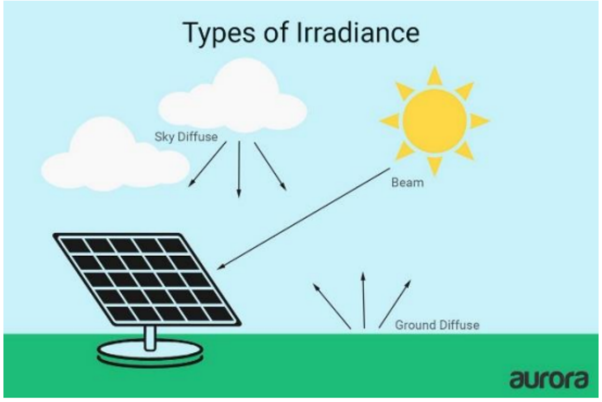


Figure 2.1: Types of irradiance, extracted from [3]

2.3 Sensor Development and Calibration

Sensor development and calibration are crucial aspects of ensuring the accuracy and reliability of light measurement systems. Various light measuring methods and devices exist, each with its own set of advantages and limitations.

One commonly used method involves utilizing phototransistors or photodiodes to measure light intensity. These semiconductor devices generate an electrical current proportional to the incident light intensity, allowing for direct measurement of light levels. Additionally, photodiodes can be integrated into sensor arrays to provide spatially resolved measurements, this enables to assess lighting uniformity across the football field or whatever space the measurement is being taken on.

Another approach involves using photovoltaic cells, which convert light energy into electrical energy. These cells can be calibrated to provide accurate measurements of light intensity, making them suitable for applications requiring high precision.

Furthermore, advancements in light-emitting diode (LED) technology have led to the development of specialized sensors, such as 1.3 μm Light-Emission-and-Detection (LEAD) diodes [4]. These diodes offer enhanced stability and sensitivity for light emission and detection applications, making them ideal for precise light measurement in football fields. Additionally, the fabrication and performance evaluation of LEAD diodes highlight their suitability for use in dynamic light control systems, where accurate measurement of light intensity is essential for optimal performance.

In parallel, the design of LED adaptive dimming lighting systems, such as those based on incremental proportional-integral-derivative (PID) controllers, offers an energy-efficient solution for dynamic light control in football fields for example. By adjusting the intensity of LED lights based on real time measurements from calibrated sensors, these systems can adapt to changing environmental conditions, ensuring consistent illumination levels throughout the game [5].

However, despite the advancements in sensor development and calibration, challenges might be encountered in achieving accurate and reliable light measurements in football fields. Factors such as environmental conditions (e.g., weather, obstructions), sensor degradation over time, and variations in light sources can affect measurement accuracy. Additionally, calibration procedures may need to be periodically performed to account for sensor drift and ensure continued accuracy.

2.4 Integration with IoT and Mobile Platforms

Integration with IoT (Internet of Things) and mobile platforms is becoming increasingly important in various fields. IoT refers to the network of interconnected devices, sensors, and software applications that communicate and exchange data over the internet. These devices can range from simple sensors and actuators to complex machinery and equipment, all connected through wireless or wired networks.

The importance of IoT lies in its ability to enable remote monitoring, control and automation of systems and processes, leading to improved efficiency, productivity, and user experience. In the context of football field lighting, IoT can revolutionize how lighting systems are managed and optimized.

By integrating light sensors, actuators, and controllers with IoT platforms, it is enabled the posibility to create smart lighting systems that adapt dynamically to changing environmental conditions and user preferences. For example, sensors can continuously monitor factors such as ambient light levels, weather conditions, and occupancy, transmitting this data to a centralized IoT platform in real time. The platform can then analyze the data and send commands to adjust the intensity, color temperature, and direction of lighting fixtures accordingly.

This level of automation and intelligence offers several benefits where it is applied. It allows for more efficient energy usage by optimizing lighting levels based on actual needs, reducing costs and environmental impact. It also enhances safety and visibility for players and spectators by ensuring consistent and appropriate lighting levels throughout the game, regardless of external factors like weather or time of day.

Furthermore, IoT enables remote monitoring and management of lighting systems, allowing maintenance personnel to detect and address issues proactively before they affect gameplay or spectator experience. This can lead to reduced downtime, improved system reliability, and lower maintenance costs in the long run.

This can practically be seen on the references used for this project, a very interesting one is "A Low-Cost Luxometer Benchmark for Solar Illuminance Measurement System [2]". Also an interesting approach would be "Wearable Inverse Light-Emitting Diode Sensor [6]". On the figure 2.2 it is possible to observe an end-to-end datapath of the IoT system named on the reference above.

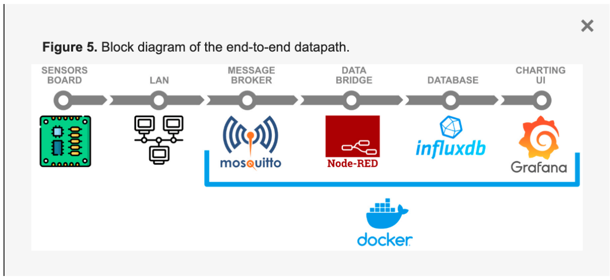


Figure 2.2: Block diagram of the end-to-end datapath, extracted from [2]

2.5 Automation and Control Systems

When it comes to illumination on different sports courts or fields, these systems involve the use of sensors, actuators, and controllers to automate processes and adjust parameters based on predefined criteria or real time data. In the context of football field lighting, automation and control systems are crucial for ensuring optimal illumination levels, energy efficiency, and user experience.

One approach to automation involves implementing automatic intensity control for lighting systems, as demonstrated in the reference to LED-based street lighting with automatic intensity control using solar PV [7]. In this approach, sensors measure environmental parameters such as ambient light levels, weather conditions, and occupancy, and send this data to a central controller. The controller then adjusts the intensity of lighting fixtures, either dimming or brightening them as needed, to maintain optimal illumination levels while minimizing energy consumption.

Another approach involves the development of distributed illumination measurement systems, as described in the reference to a distributed illuminance measurement system based on digital signal processors [8]. With this approach, multiple sensors can be distributed throughout the football field to measure illumination levels at various points in real time. These sensors communicate with a central processing unit, which aggregates and analyzes the data to provide a comprehensive view of illumination distribution across the field. This helps to identify areas with insufficient or excessive lighting and make adjustments to optimize visibility and energy usage.

Overall, automation and control systems are essential for optimizing the ongoing development to meet the diverse needs of players, spectators, and operators. By implementing automatic intensity control, dynamic adjustment capabilities, and distributed measurement systems, it is possible to ensure optimal illumination levels, energy efficiency, and user experience, enhancing the overall quality and safety of football field environments.

2.6 Data Analysis and Visualization

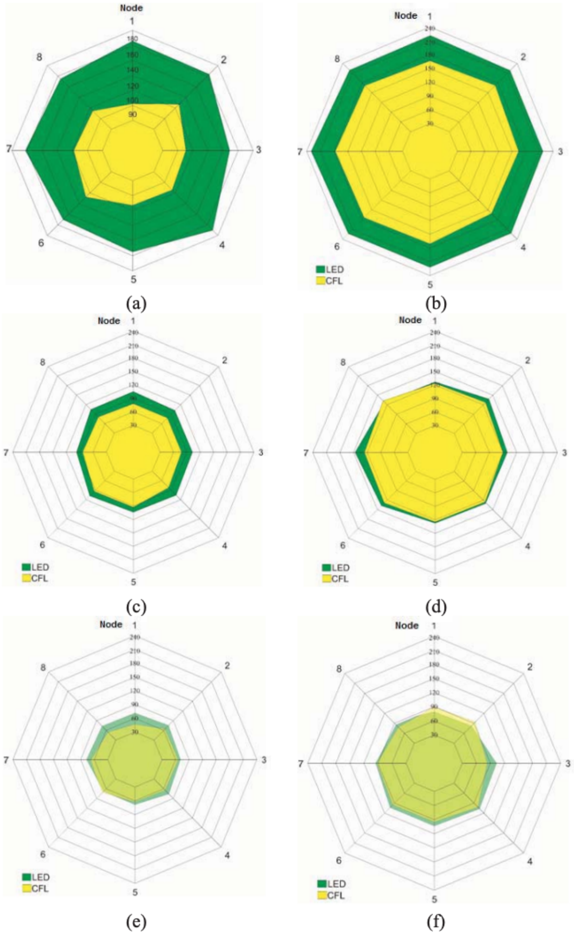
This perspective plays a crucial role in extracting insights, identifying patterns, and making informed decisions based on the data collected from football field lighting systems. These processes involve analyzing raw data, deriving meaningful information, and presenting it in a visually comprehensible manner. In the context of football field lighting, data analysis and visualization are essential for optimizing lighting performance, identifying areas for improvement, and ensuring optimal energy usage.

One popular method of data analysis involves mapping lighting intensity, as demonstrated in the reference to mapping lighting intensity from LED and CFL lamps [9]. By collecting data on light intensity levels from different types of lamps across the field, it is feasible to create spatial maps that visualize light distribution patterns. These maps provide valuable insights into the uniformity of lighting across the field.

On the figure 2.3 it is possible to observe an interesting approach to a heatmap obtained by measuring the intensity of LED Lamps in a certain distance.

Additionally, data analysis can involve monitoring environmental parameters, such as temperature, humidity, and air quality, as demonstrated in the reference to indoor environment monitoring in search of gas leakage by mobile robots. By integrating sensors with mobile robots or other monitoring systems, there is potential to collect data on environmental conditions in real time and analyze it to identify potential issues or areas for improvement. For example, monitoring air quality can help identify sources of pollution or gas leaks that may affect player health and safety [10].

Python is often used as a powerful tool for data analysis and visualization in various



(a) (b) (c) (d) (e) (f)

Figure 2.3: The results of measurements of lighting intensity at a certain distance, extracted from [9]

fields, including sports science and engineering. Its rich ecosystem of libraries, such as NumPy, pandas, and Matplotlib, provides tools for data manipulation, statistical analysis, and visualization. It is possible to use Python to process raw data collected from football field lighting systems, perform statistical analysis to identify trends or anomalies, and create visualizations such as charts, graphs, and heatmaps to present the findings in an intuitive and informative manner.

Chapter 3

System Architecture

On this chapter an overview of the project is presented indicating the protocols and mechanisms used to connect the different parts of the developed device. A BPX 43/3 phototransistor is used to measure light levels, and this sensor is connected to an ESP32 board (specifically the Wemos D1 R32 model) through an analog input. The readings from this sensor are converted into lux units by the ESP32.

This project is crucial as an application for dynamic light sensing because it allows for real time monitoring and recording of light intensity in various environments. Such capability is essential in fields like sports infrastructure, where understanding and reacting to changing light conditions can lead to better resource management, enhanced safety, and improved overall efficiency.

In more detail, the BPX 43/3 phototransistor senses light and generates a corresponding electrical signal. This signal is converted into an analog voltage that varies with the intensity of the light hitting the phototransistor. The ESP32 reads this signal through one of its analog input pins. An analog input on the ESP32 refers to a pin that can read varying voltage levels rather than just the binary on/off states typical of digital inputs. The ESP32 includes an analog-to-digital converter (ADC), which is a crucial component that transforms the continuous analog signal into a digital value that the microcontroller can process. The ADC samples the analog signal at a high rate and converts these samples into digital values, enabling the ESP32 to quantify the light intensity accurately.

The system is triggered via Bluetooth, a wireless communication protocol designed for short-range data exchange. Bluetooth operates in the 2.4 GHz ISM band and supports both voice and data transmissions, making it versatile for various applications. The ESP32 comes with an integrated Bluetooth module, simplifying the process of establishing wireless communication with other devices, such as the smartphone used in this project. The smartphone app sends GPS coordinates to the ESP32, signaling it to take a light measurement at a specific location. This integration of Bluetooth technology enables seamless and efficient data collection in real time and nevertheless the action of the whole device remotely as it is going to be explained in chapter 4.

