GLASGOW CALEDONIAN UNIVERSITY

MEng Group Research Project

MMH723842-24-AB-GLAS

Design and implementation of a PSD-Based Analogue 2D Sun Sensor

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Contents

List of Figures

Abstract

add abstract here

1. Acknowledgements

2. Introduction

2.1 Problem Statement

With the ever-increasing commercialization of the space and satellite industry there is a growing need for a cost-effective method of attitude tracking for smaller satellite missions of such as CubeSat as these missions are purpose built for very specific objectives. Whilst the larger commercial satellite missions make use of expensive digital camera systems for tracking purposes, this is not feasible for much smaller CubeSat setups. CubeSats are defined from 1 unit to 12 – where 1U is a 10x10x10 cm satellite. Consequently, there is a demand for a cost-effective and easily implementable attitude tracking system that can provide accurate measurements for CubeSat missions, such as a Position Sensitive Detector (PSD) using photodiodes.

2.2 Aim of the Project

"To investigate and develop a cost-effective and reliable sun sensing solution suitable for Low Earth Orbit (LEO) nanosatellite attitude determination."

2.3 Objectives of the Project

To investigate the design of a sun sensing system for nanosatellites, used in orientation determination, through detection of its relative position to the sun using analogue sensors located on the satellite's body. Our goal is to create a system which balances cost-effectiveness and simplicity. To achieve this, we will create a software model of the analogue sensor(s) to simulate the system's ability to track the sun from various angles in orbit. After which, we aim to build a physical prototype and use a movable light source to simulate the sun's movement, allowing comparison between the real sensor's performance against our simulations. Although the physical prototype will be built using non-space-grade materials, one of the objectives is to look at and analyse materials required for building a space-grade PCB and sensor. For this step, the Mechanical side of the team will perform Printed circuit board (PCB) and aperture device finite analysis using ANSYS to determine resilience to environmental factors such as stress and thermal simulation. Throughout the project, we will address challenges like interference from other light sources (such as the moon), reflections from the Earth's surface, and how factors like radiation and temperature changes in space might impact the sensor's accuracy. The application of signal processing will be explored to provide usable data, filter out noise, and improve the system's accuracy. This approach aims to develop a cost-effective and reliable, in-house sun sensing solution specifically for nanosatellites operating in Low Earth Orbit. Major Objective points:

- **Conduct literature review:**
  - Analyse existing research on sun sensing technologies, with a focus on PSD-based analogue sensors and their applications in nanosatellites.
  - Identify current challenges, best practices, and advancements in attitude determination in Low Earth Orbit. Use these insights to guide the design and optimisation of the proposed sun sensing system.
- **Develop software model:**
  - Simulate the performance of the PSD-based analogue sun sensor in tracking the sun's position from various angles in Low Earth Orbit.
- **Design and fabrication of physical prototype:**
  - Integrate analogue sun sensor components, test and validate its performance under controlled conditions.
- **Compare simulated and experimental results:**
  - Establish evaluation methodology between simulated and experimental test results to ensure that topology evaluation is applicable.
- **Optimise sensor topology:**
  - Research and evaluate various configurations of analogue sun sensing systems to maximise sun detection accuracy and minimise blind spots.
- **Investigate environmental factors:**
  - Evaluate the impact of relevant LEO specific environmental factors on the sensor's accuracy and reliability.
  - Evaluate the material requirements of the PCB and aperture device.
- **Implement signal processing algorithms:**

  - Investigate the filtering of noise to enhance the signal-to-noise ratio and otherwise ensure the acquisition of usable data for accurate sun position determination.
  - Implement data handling which optimises scanning rates and efficiently processes the analogue signal data for real-time attitude determination.

- **Document results and overall cost-effectiveness:**
  - Develop criteria for final evaluation of sun sensing systems, on which to base the final presentation of project findings.

3. LiteratureReview

3.1 CubeSat Design

Puig-Suari, Turner and Ahlgren published an IEEE paper in 2001 with the help of their students at California Polytechnic State University exploring a need for micro satellites for use by universities in an ever-expanding space programme. They provide as a solution a standard satellite form-factor that will bring down the cost of both manufacture and deployment of satellites by smaller entities: the CubeSat. The paper identifies a key component for the success of this form factor a need for a standard CubeSat deployer mechanism which can deploy several satellites safely and develop such a platform, called Poly Picosatellite Orbital Deployer or P-POD. They point out the need and provide microsatellite size and shape of the CubeSat form factor [1]. Sai balaji et al. performed a study using MATLAB simulation of several attitude control algorithms to look at the ability to control a CubeSat of size 1U. They also simulated sensors such as sun sensors, magnetometer, and gyroscope. They concluded that it is possible to operate the satellite using a magnetorquer type actuator and an array of mathematical models and algorithms: it would take 2000 seconds for a 1U satellite to stabilize at 505km, 98° degree attitude in orbit with the methods utilized by them [?]. Incentivised by the rapidly increasing use of LEO, Lopez-Calle and Franco perform a quantitative comparative study on the catastrophic failure of CubeSats and Nanosats from radiation exposure due to the harsh environment of space versus failure due to collisions in the increasingly busy Low Earth Orbit (LEO). The authors concluded that while sustained damage and damage protection from radiation exposure used to be and currently still is the most crucial factor in protecting LEO microsatellites, increasingly the risk of debris collisions is becoming more important and will become the most important in the following 50 to 70 years. The authors conclude that microsatellite designers need to move their focus more towards defence from debris impacts as these, even if not resulting in catastrophic failure of the satellite, they will impact the attitude of the satellite [?].

3.2 PSD Enabled Sun Sensor

3.3 Mechanical Design and Analysis

3.4 Photodiode Simulation and Signal Analysis

3.5 IoT Communication Enhancement with LEO Satellites

4. Background

5. Methodology

5.1 System Design Overview

This section provides an overview of the System Design Overview.