Once a light measurement is taken, the data is stored on an SD card. The SD card is connected to the ESP32 through an SD card module using the Serial Peripheral Interface (SPI) protocol. SPI is a synchronous serial communication protocol used for short-distance communication, primarily in embedded systems. It involves a master-slave architecture where the master device (the ESP32 in this case) controls the data exchange with the slave device (the SD card). SPI enables fast data transfer rates, which is essential for efficiently writing measurement data to the SD card.

An SD storage module is a compact, portable storage device that uses Secure Digital (SD) card technology. These modules provide a convenient way to store large amounts of data in a small form factor, making them ideal for applications like this one where data needs to be recorded and retrieved easily.

When the robot carrying the device returns, the ESP32 is connected to a computer via USB. USB (Universal Serial Bus) is a standard interface used for communication between devices and a host controller, typically a PC. USB supports data transfer rates ranging from low-speed (1.5 Mbps) to super-speed (up to 5 Gbps and beyond), making it versatile for various applications. In this project, the USB connection allows for easy data transfer from the SD card to the computer. By pressing the reset button on the Wemos board, a Python script on the computer automatically copies all the files from the SD card. This script then opens the latest data file and displays the light measurements on a heatmap. The heatmap visually represents the light intensity measurements correlated with the specific GPS coordinates where they were taken, providing an intuitive way to analyze the collected data. An explanatory block diagram, shown in figure 3.1, indicates not only the communication paths but also the protocols and applications used in this project.

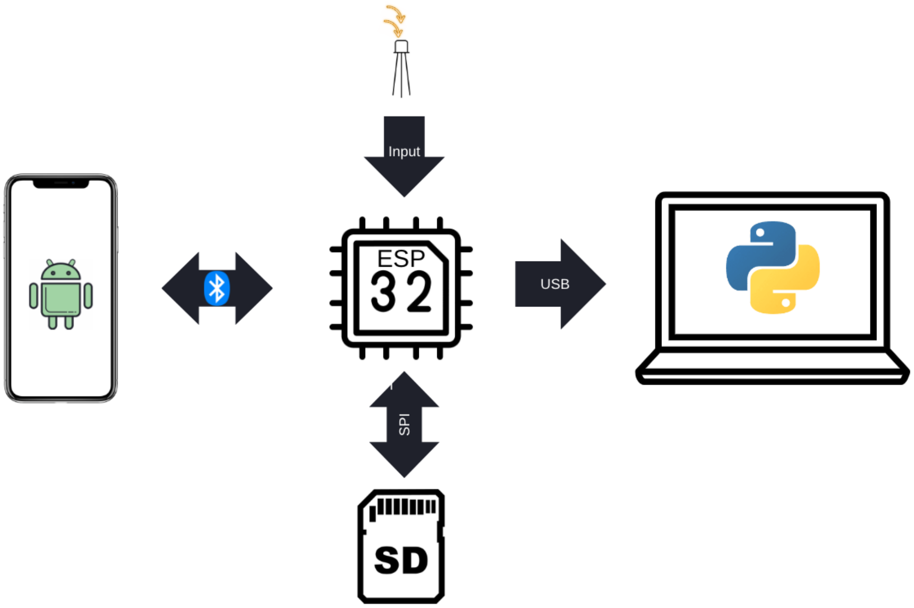


Figure 3.1: Architecture block-diagram

3.1 Serial Peripheral Interface (SPI) protocol

The Serial Peripheral Interface (SPI) protocol is a method used in many electronic devices for exchanging data between a main device (called the master) and other connected devices (called slaves). It's often used in things like computers and electronic gadgets to help them communicate quickly and efficiently with each other.

SPI works by using four special wires to send and receive data. These wires are called MOSI, MISO, SCK, and CS. MOSI is used to send data from the main device to the connected devices, while MISO is used to send data back from the connected devices to the main device. SCK is a special wire that helps all the devices stay in sync with each other. And CS is a wire that tells the connected devices when they should pay attention to the data being sent.

On this project, SPI is used to help the Wemos D1 R32 talk to the memory card module, so it can save the data it collects from the light sensor. This way, the board can save lots of data quickly and efficiently without having to slow down or stop what it's doing. The SPI protocol overview is depicted on figure 3.2.

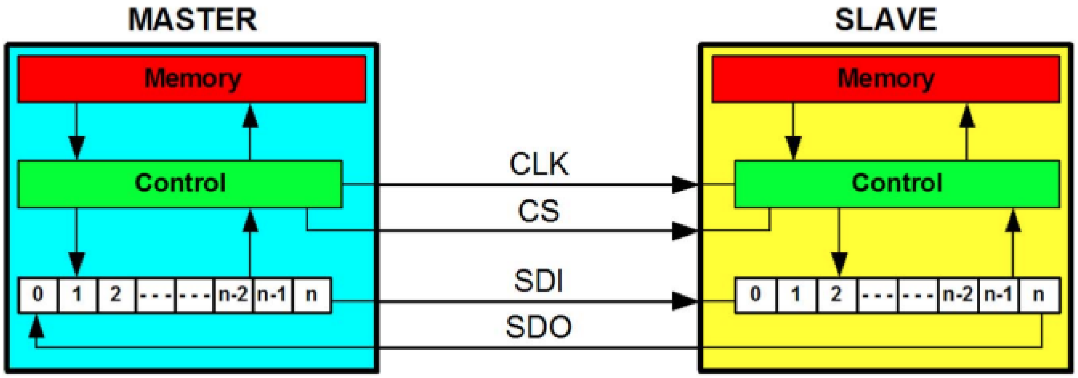


Figure 3.2: SPI Protocol Overview, taken from [11]

3.2 Bluetooth

Bluetooth is a wireless communication technology that enables devices to exchange data over short distances without the need for cables or internet connection. It operates in the 2.4 GHz frequency band and is widely used in various consumer electronics, including smartphones, tablets, headphones, and smartwatches.

In the context of the Wemos D1 R32 board, Bluetooth functionality is integrated directly into the hardware. This means that the board is equipped with a Bluetooth module that enables it to establish wireless connections with other Bluetooth-enabled devices, such as smartphones. This integration simplifies the setup process and allows for seamless communication without requiring additional external components.

Bluetooth works by using radio waves to transmit data between devices. When two

Bluetooth-enabled devices come within range of each other, they can establish a connection and start communicating. This communication can involve sending and receiving data, such as files, messages, or commands.

On this project, Bluetooth plays a crucial role in enabling remote control and data exchange between the Wemos D1 R32 board and a smartphone. Specifically, the smartphone acts as a control interface, allowing the user to activate and deactivate the device remotely. This is achieved by sending commands to the Wemos D1 R32 board via Bluetooth. Additionally, the smartphone app sends GPS coordinates to the board, providing location-specific information for light intensity measurements. This enables precise control over when and where the measurements are taken, enhancing the versatility and efficiency of the device. The classical bluetooth protocol model is depicted on figure 3.3 .

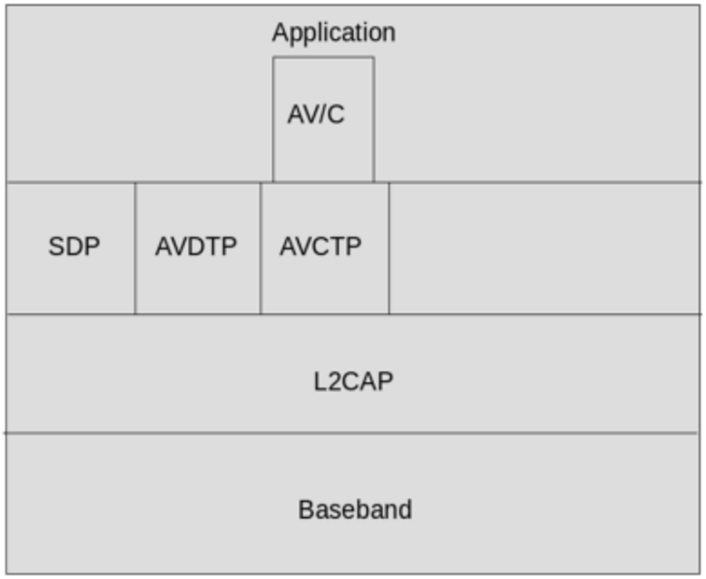


Figure 3.3: Bluetooth Protocol Model: Figure taken from ESP32 Datasheet

3.3 Analog Digital Converter ADC

An Analog-to-Digital Converter (ADC) is a fundamental component in the realm of electronics. Its primary function is to bridge the gap between the continuous, fluctuating signals of the analog world and the discrete, quantifiable values of the digital realm. In simpler terms, it translates real world phenomena, such as light intensity in this case, into numbers that a microcontroller, like the one on the Wemos D1 R32 board, can understand and process.

On the Wemos D1 R32 board, the ADC serves as a vital interface between the external environment and the microcontroller. When connected to a sensor, such as a light sensor, the ADC samples the analog signal produced by the sensor at regular intervals. It then converts these continuous analog voltage levels into discrete digital values, typically represented by binary numbers. This process allows the microcontroller to interpret and respond to changes in the physical world, such as variations in light intensity.

The range of values produced by the ADC is determined by its resolution, which refers to the number of discrete steps it can distinguish within the analog signal range. In the case of the Wemos D1 R32 board, the ADC has a resolution of 12 bits. This means it can divide the full analog input range into 2^{12} (4096) distinct steps, ranging from 0 to 4095. Each step represents a specific voltage level, allowing for precise quantification of the analog input signal.

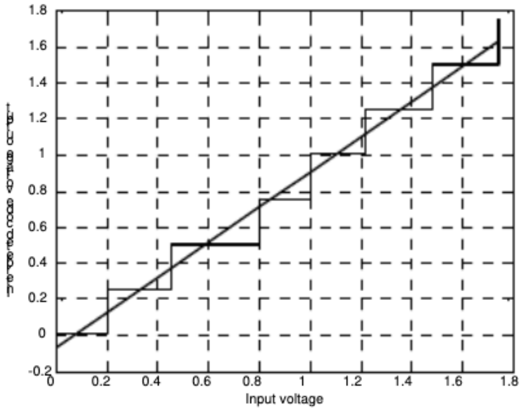


Figure 3.4: A non-ideal ADC transfer curve and its endpoint fit line. Taken from [12]

In practical terms, the range of 0 to 4095 provided by the ADC allows for fine-grained measurement of light intensity. By converting analog light signals into digital values within this range, the Wemos D1 R32 board can accurately capture variations in light levels, enabling sophisticated analysis and responsive decision-making based on the observed environmental conditions. Nevertheless it is important to clarify the discrepancy between the ideal and real obtained values, as explained on [12], a graphical approach is presented on figure 3.4.

Chapter 4

Development

This chapter describes the thorough development process undertaken for this project, emphasizing the integration of hardware and software components to develop a dynamic light sensing system.

The hardware development process began with the meticulous selection of components, particularly the BPX-43/3 phototransistor, which was chosen as the primary sensor for measuring light levels. The sensor is connected to an ESP32 board (specifically the Wemos D1 R32 model) through an analog input. The ESP32 reads the analog signal from the phototransistor and converts it into digital values using its built in Analog to Digital Converter (ADC). The ADC on the ESP32 can convert analog signals into digital values ranging from 0 to 4095, providing fine-grained measurement of light intensity.

The BPX-43/3 phototransistor senses light and generates an analog current that is further converted to voltage that varies with the intensity of the light. This signal is read by the ESP32 through its analog input pins. The ADC samples the analog signal at a high rate and converts it into digital values, which the microcontroller processes to quantify light intensity accurately.

To ensure accurate light measurements, a crucial step was developing an automated calibration system. This system uses three resistors with different values to calibrate the sensor, covering its entire operational range and ensuring responsiveness across varied conditions. The calibration process involved extensive testing under diverse conditions to validate the sensor's performance against its datasheet and to delineate its characteristic curve.

Hardware adaptation was necessary to accommodate the sensor's responsiveness. Various circuit configurations were proposed to optimize the sensor's performance, and complementary code was developed to automate the calibration process, streamlining operational efficiency. A Printed Circuit Board (PCB) was designed to integrate the components and to ensure compatibility with the Wemos D1 R32 board. Additionally, a 3D piece was designed to house the entire device, providing a robust and portable solution.

The software development process encompassed several key aspects: the creation of an Android app, the writing of Python scripts for data processing, and the development of a data visualization tool.

An Android app was developed using MIT App Inventor. This app allows the user to control the device remotely, sending GPS coordinates and commands to the ESP32 via Bluetooth. The integrated Bluetooth module on the Wemos D1 R32 board facilitates this communication, allowing the smartphone to send location information to the microcontroller and to activate or deactivate the device as needed.

Once a light measurement is taken, the data is stored on an SD card connected to the ESP32 via an SD card module using the Serial Peripheral Interface (SPI) protocol. For data management and visualization, Python scripts were developed. The first scripts provide the calibration coefficients for each calibration function to be included on the microprocessor's code, urged to convert the raw measurements obtained into lux. Another script automates the process of copying files from the SD card to a computer when the ESP32 is connected via USB. The script reads the data files and displays the light measurements on a heatmap. This heatmap visually represents the light intensity measurements correlated with specific GPS coordinates, providing an intuitive way to analyze the collected data.

Figure 4.1: Developing Process

4.1 Hardware Development

This section outlines the process of selecting the appropriate sensor, performing the data acquisition task, calibrating the system, designing the printed circuit board (PCB) shield, and creating the 3D design of the device. Also in this section a comprehensive look at the hardware components and their integration is provided, ensuring that the system functions effectively and meets the project's requirements.

4.1.1 Sensor Selection

From a diverse array of sensor options, four candidates emerged as the most promising for the task at hand.

The photoresistor was thoroughly tested across various conditions. It demonstrated notable attributes, particularly its logarithmic response to light interaction. Utilizing a cadmium sulfide (CdS) photoresistor as its primary light-sensing component, it proved sensitive to light changes and was easy to integrate [13]. However, its limited measurement range posed a challenge, making it unsuitable for this application.

An IR detector, while viable for testing with Arduino, required additional circuitry to be compatible with the ESP32's 3.3V, making it a secondary priority. Despite this, the availability of datasheets and open-source libraries provides avenues for further exploration.

A photovoltaic cell, although offering potential for autonomous and eco-friendly applications, lacked precision and had unfavorable size characteristics, rendering it less suitable for this project's requirements.

The phototransistor BPX43/3 was distinguished by its relatively linear response to light irradiance, providing a broader spectrum coverage than the photoresistor. It is focused primarily on measuring luminous flux and operates by creating a voltage divider between a resistor and the phototransistor. Essentially, it is an NPN transistor with a photodiode connected from base to collector, modulating resistance based on light intensity, the equivalent circuit is shown on figure 4.2. This inherent behavior facilitates accurate estimation of lux values across varied conditions, aligning with the project's objectives.

The BPX43/3 phototransistor offers several advantages that make it ideal for this project. Its almost linear response to varying light intensities ensures precise and reliable measurements, crucial for dynamic light sensing applications. The broader spectrum coverage allows it to detect a wide range of light conditions, enhancing its versatility in different environments.

In this project, the calibration resistor will be connected to the collector, where measurements will be taken, describing an inverse relationship between the measured voltage and the light intensity applied to the sensor. This setup will help in accurately converting the analog signal into digital values that the microcontroller can process.

Given its superior performance characteristics, the BPX43/3 phototransistor will be used as the main sensor for the project. Its ability to provide accurate, real time light measurements makes it indispensable for applications that require precise monitoring and analysis of light conditions. From now on, all development efforts will be centered around optimizing the use of this phototransistor to achieve the project's objectives.

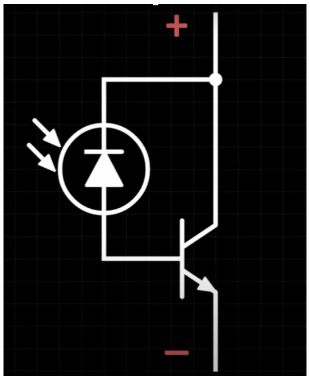


Figure 4.2: Equivalent circuit of the sensor

4.1.2 First Step: Data Acquisition

Utilizing the circuit configuration depicted in the figure 4.3, the voltage between the collector, as indicated, is measured, providing values ranging from 0 to 4095 bits depending on the detected light intensity. As explained in the sensor selection section, a value of 0 corresponds to maximum light intensity, while 4095 signifies the darkest scenario. However, a notable challenge arises during this phase. Despite the considerable variation in values, the sensor's behavior is not linear. Oscillations in dark conditions differ markedly from those in well-lit environments, necessitating different approaches for indoor, outdoor, cloudy, sunny, and nocturnal settings.

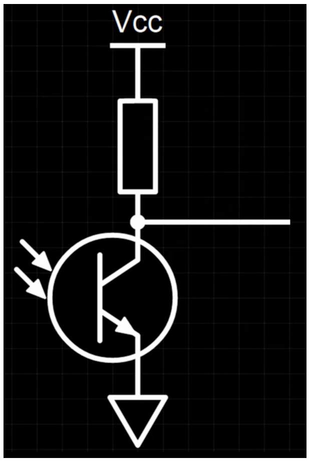


Figure 4.3: Adquisition circuit of the sensor

4.1.3 Second Step: Calibration

The first step in the calibration process involves taking measurements by comparing the raw values obtained using the ESP32 configuration with the sensor, alongside a phone app capable of measuring lux using the phone camera.

During this experiment, numerous measurements were conducted for comparison. It was discovered that the sensor's response is not linear, instead varying, as depicted in Figure 4.4. This finding is crucial in the development process. To convert bits to lux, two approaches are considered:

- Linear Interpretation: Applying a simple rule of proportionality between the contrasted bit values and lux measurements obtained via luximeters or similar applications. This should be a simple way to make the conversion but the values will radically be in a range of uncertainty and the given lux value will be just an statistical approximation to a more objective measurement.

- Curve Fitting: By conducting a series of measurements and defining a calibration curve using the obtained data points.

The curve fitting approach was chosen and the entire response range was divided into three segments, labeled A, B, and C respectively, as indicated in Figure 4.4.

These three segments will correspond to three different resistor values, referred to as "calibration resistors," which can be easily adjusted. In the hardware setup, these are represented by trimmers and are adjustable to accommodate various needs, including different light levels, environments, and sensitivities. In this project, the aim is to measure football fields, which may involve both artificial and natural light.

Each segment is defined by a curve equation that best describes its response. Segments A and B, corresponding to calibration resistors 1 and 2 respectively, are defined by quadratic equations, while segment C, related to resistor 3, exhibits an exponential behavior.

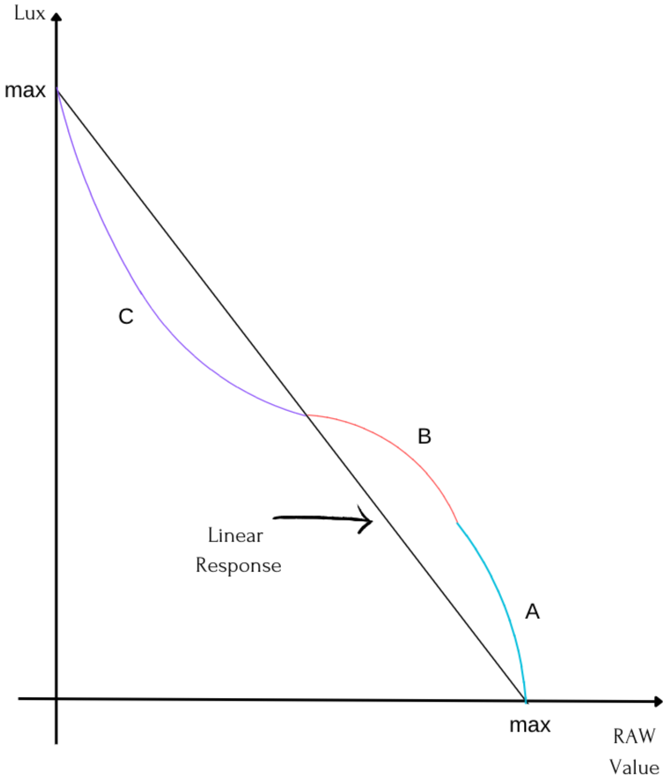


Figure 4.4: Response graphic

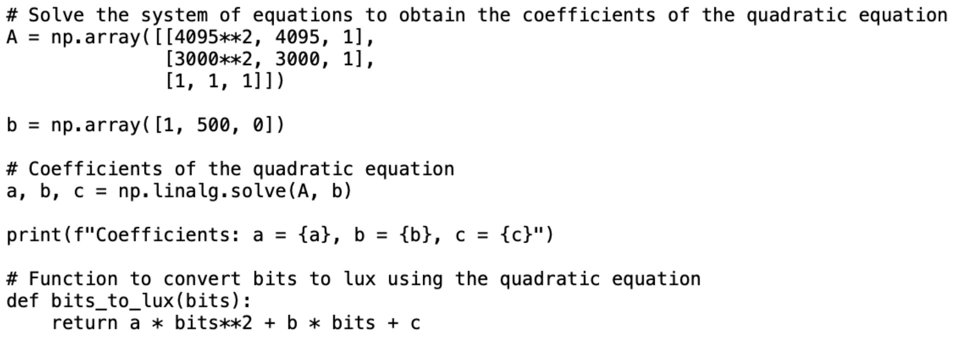
The approach to using these equations

Using Excel to interpreting the information obtained, three different equations where provided as a first insight to understand the behavior of the response. Recognizing that there are three equations used in the calibration process to convert raw measurements into lux, three separate Python scripts were developed. The primary purpose of these scripts is to determine the most accurate coefficients to generate a characteristic equation that converts raw values into lux, using the most accurate approach depending on the calibration resistor in use. In simpler terms, the user can analyze the raw measurements and compare them with the most suitable device for the location. These measurements will determine the lux values and raw values, which in turn dictate which equation is applied to each range.

In this project's approach, the full conversion response is divided into three different ranges as follows:

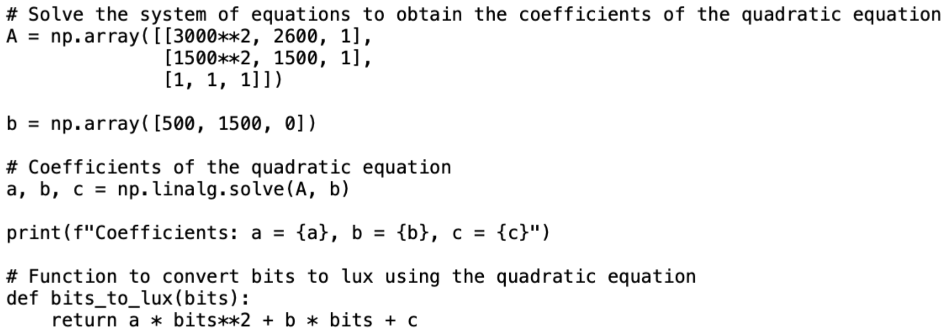
- 3500 to 4095 bits corresponds to Resistor 1. Figure 4.8
- 2500 to 3500 bits corresponds to Resistor 2. Figure 4.9
- 0 to 2500 bits corresponds to Resistor 3. Figure 4.10

The obtained calibration equations and coefficients are to be observed on the figures 4.5, 4.6 and 4.7.