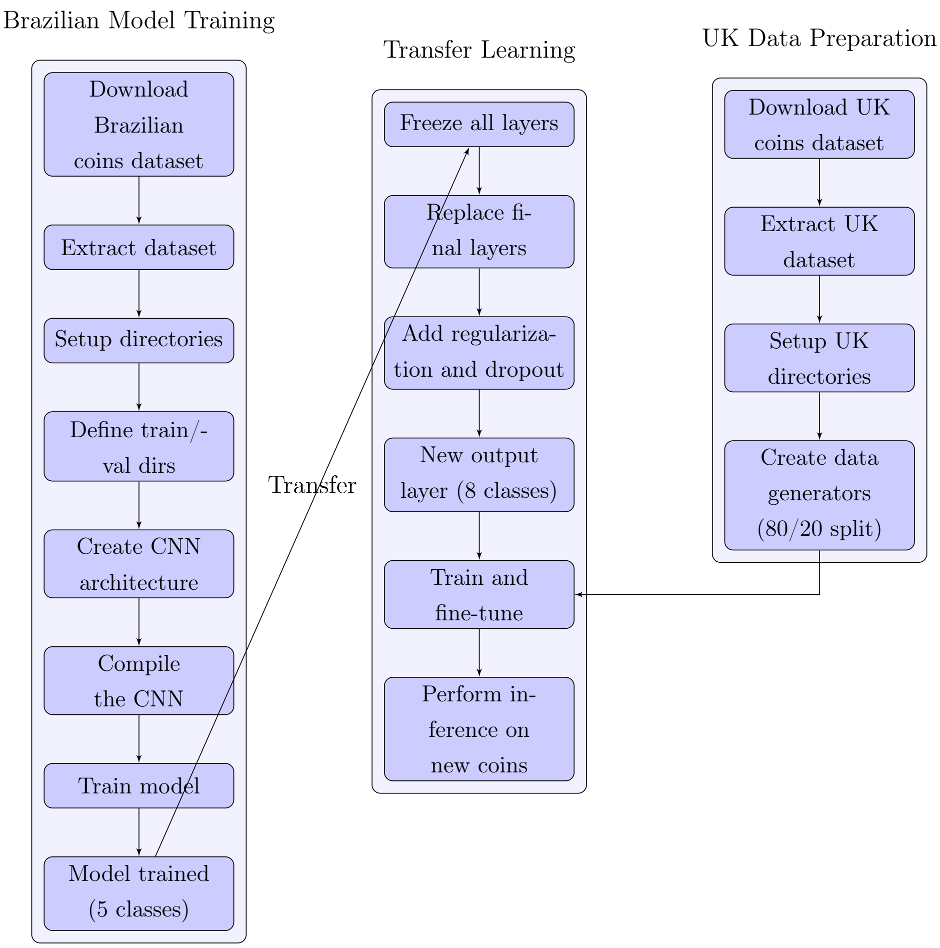

Figure 5.1: System Design Overview Flowchart

5.1.1 Functional Requirements

5.1.2 Design Approach

5.1.3 System Architecture

As shown in Figure 5.1 the system architecture consists of various components.

```
# Your code here
```

Listing 5.1: System Architecture Code Example

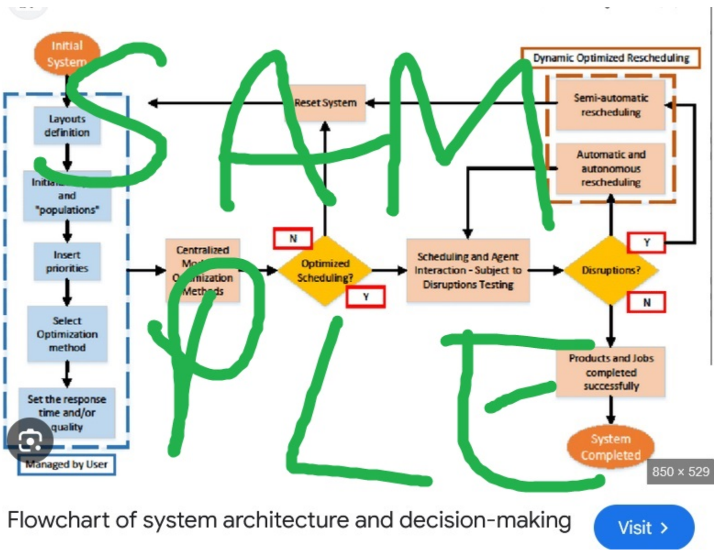

Figure 5.2: System Architecture Diagram

5.2 Sensor Array Development

This section provides an overview of the Sensor Array Development.

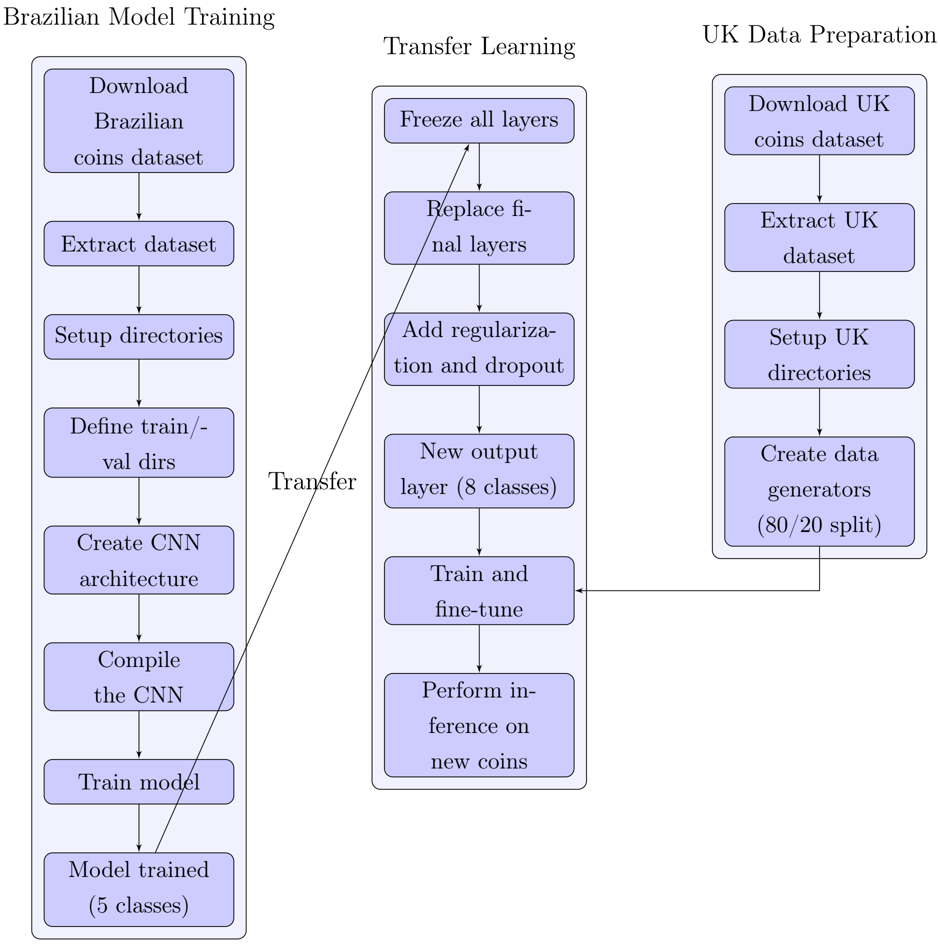

Figure 5.3: System Design Overview Flowchart

5.2.1 Functional Requirements

5.2.2 Design Approach

5.2.3 System Architecture

As shown in Figure 5.3 the system architecture consists of various components.

```
# Your code here
```

Listing 5.2: System Architecture Code Example

5.3 Signal Conditioning Circuitry

This section provides an overview of the Signal Conditioning Circuitry.

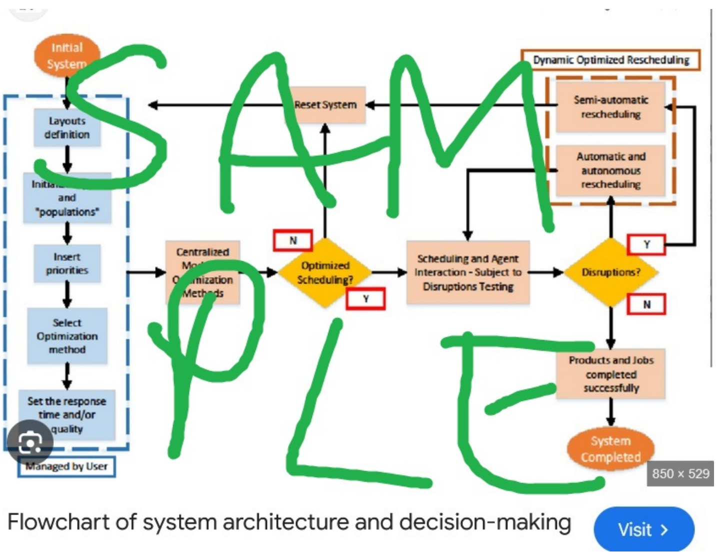

Figure 5.4: System Architecture Diagram

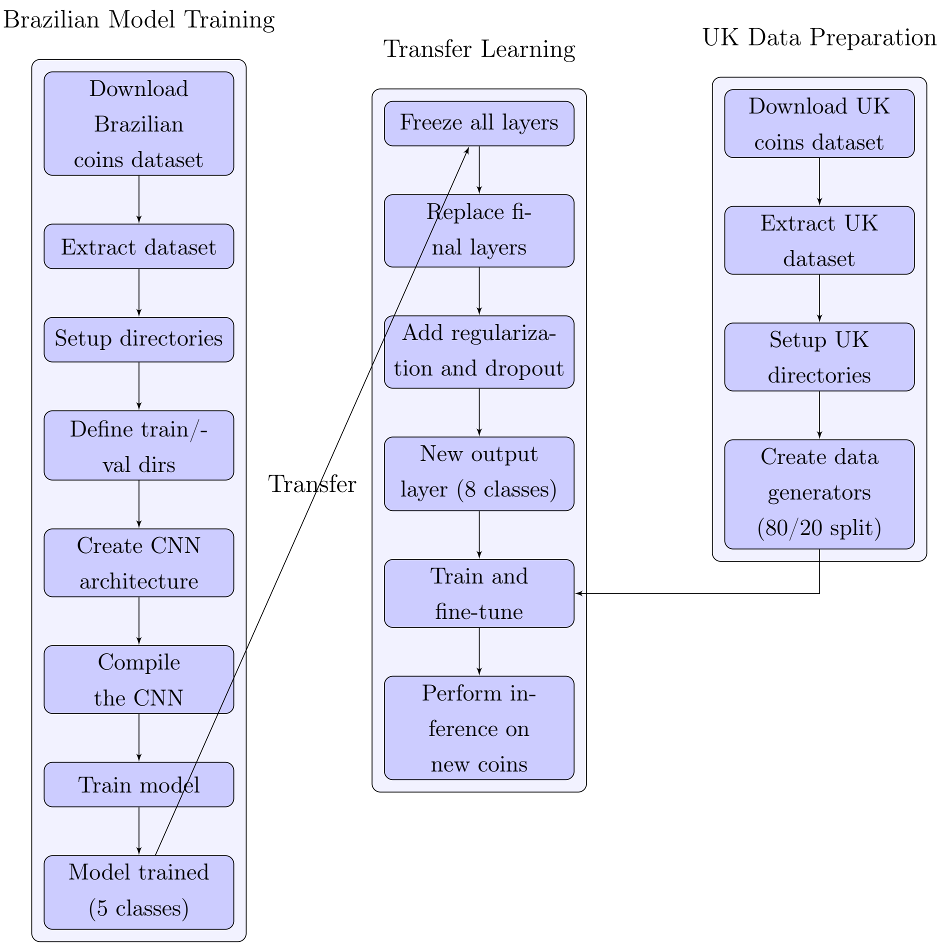

Figure 5.5: System Design Overview Flowchart

5.3.1 Functional Requirements

5.3.2 Design Approach

5.3.3 System Architecture

As shown in Figure 5.5 the system architecture consists of various components.

```
# Your code here
```