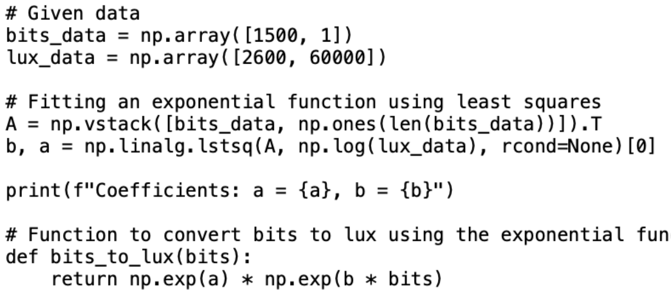
```
# Solve the system of equations to obtain the coefficients of the quadratic equation
A = np.array([[4095**2, 4095, 1],
              [3000**2, 3000, 1],
              [1, 1, 1]])

b = np.array([1, 500, 0])

# Coefficients of the quadratic equation
a, b, c = np.linalg.solve(A, b)

print(f"Coefficients: a = {a}, b = {b}, c = {c}")

# Function to convert bits to lux using the quadratic equation
def bits_to_lux(bits):
    return a * bits**2 + b * bits + c
```

Figure 4.5: Calibration coefficients calculation for resistor 1



```
# Solve the system of equations to obtain the coefficients of the quadratic equation
A = np.array([[3000**2, 2600, 1],
              [1500**2, 1500, 1],
              [1, 1, 1]])

b = np.array([500, 1500, 0])

# Coefficients of the quadratic equation
a, b, c = np.linalg.solve(A, b)

print(f"Coefficients: a = {a}, b = {b}, c = {c}")

# Function to convert bits to lux using the quadratic equation
def bits_to_lux(bits):
    return a * bits**2 + b * bits + c
```

Figure 4.6: Calibration coefficients calculation for resistor 2



```
# Given data
bits_data = np.array([1500, 1])
lux_data = np.array([2600, 60000])

# Fitting an exponential function using least squares
A = np.vstack([bits_data, np.ones(len(bits_data))]).T
b, a = np.linalg.lstsq(A, np.log(lux_data), rcond=None)[0]

print(f"Coefficients: a = {a}, b = {b}")

# Function to convert bits to lux using the exponential function
def bits_to_lux(bits):
    return np.exp(a) * np.exp(b * bits)
```

Figure 4.7: Calibration coefficients calculation for resistor 3

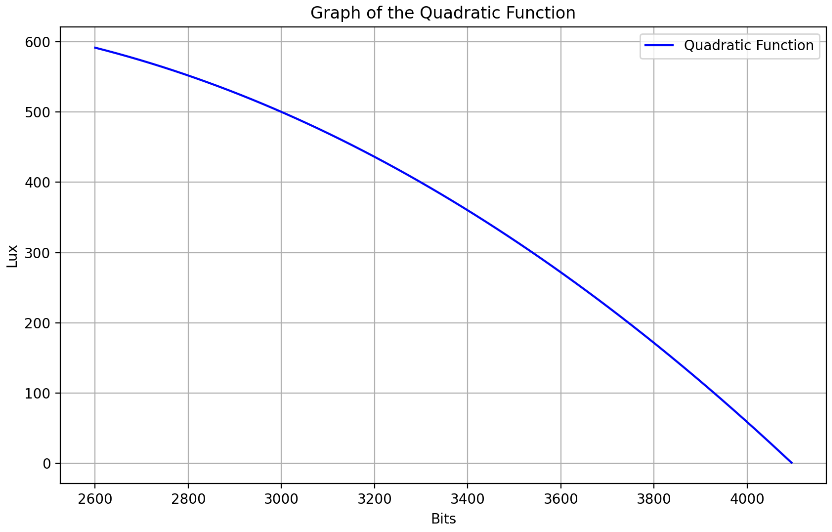


Figure 4.8: Calibration curve for resistor 1

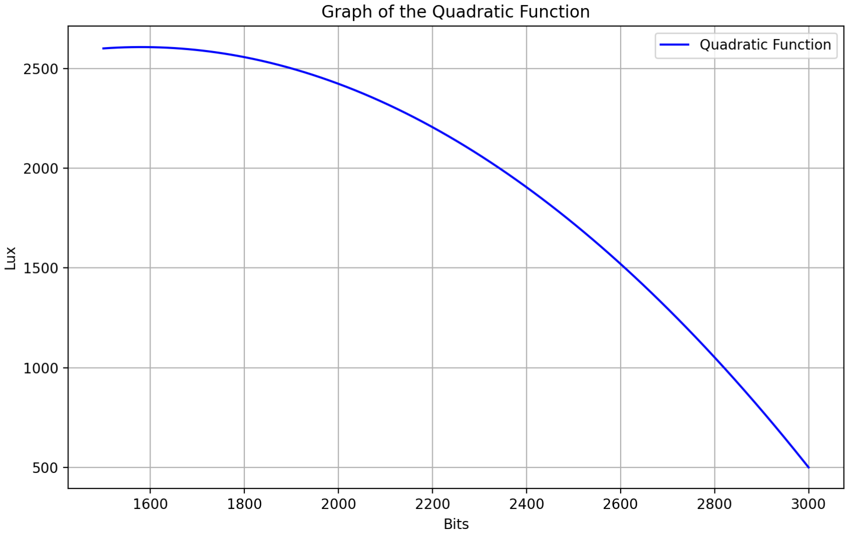


Figure 4.9: Calibration curve for resistor 2

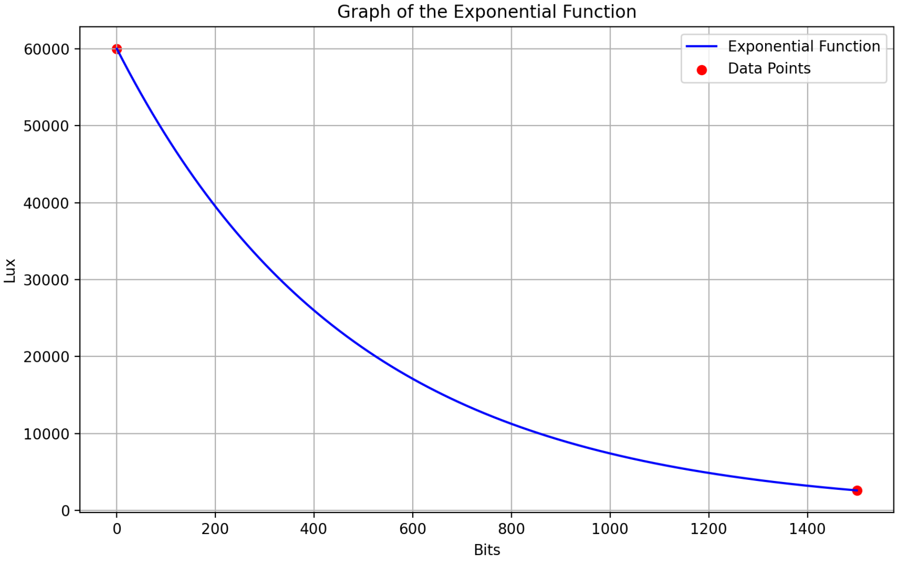


Figure 4.10: Calibration curve for resistor 3

The generated functions are the result of exhaustive analysis of obtained measurements. As depicted in the graphs, the saturation point occurs at approximately 60,000 lux for normal daylight conditions in a semi-covered outdoor area, naturally, for the chosen calibration resistor values.

The obtained equations and coefficients for each segment are indexed and used for the calibration on the Wemos Board code as presented on section 4.2, Software Development.

4.1.4 KiCad Board Design

The board for this project was designed using KiCad, which is an open-source software suite for Electronic Design Automation (EDA). It allows users to design schematics for electronic circuits and convert these schematics into printed circuit board (PCB) layouts. KiCad is popular among electronics hobbyists and professionals because it is free, versatile, and has a large community that provides support and resources.

The PCB is designed with the same shape as the Wemos D1 R32 board. This allows it to be plugged in as a shield on the Wemos board, creating a more compact, robust, and secure solution. By fitting perfectly on top of the Wemos board, the shield ensures that all connections are stable and reduces the risk of loose wires or accidental disconnections.

On the board, the three trimmers are mounted in a way that makes them easy to access. This design choice was made to facilitate the recalibration of the device whenever necessary. Trimmers are adjustable resistors that allow for fine tuning of the circuit, and having them accessible makes the calibration process much simpler and more efficient.

The SD card module is also mounted on the board, positioned on the same side as the trimmers. This arrangement ensures that the SD card is easy to access, whether for troubleshooting malfunctions or simply changing the memory card.

Additionally, the board includes a connector for the phototransistor sensor. This connector allows the sensor to be easily connected or replaced in case of a malfunction. It also gives the flexibility to mount the sensor on the device's case, which will be explained further later in this chapter.

The schematic and full shield's 3D model can be observed on the images 4.11 and 4.12 respectively.