Listing 5.3: System Architecture Code Example

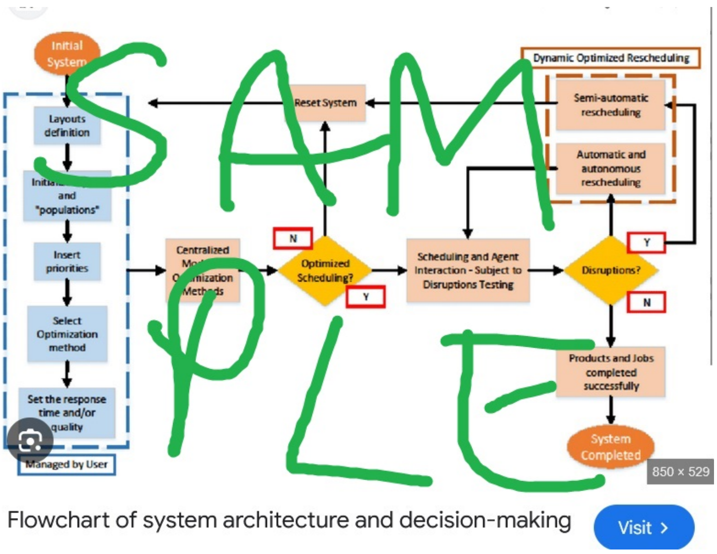

Figure 5.6: System Architecture Diagram

5.4 Enclosure Design And Fabrication

This section provides an overview of the Enclosure Design And Fabrication.

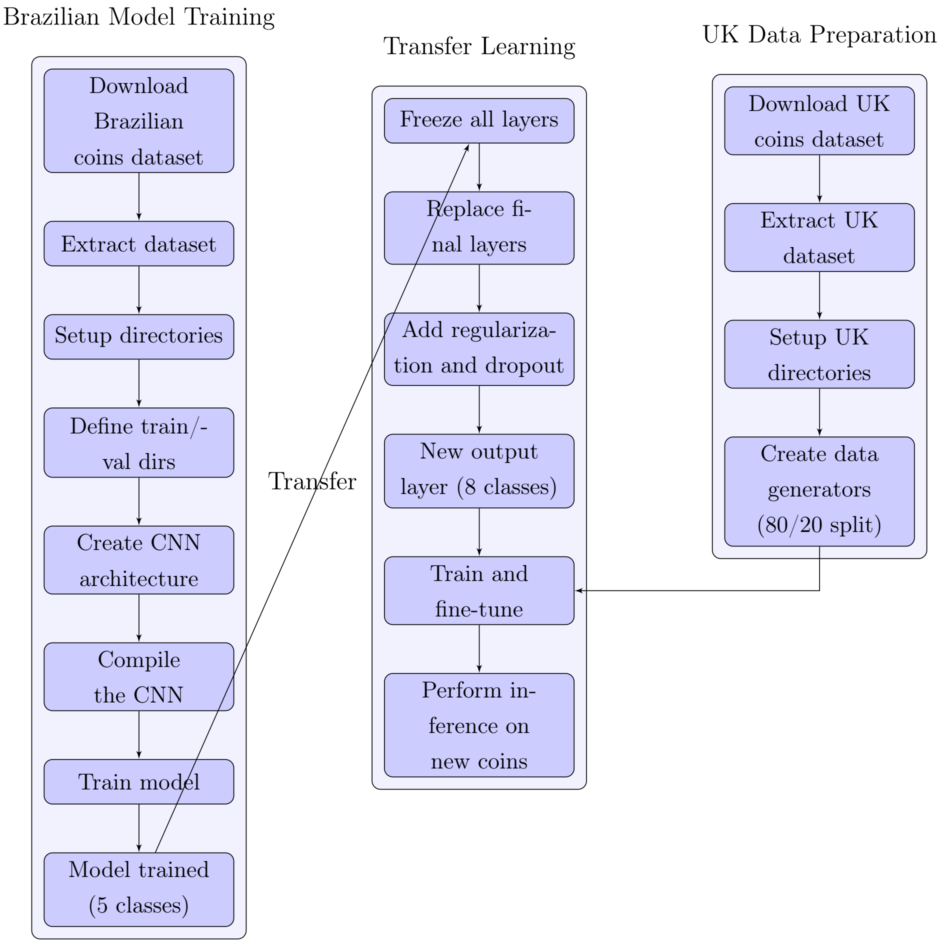

Figure 5.7: System Design Overview Flowchart

5.4.1 Functional Requirements

5.4.2 Design Approach

5.4.3 System Architecture

As shown in Figure 5.7 the system architecture consists of various components.

```
# Your code here
```

Listing 5.4: System Architecture Code Example

5.5 Data Acquisition System

This section provides an overview of the Data Acquisition System.