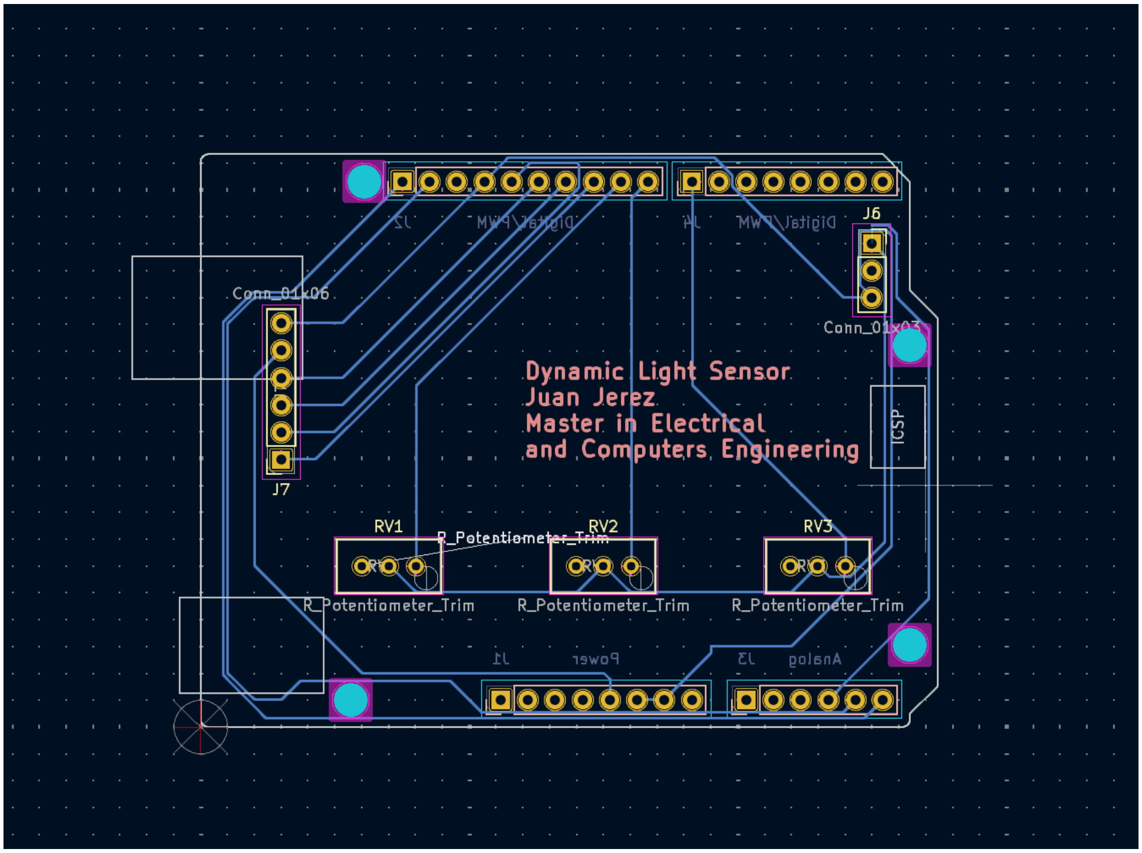


Figure 4.11: Schield schematic design

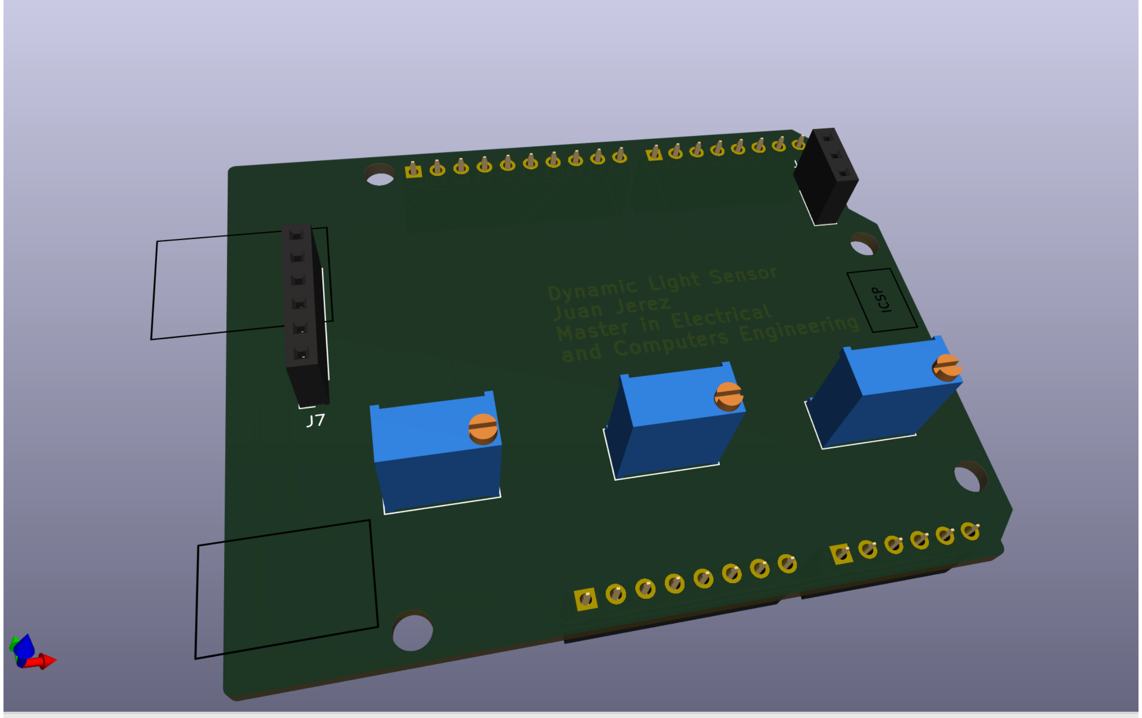


Figure 4.12: Schield PCB design

4.1.5 3D Design

The primary focus of this support case, designed using SolidWorks, is to create a casing solution that accomplishes the integration of various components into a robot's arm or surface. These components include boards, particularly the Wemos and the project designed shield board attached to it, the sensor positioned atop the case and linked to the boards via wires and the smartphone, situated on the opposite side of the case.

The crucial point of the matter lies in designing a case that securely houses these components. Placing the sensor on top of the case is pivotal for optimal light measurement. This setup ensures the sensor is positioned efficiently to capture light, thereby enhancing its sensing capabilities.

The case's design facilitates seamless integration of components, maintaining stability and ease of access for maintenance or adjustments while ensuring the sensor is strategically placed for effective light measurement. The final case model is exhibited on 4.13 and 4.14

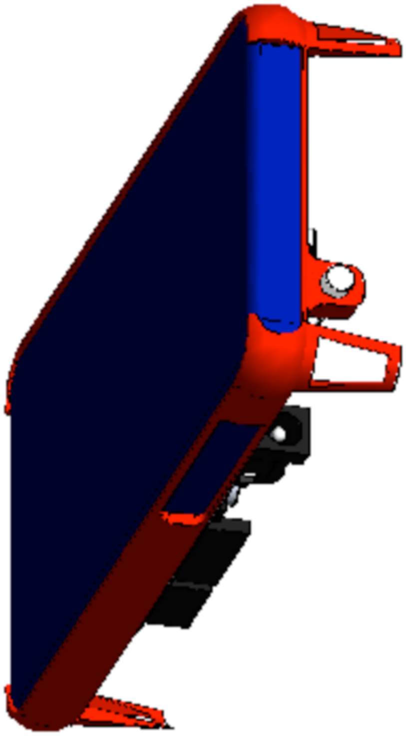


Figure 4.13: Case and sensor upper-side view

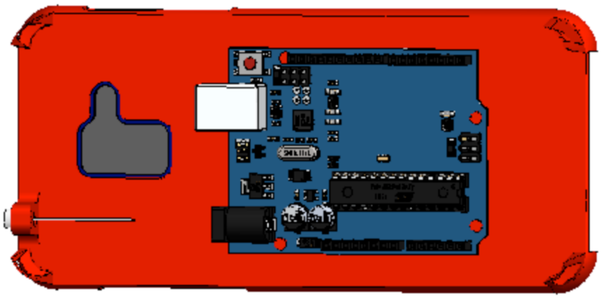


Figure 4.14: Case and Esp32 board back view

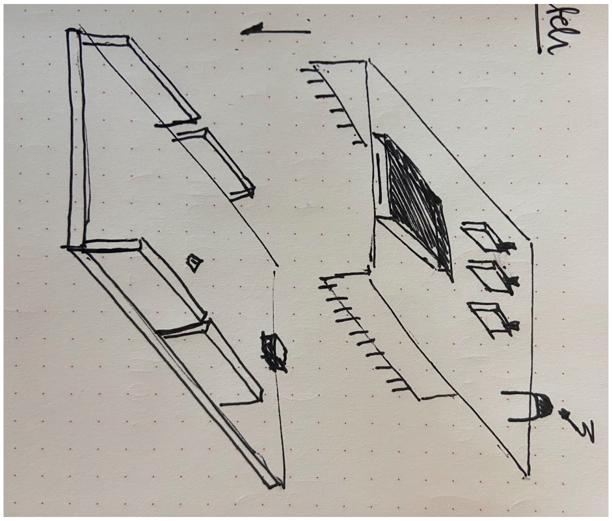


Figure 4.15: First Sketch Idea

4.2 Software Development

In the domain of software development, the project goes for some tools and methodologies to elevate its capabilities and user experience. Software development plays an important role in orchestrating the integration and operation of the device, ensuring both precision in data collection and intuitive user interaction.

On the user application's side the developing tool is MIT App Inventor. MIT App Inventor offers a visual programming interface, enabling rapid development and deployment of feature-rich applications tailored to the project's requirements.

The developed Android application, serves as a cornerstone of the project's functionality, offering two key functionalities to enhance user experience and device control:

Automatic GPS Coordination: The application leverages the device's GPS capabilities to periodically send precise location coordinates (latitude and longitude) at user-defined intervals. This functionality ensures accurate spatial mapping of measurements, enhancing the overall utility of the device in diverse environments.

Device Control: With intuitive controls embedded within the application interface, users can effortlessly initiate and terminate device operations with the tap of a button. This smooth control mechanism enhances user convenience and flexibility, allowing the integration of the device into various workflows and applications.

By using this important tool, the Android application embodies the essence of the user experience design, offering functionality, ease of use, and adaptability. This software driven approach underscores the project's commitment to delivering a solution.

4.2.1 Android Application

MIT App Inventor operates through a visual programming interface, allowing users to design and develop applications by arranging visual elements and connecting them with blocks of code, as shown on the figure 4.16

Creating an app starts by designing the app's interface, selecting components such as buttons, text boxes, and menus to create the desired layout. Then the app's functionality

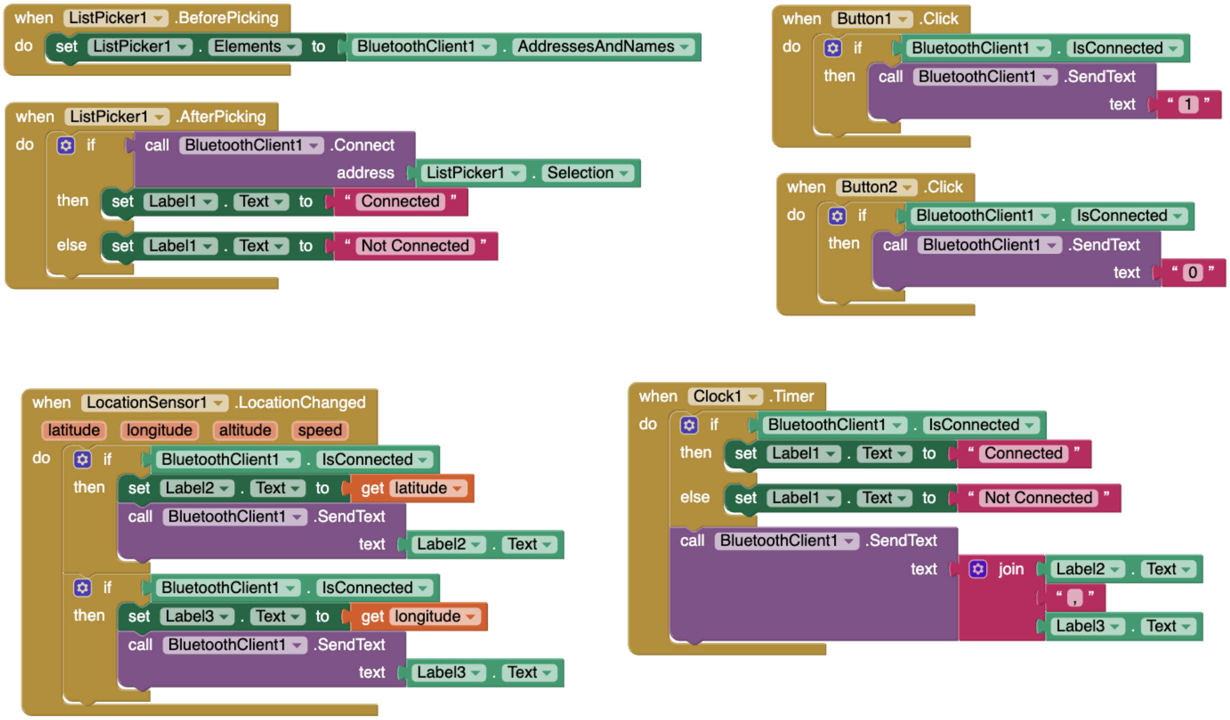


Figure 4.16: Android App backend blocks

is designed by adding blocks of code that specify how the app should respond to user interactions and events, this is the back end part.

On the back end section the main functionality of the app is described in four big blocks:

- Connectivity Block: Where the bluetooth connection is established
- Location Sensor: It allows the location services to start working and defines their properties
- Buttons: Defines what the on/off buttons do and which messages they trigger
- Message sending: When and how the messages are going to be transmitted to the ESP32

Once the app is created, it can be easily installed and updated on a smartphone. By downloading the .apk file generated by MIT App Inventor it is possible to install the app manually. Alternatively, it can also be published on the App Store for an easy access.

Regarding the structure and functionality of the Android application developed for this project. The app continuously monitors position changes using a position sensor, displaying the latitude and longitude separately on the screen. Additionally, it features a sliding menu that lists all available devices to be found via Bluetooth.

The app's main functionality revolves around connecting to the Wemos board via Bluetooth. Once the connection is established, the app indicates "connected" on the screen. It then initializes the GPS server, which may take a few seconds initially until a provider is found, and displays it on the screen.

A menu within the app contains two buttons: "on" and "off." When these buttons are pressed, a message is sent to the Wemos board indicating 1 or 0, respectively. This functionality enables users to control the device remotely with ease. This is to be further explained on the following subsection "Operational Workflow" and a picture of the user's interface is shown on figure 4.17.

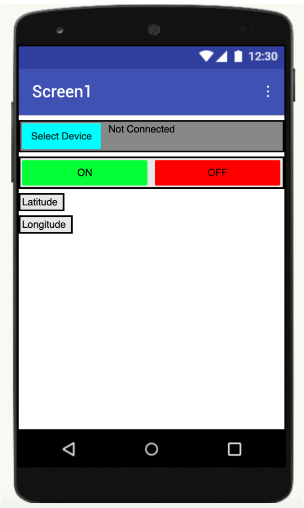


Figure 4.17: Android app user interface

Furthermore, the app sends a message every 5 seconds (adjustable) containing the latitude and longitude parsed as a string, with both values separated by a comma. This periodic communication ensures that the device receives real time location data, facilitating accurate data collection and analysis.

4.2.2 Operational Workflow

The structure of the main algorithm flashed on the ESP32 for the project operates as follows:

Initially, the device remains inactive until it receives an "on" command via Bluetooth, which is indicated by a 1. Upon receiving this command, several actions are triggered. A new file is created on the SD card with the name format "data_n," where "n" represents the version number. The system checks the SD card to determine the name of the last file created to ensure the new file name is unique. Additionally, the integrated LED on the Wemos board is turned on to indicate that the device is running.

When a new message is received, which occurs at the interval set by the app (5 seconds by default), a new measurement is taken. The raw sensor value is converted to lux, as explained in the "hardware development" section. These three values—the raw sensor value, the lux value, and the GPS coordinates—are saved to a CSV file on the SD card.

The board continues to receive GPS coordinates, take measurements, and store them until an "off" command is received, which is indicated by a 0. When the "off" command is received, any information not yet saved is automatically flushed from the buffer, the file is closed, and the system returns to a ready state for a new "on" command.

Once the necessary measurements are taken, the board can be connected to a computer via Bluetooth. By running a Python script, all new files from the SD card are saved in the "received files" folder on the computer. The last saved file is then automatically read and displayed as a heatmap.

The heatmap provides an interactive way to display the CSV file information. The latitude and longitude are plotted on the two axes, and each coordinate corresponds to a dot that indicates the light measurement in lux, represented with a color scale. By sliding the cursor over each dot, detailed information is displayed on the screen, including the latitude, longitude, and lux value.

This algorithm ensures efficient data collection, storage, and visualization, making it an integral part of the project's overall functionality.

On the figure 4.18 the overall workflow of the program is shown. This is an easy to read workflow diagram for the mere purpose of understanding the device's main states and actions to be performed and in which order they occur.

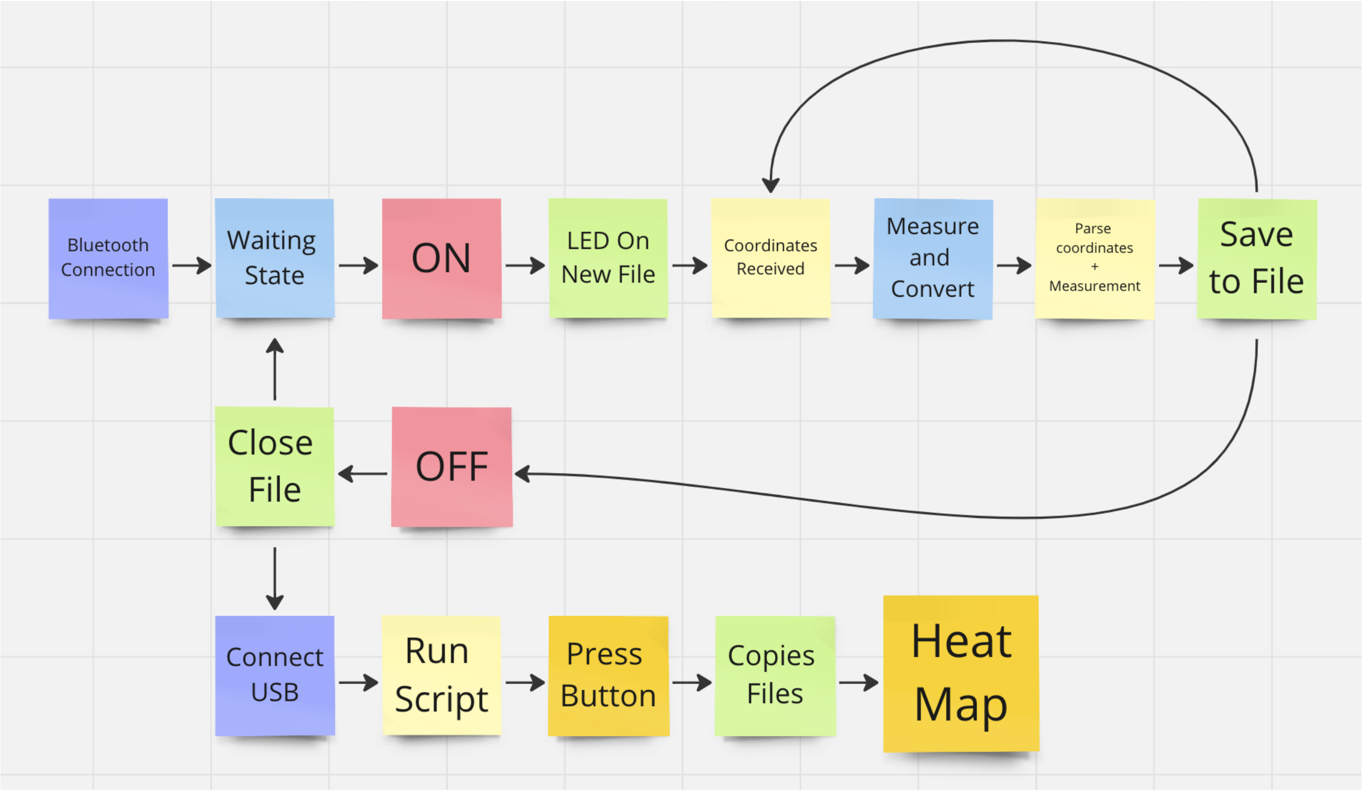


Figure 4.18: Operational Workflow

Chapter 5

Results

In this chapter, the findings from three distinct experiments are presented, designed to evaluate various aspects of the project. The first experiment focuses on testing the GPS functionality by recording only raw measurements, ensuring the GPS works accurately and reliably. The second experiment exposes the sensor to extreme conditions, allowing to observe its behavior and response when paired with GPS coordinates under a challenging scenario. The final experiment is a full-scale test involving different lighting conditions to verify the sensor and GPS work properly together, ensuring consistent performance and accurate data collection in real world settings.

5.1 Raw Measurements in an Open Space

Before fully implementing the light sensing functionality, it was crucial to conduct an initial experiment to test the GPS precision of the device. Ensuring accurate location tracking is fundamental for the success of the project, as the reliability of the data is heavily dependent on precise geolocation.

Accurate GPS coordinates are essential for mapping light measurements to specific locations. Inaccurate or inconsistent GPS data would undermine the reliability of the collected light measurements, rendering the entire data set less useful for analysis. Therefore, testing the GPS precision early in the development process allows us to verify that the device can provide accurate geolocation data, ensuring the quality and integrity of the final light sensing application.

The test was conducted at Treptower Park, a well known location that offers a variety of environmental conditions for testing comparable to a football field for its extension and architectural characteristics. The device was fully assembled, although for this initial test, the focus was solely on evaluating the raw GPS measurements rather than converting these measurements into lux values.

During the experiment, the device was moved around the park while continuously recording GPS coordinates. The primary goal was to assess the precision of the recorded locations and to verify that the device could accurately track changes in position.

The results were encouraging. The GPS coordinates recorded by the device showed a high level of precision. When plotted on a heat map of Treptower Park (check figure 5.2), the obtained heat map clearly reflected the paths taken during the test. Even slight deviations in the movement were accurately marked, indicating the device's ability to detect and record small changes in position effectively.

To further test the precision, deliberate deviations were made from a predefined path. These deviations were indeed accurately recorded on the heat map, demonstrating the device's capability to capture and reflect real time positional changes with high fidelity.

The accompanying image of Treptower Park's map (check figure 5.1) alongside the obtained heat map vividly illustrates the precision of the GPS tracking. The heat map shows clusters of recorded coordinates that match the actual paths taken during the test. This visual representation confirms the device's ability to provide accurate and reliable location data, which is crucial for the subsequent light measurement experiments.

An extended testing was conducted in different locations with varying environmental conditions to ensure consistent GPS performance across diverse settings. Dynamic testing was also carried out to test the device while moving at different speeds to evaluate how well it tracks rapid changes in position this was contrasted on the app's display.

The initial GPS precision test at Treptower Park was a success, confirming that the device can accurately record location data. This precision lays a solid foundation for the next phase of the project, where light measurements will be integrated with GPS data to provide valuable insights into light conditions across different environments. Ensuring the accuracy of the GPS coordinates was a critical step, and the positive results from this experiment instill confidence in the device's overall performance and reliability.