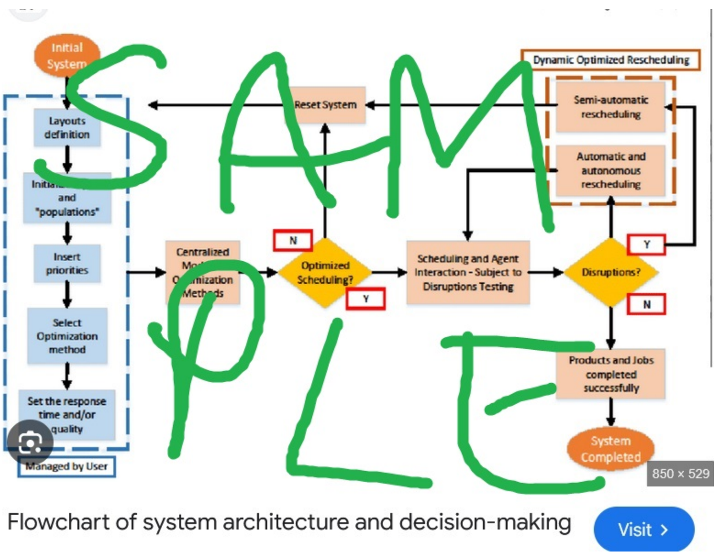

Figure 5.8: System Architecture Diagram

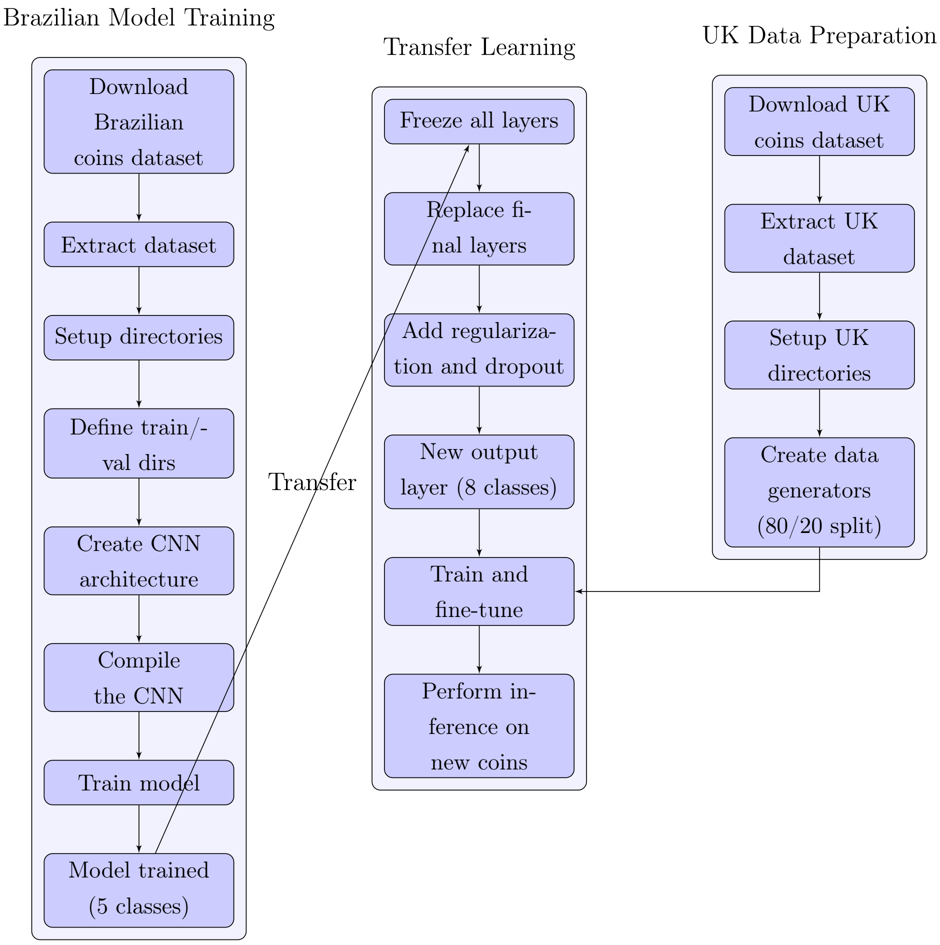

Figure 5.9: System Design Overview Flowchart

5.5.1 Functional Requirements

5.5.2 Design Approach

5.5.3 System Architecture

As shown in Figure 5.9 the system architecture consists of various components.

```
# Your code here
```

Listing 5.5: System Architecture Code Example

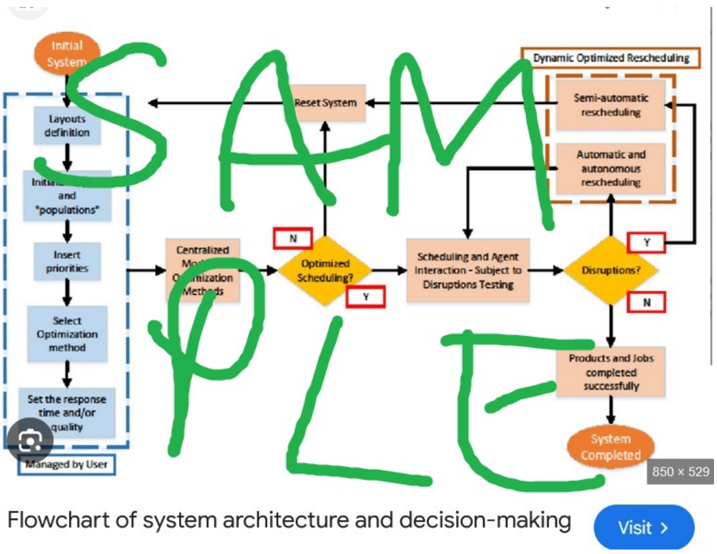

Figure 5.10: System Architecture Diagram

5.6 Testing Apparatus

This section provides an overview of the Testing Apparatus.