Figure 5.1: Treptower Park google maps view

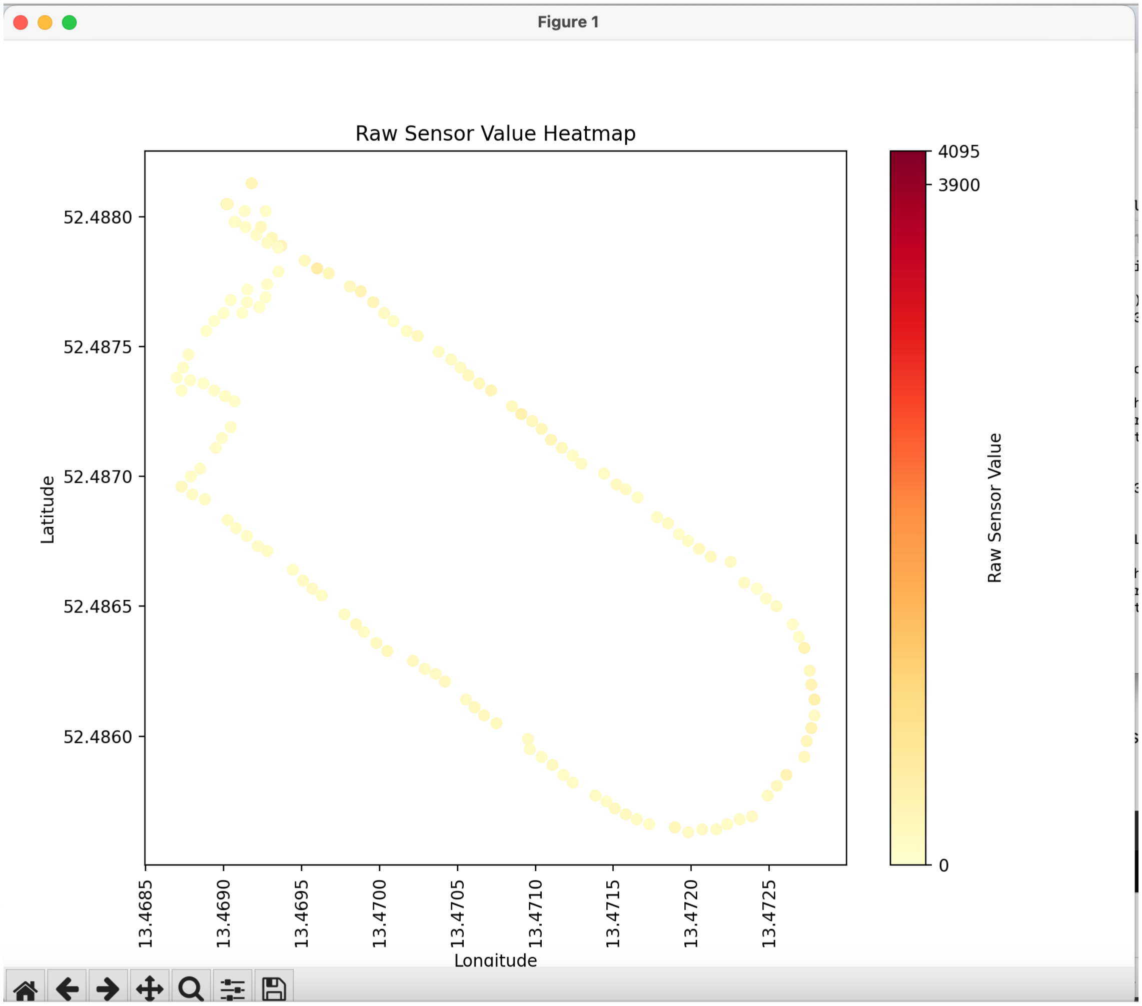


Figure 5.2: Treptower Park heatmap view

5.2 Light Exposure Experiment in Open Dark Conditions

Following the initial success of the GPS precision test, a second experiment was conducted to evaluate the sensor's performance under minimal light intensity conditions in an open space at night. The objective was to observe the comprehensive outcomes of the project, integrating both the GPS and light sensing functionalities.

For this experiment, the sensor was subjected to the lowest light intensity achievable within an open area during nighttime. This setting provided a challenging environment to test the sensitivity and accuracy of the light sensor under near-dark conditions. The experimental route involved circumnavigating a square area, as delineated in the reference picture.

As the device moved around the square, it continuously recorded light intensity measurements in lux, along with the corresponding GPS coordinates. The collected data were then visualized in a heatmap, depicted in the second figure. This heatmap illustrates the distribution of light intensity along the perimeter of the square, with a color scale reference provided for interpretation. Check the heatmap on figure 5.4

The results from this experiment were quite revealing. The heatmap clearly shows variations in light intensity around the square area, even under minimal light conditions. The lux values recorded by the sensor accurately reflected the changes in ambient light, demonstrating the sensor's capability to detect and measure low light levels effectively.

Additionally, the GPS data remained precise, ensuring that each light measurement was accurately mapped to its corresponding location. This accuracy is crucial for creating a reliable dataset that can be used for further analysis and applications.

An important feature of the system is the ability to access both the actual measurement values and their corresponding coordinates not only through the CSV file but also interactively. By hovering the mouse over points of interest on the heatmap, users can instantly view detailed information about each measurement, including the lux value and the exact GPS coordinates. This interactive feature enhances the usability and accessibility of the data, making it easier to analyze and interpret the results.

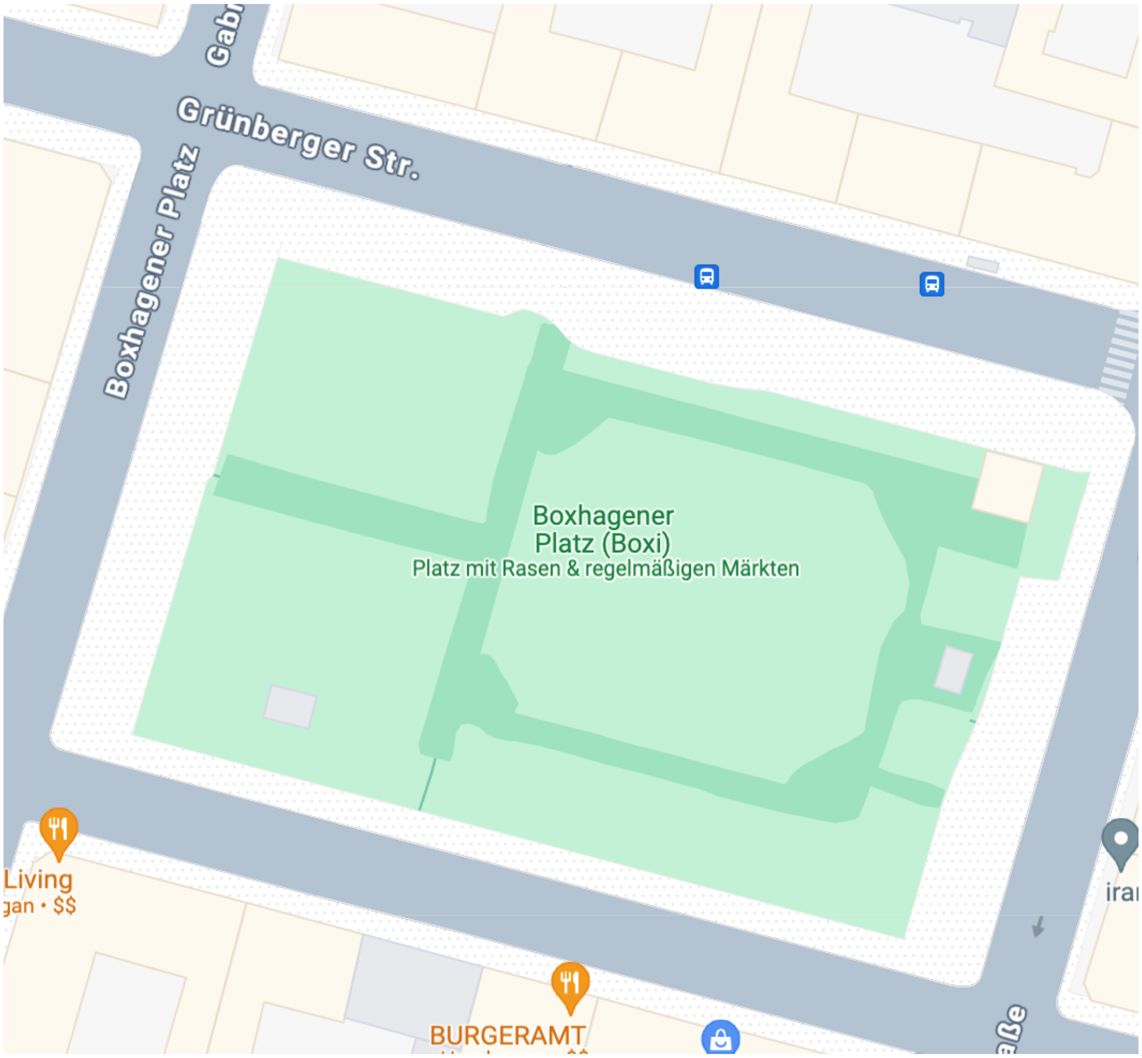


Figure 5.3: Boxhagener Platz maps view

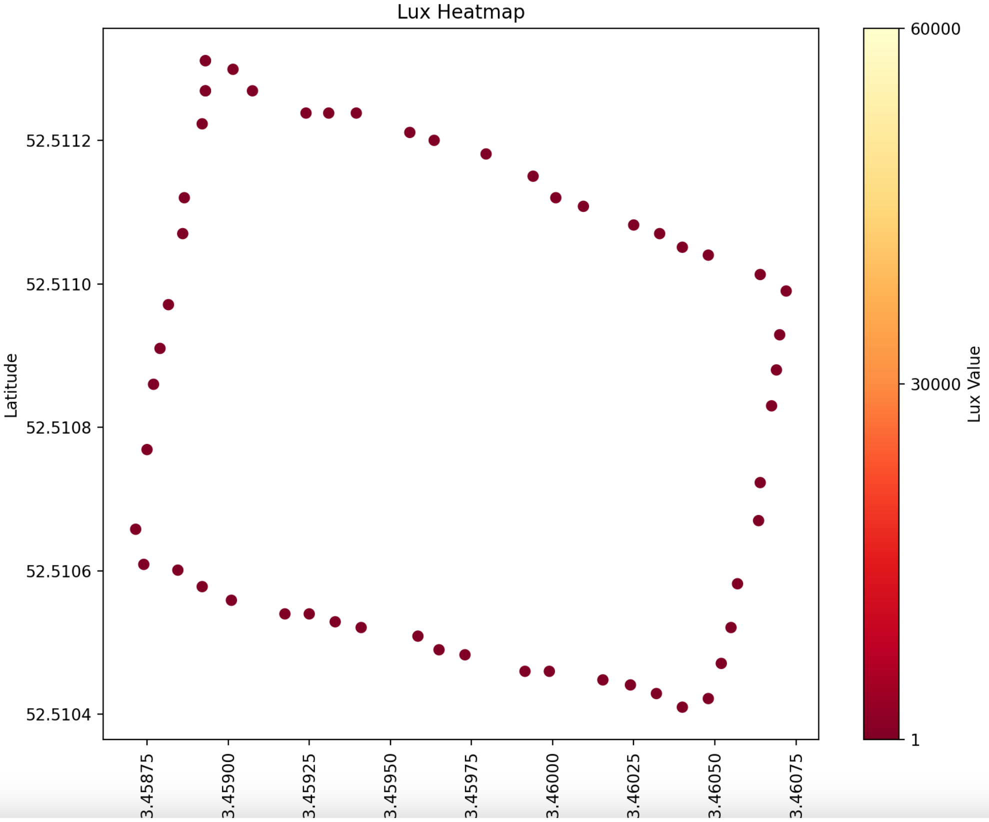


Figure 5.4: Boxhagener Platz heatmap view

5.3 Light Exposure Experiment in Open Changing Conditions

Following the initial success of the GPS precision test, a subsequent experiment was conducted to evaluate the sensor's performance under a variety of light conditions, ranging from very bright to heavily shaded areas. The main purpose was to see how effectively and quickly the sensor could adapt to different lighting environments, showing its full operational range.

This experiment was conducted in an area comparable to a small football field, that can be observed on the figure 5.5. The device was moved through different conditions, including regions with a lot of light and areas with significant shade. This setup provided a comprehensive environment to test the sensitivity and accuracy of the light sensor as it transitioned between extremes.

As the device traversed the field, it continuously recorded light intensity measurements in lux, along with the corresponding GPS coordinates. The collected data were visualized in a heatmap, which illustrates the distribution of light intensity across the area. The heatmap, depicted in the reference figure 5.6, shows properly the lighted and shadowed areas. The table of measurements is shown on the figure 5.7 (shortened version)

It is important to note that this experiment was conducted in an open public space with people present, moving at varying speeds and along different paths. This means the resulting heatmap aims to show the full scale of the sensor's response, which should be compared with the image in figure 5.5.

Figure 5.5: Park where the last test was made

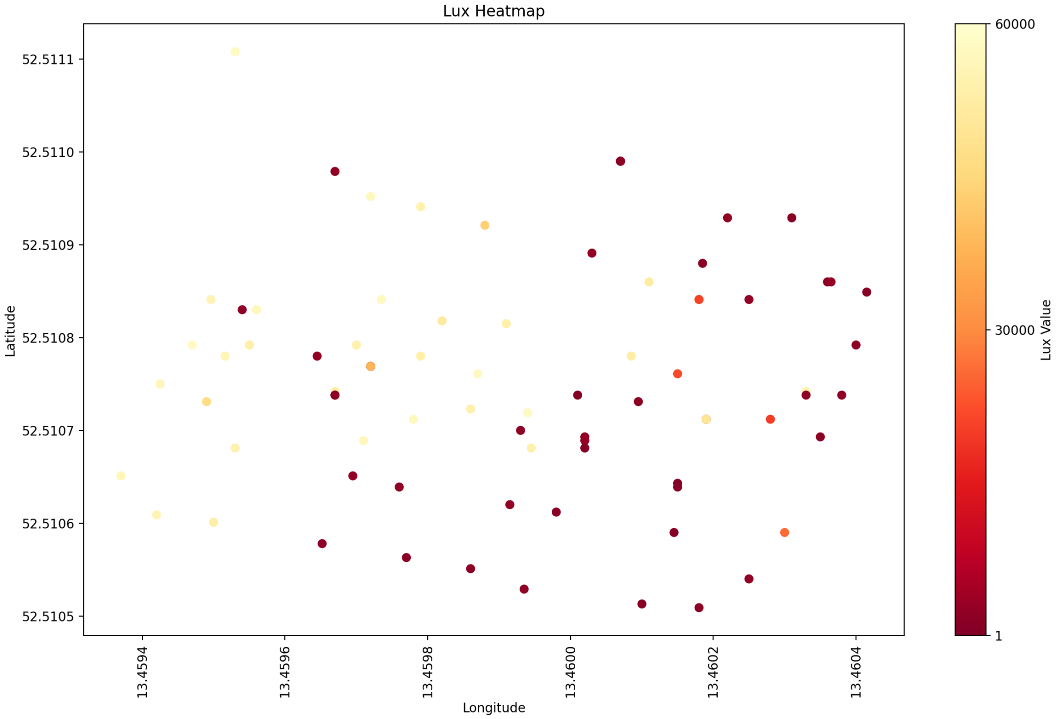
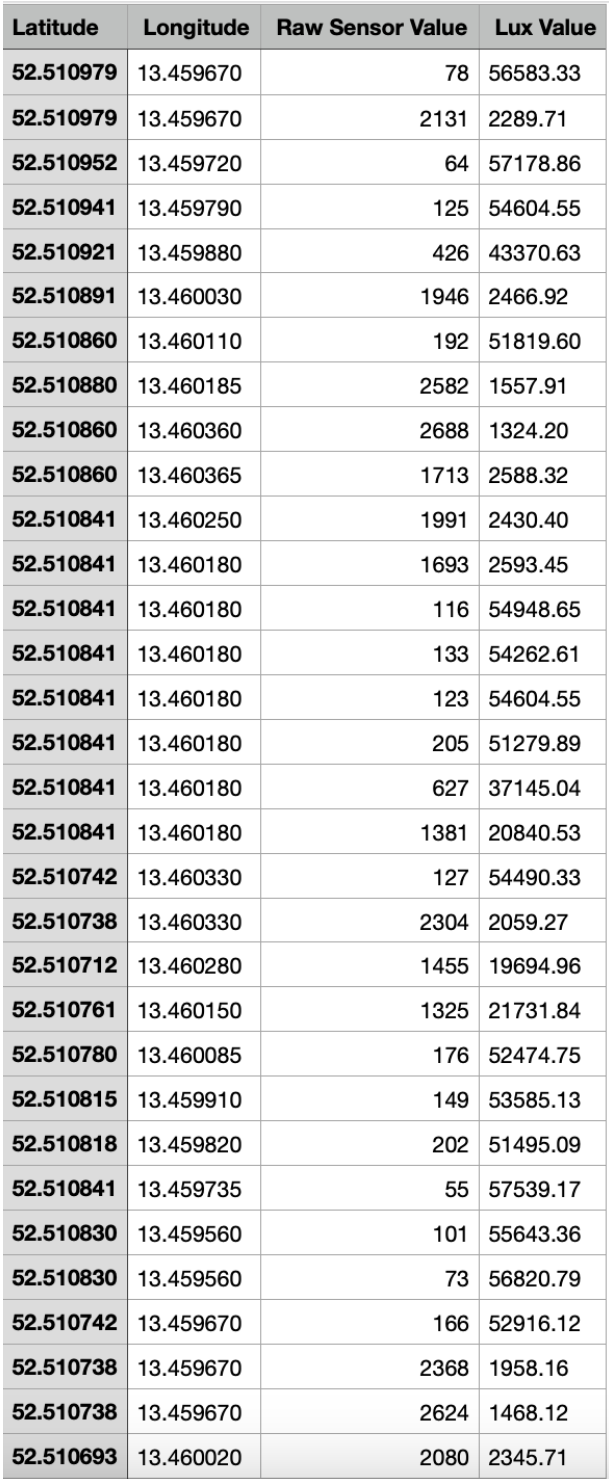


Figure 5.6: Heatmap in changing light conditions



Latitude	Longitude	Raw Sensor Value	Lux Value
52.510979	13.459670	78	56583.33
52.510979	13.459670	2131	2289.71
52.510952	13.459720	64	57178.86
52.510941	13.459790	125	54604.55
52.510921	13.459880	426	43370.63
52.510891	13.460030	1946	2466.92
52.510860	13.460110	192	51819.60
52.510880	13.460185	2582	1557.91
52.510860	13.460360	2688	1324.20
52.510860	13.460365	1713	2588.32
52.510841	13.460250	1991	2430.40
52.510841	13.460180	1693	2593.45
52.510841	13.460180	116	54948.65
52.510841	13.460180	133	54262.61
52.510841	13.460180	123	54604.55
52.510841	13.460180	205	51279.89
52.510841	13.460180	627	37145.04
52.510841	13.460180	1381	20840.53
52.510742	13.460330	127	54490.33
52.510738	13.460330	2304	2059.27
52.510712	13.460280	1455	19694.96
52.510761	13.460150	1325	21731.84
52.510780	13.460085	176	52474.75
52.510815	13.459910	149	53585.13
52.510818	13.459820	202	51495.09
52.510841	13.459735	55	57539.17
52.510830	13.459560	101	55643.36
52.510830	13.459560	73	56820.79
52.510742	13.459670	166	52916.12
52.510738	13.459670	2368	1958.16
52.510738	13.459670	2624	1468.12
52.510693	13.460020	2080	2345.71

Figure 5.7: Table of measured values in changing light conditions

Chapter 6

Conclusion and Future Work

The goal of this project was to develop a system capable of measuring light intensity with high precision, and this objective was successfully achieved. The integration of various technologies, such as light sensors, GPS modules, and wireless communication, resulted in a robust and accurate device that could dynamically sense and record light levels in different environments. The project demonstrated that it is possible to achieve precise light intensity measurements, providing valuable data for applications in sports centres. The effectuated tests were all made in environments comparable to football fields in different lighting situations.

Throughout this project, significant learning milestones were accomplished. One of the key achievements was the ability to organize a complex project effectively. This involved meticulous planning, coordinating different components, and ensuring that all parts worked seamlessly together. The process highlighted the importance of project management skills, such as setting milestones, managing resources, and troubleshooting issues as they arose.

Another major accomplishment was the creation of an Android application. The used platform allowed for the development of a user friendly app that facilitated GPS coordination and device control. Learning to use this tool was invaluable, as it provided insights into mobile app development and user interface design. The experience underscored the importance of software development skills in creating intuitive and functional applications that enhance the user experience.

The project also provided extensive hands-on experience with both basic and complex electronics. From selecting and testing various sensors to designing and building electronic circuits, each step involved practical experimentation and learning. This process deepened the understanding of electronic components and their interactions, pursuing a comprehensive knowledge of hardware design and integration. Specifically, when the phototransistor was analysed a very deep analysis of the datasheet and functionality of the part was done, encountering the very interesting behavior of it, the device was run in different situations and conditions and the continuous testing of it delimited the best condition for its proper polarization.

Data storage and connectivity were crucial aspects of the project. The ability to store data efficiently on an SD card and establish reliable wireless connections via Bluetooth were essential for the system's functionality. These tasks involved learning about different communication protocols, data formats, and storage techniques, contributing to a well-rounded skill set in data management and wireless communication.

One of the significant challenges faced during the project was designing the electronic circuitry and the industrial piece. Creating a printed circuit board (PCB) using KiCad required precise planning and attention to detail. The board was designed to fit the shape of the Wemos D1 R32, enabling it to plug in as a shield for added safety, compactness, and robustness. The inclusion of trimmers and an easily accessible SD card module on the board facilitated calibration and data retrieval. Additionally, the industrial design of the case, crafted using SolidWorks, ensured that all components were securely housed and optimally positioned, particularly the sensor, which needed to be exposed to light accurately.

This project not only achieved its primary goal of measuring light intensity with precision but also provided a comprehensive learning experience across multiple disciplines. The skills gained in project organization, Android app development, electronics experimentation, data storage, and connectivity were invaluable. The challenges faced in designing the electronic circuitry and industrial piece were met with innovative solutions, resulting in a functional and reliable light sensing system. This project demonstrated the potential for integrating various technologies to create practical and efficient solutions for real world applications, laying the groundwork for future advancements in dynamic light sensing and related fields.

Thinking about future improvements is essential for several reasons and is particularly important in the context of engineering projects. Continuous improvement and innovation drive progress, ensure sustainability, and enhance the impact of the work done.

Enhancing functionality and performance is one of the primary reasons for considering future improvements. In our light intensity measurement project, advancements could lead to more precise measurements, faster data processing, and greater reliability. Such enhancements would broaden the application scope and increase the system's value in various fields such as environmental monitoring and smart city planning. Some proposals are listed as follows:

Adjusting Sensitivity Using the Base Pin

Calibrating using the base pin on a phototransistor involves adjusting its sensitivity and response by manipulating the current flow through the base pin. This method is useful for fine-tuning the phototransistor's performance to match more precise light sensing requirements.

Using more calibration trimmers

Using additional resistors for calibration enhances the accuracy of phototransistor measurements by providing finer control over sensitivity and response. By employing trimmer resistors with varying values or precision resistors with stable characteristics, adjustments can be made to fine-tune the base current flowing through the phototransistor. This allows for the creation of precise calibration curves and optimized performance across a wider range of light intensities, resulting in more reliable and repeatable measurements for light sensing applications.

Creating a menu on the app to set the messages time

Creating another menu option to set the time intervals for the triggers would be of great impact, then it would guide the obtained measurements according to user's requirements in a more friendly way, as well as generating a more efficient use of the available memory. Also, this would provide an easier way to create heatmaps that could show more information or smoother transitions between different light condition areas on the measuremed field.

Creating an IoT Data Logging System with Wemos Wi-Fi Module

Utilizing the Wemos Wi-Fi module, it can be established an IoT data logging system capable of collecting, storing, and analyzing sensor data over the internet. This system enables seamless communication with sensors, allowing real time transmission of data for remote monitoring and analysis.

Using other sensor's functionalities

This kind of sensor provides a wide range of other functionalities that could be applied to the project, a very important one would be the wavelength measurement. This could be useful to determine very important information about the sport courts and fields in general. A great update on the project would be adding other sensor/s, the integration of them would not be a major problem for the reliable and stable structure of the device that is already running.

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Appendix A

Original Project Proposal

Measuring light intensity in sports facilities is important because good lighting makes a big difference in how well sports are played and how enjoyable they are. This project aims to create a tool that can measure light intensity accurately, both indoors and outdoors.

The project will use a robot developed by the UFPN in Brazil. The plan is to make a sensor that works with this robot. The robot will go to different spots on the field, take measurements, and then show the results in a way that is easy to understand. This will help to make sure the lighting is just right, no matter the time of day or weather.

There are a few technical issues to tackle. One is making sure the sensor gives precise and consistent readings. Another is keeping the device simple and efficient, using as little electronic hardware as possible. Also, managing the data collected and making it easy for users to see and use the information is very important.

By solving these problems, the project aims to improve lighting in sports facilities. This will make playing conditions better, which helps players perform well and keeps everyone safe. This project is part of a larger effort to use advanced technology to enhance sports environments.