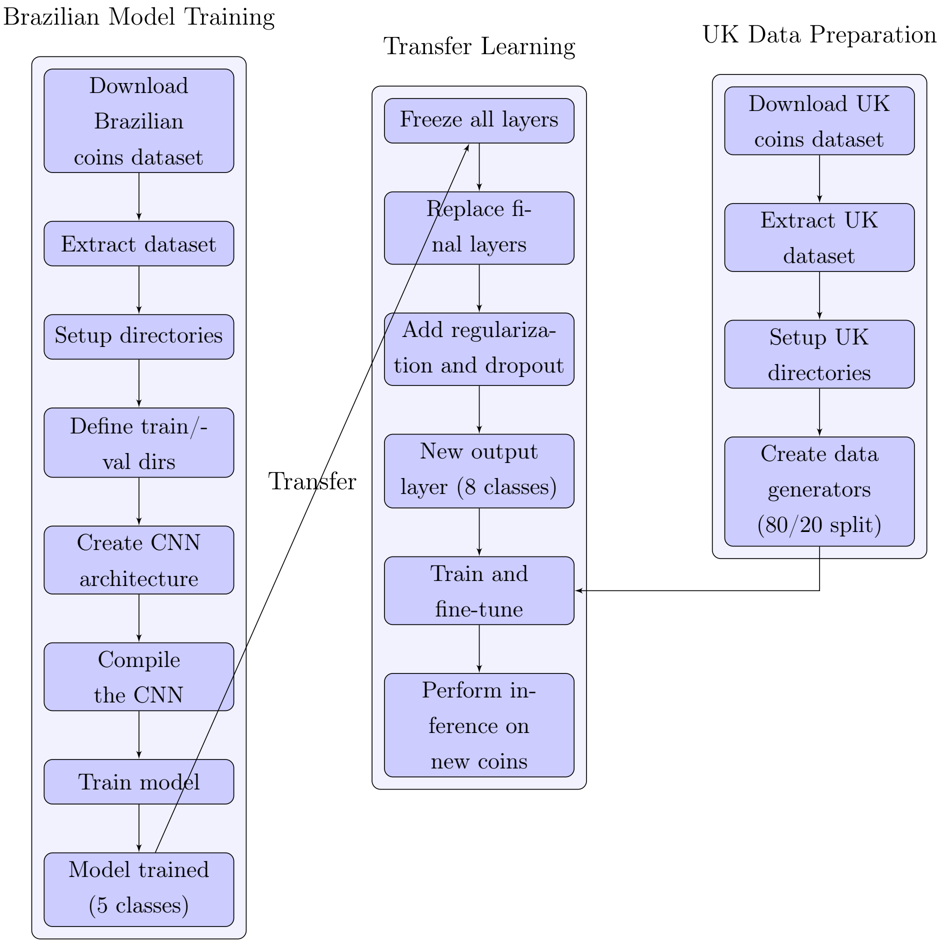

Figure 5.11: System Design Overview Flowchart

5.6.1 Functional Requirements

5.6.2 Design Approach

5.6.3 System Architecture

As shown in Figure 5.11 the system architecture consists of various components.

```
# Your code here
```

Listing 5.6: System Architecture Code Example

5.7 Prototype Develop ment Lifecycle

This section provides an overview of the Prototype Develop ment Lifecycle.

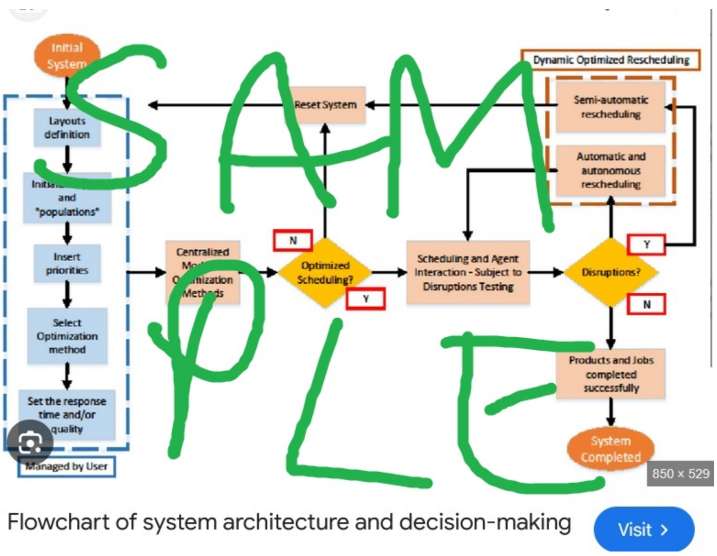

Figure 5.12: System Architecture Diagram

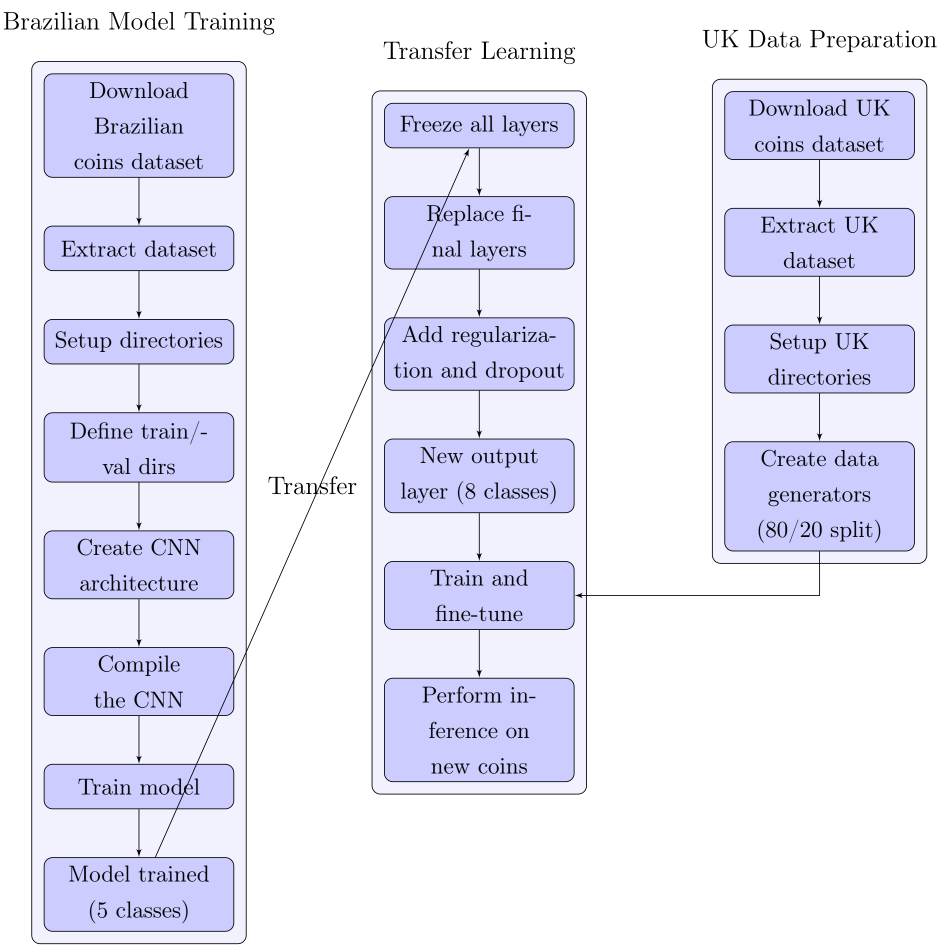

Figure 5.13: System Design Overview Flowchart

5.7.1 Functional Requirements

5.7.2 Design Approach

5.7.3 System Architecture

As shown in Figure 5.13 the system architecture consists of various components.

```
# Your code here
```

Listing 5.7: System Architecture Code Example

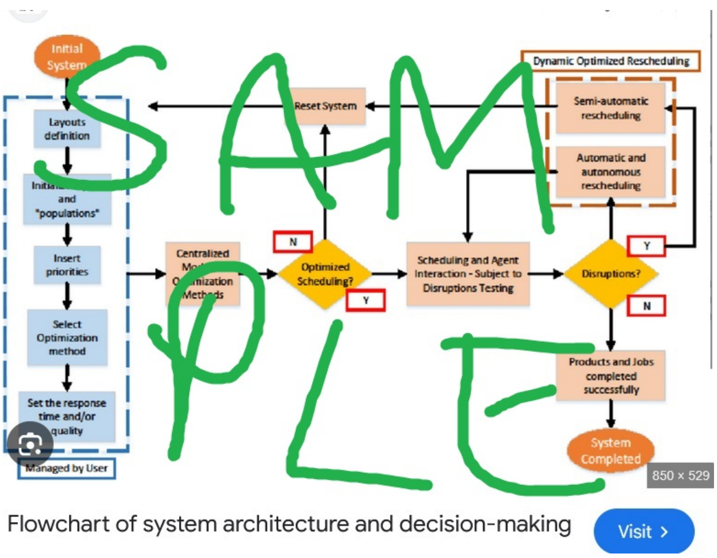

Figure 5.14: System Architecture Diagram

6. Results

6.1 Sensor Characterization

For the SensorCharacterization.tex file, you'd want to focus on the fundamental properties and performance of your photodiodes themselves, distinct from the other subsections. Here are some key elements that would belong specifically under SensorCharacterization:

Basic Photodiode Electrical Characteristics:

Dark current measurements Junction capacitance I-V characteristics in different lighting conditions Spectral response profiles (sensitivity vs. wavelength)

Individual Sensor Benchmarking:

Performance comparison between the 4 photodiodes (matching/differences) Responsivity measurements (A/W) Quantum efficiency calculations Detection threshold levels

Response Linearity:

Measurements showing linear range of the photodiodes Saturation point characterization Recovery time from saturation

Temperature Dependency:

Performance drift with temperature Baseline shift measurements Temperature compensation data

Aging/Stability Tests:

Long-term drift measurements Repeatability of measurements over time

This section should focus on the inherent properties of the photodiodes themselves - essentially providing the baseline characterization data that underpins all the other analysis. The other sections then build on this foundation by examining how these sensors perform when integrated into the complete system with amplification, angular positioning, enclosure effects, etc.

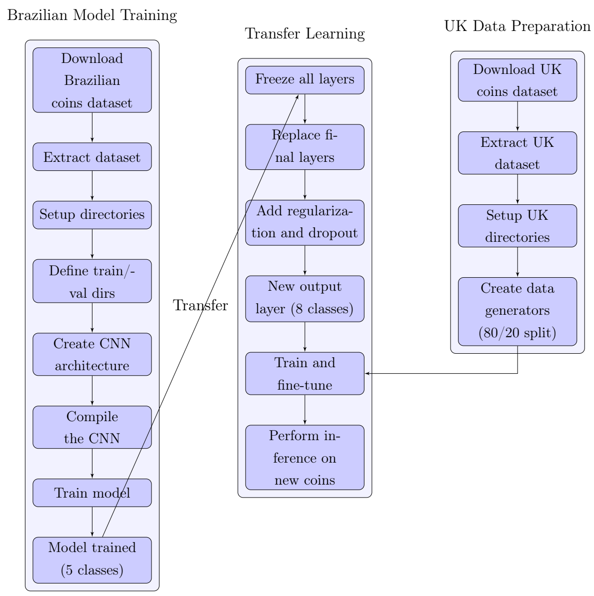

Figure 6.1: System Design Overview Flowchart

6.1.1 Functional Requirements

6.1.2 Design Approach

6.1.3 System Architecture

As shown in Figure 6.1 the system architecture consists of various components.

```
# Your code here
```

Listing 6.1: System Architecture Code Example

6.2 Amplification Performance

This section provides results of the amplifier performance.

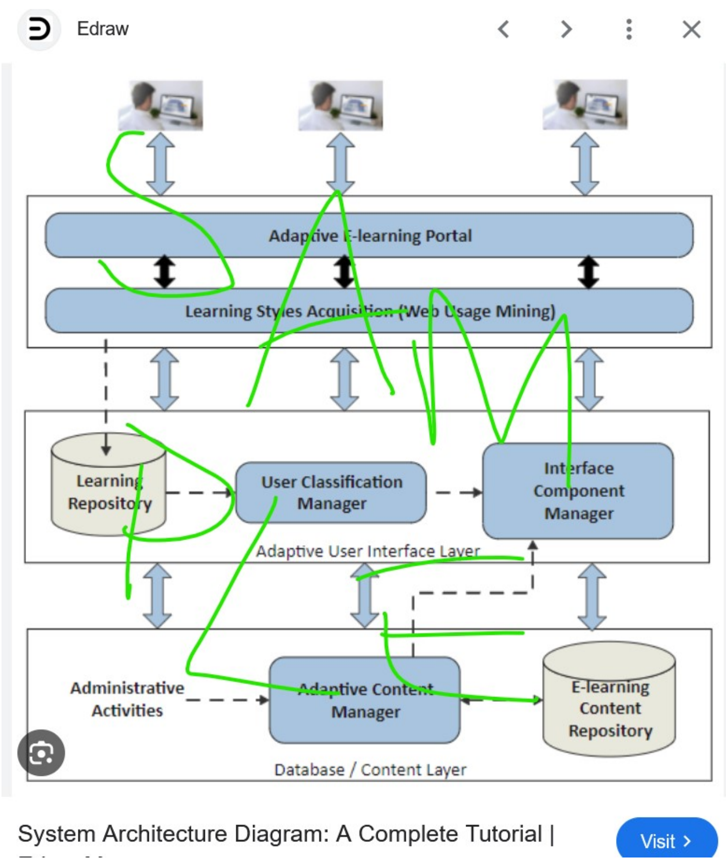

Figure 6.2: System Architecture Diagram

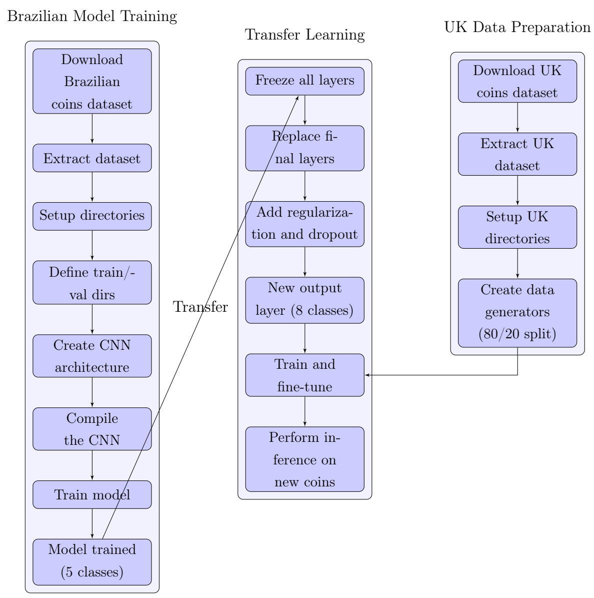

Figure 6.3: System Design Overview Flowchart

6.2.1 Functional Requirements

6.2.2 Design Approach

6.2.3 System Architecture

As shown in Figure 6.3 the system architecture consists of various components.

```
# Your code here
```

Listing 6.2: System Architecture Code Example

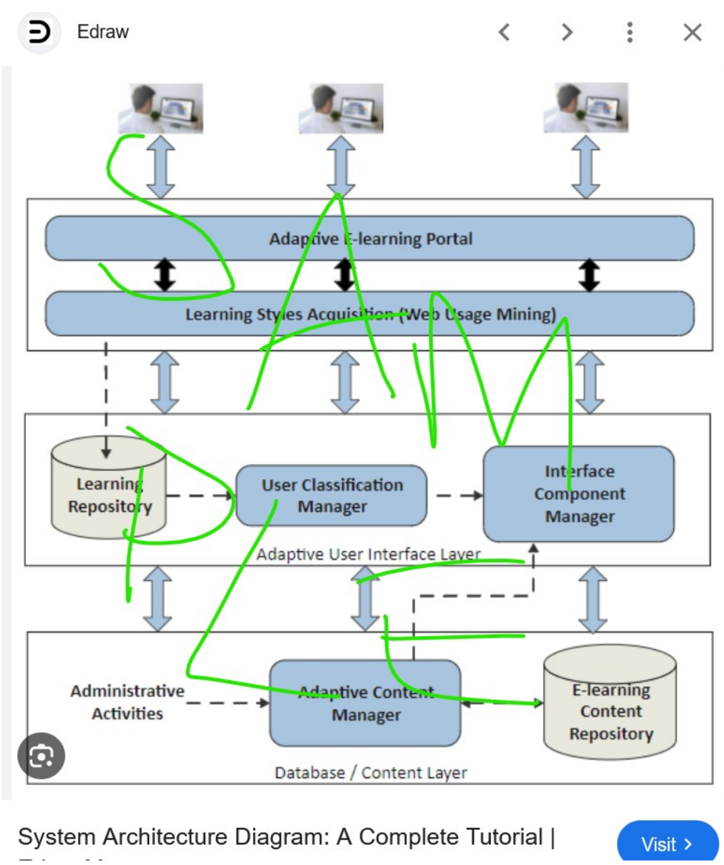

Figure 6.4: System Architecture Diagram

6.3 Photodiode Angular Response

This section discusses the results of the response of the solar sensor to angular changes of the light source.

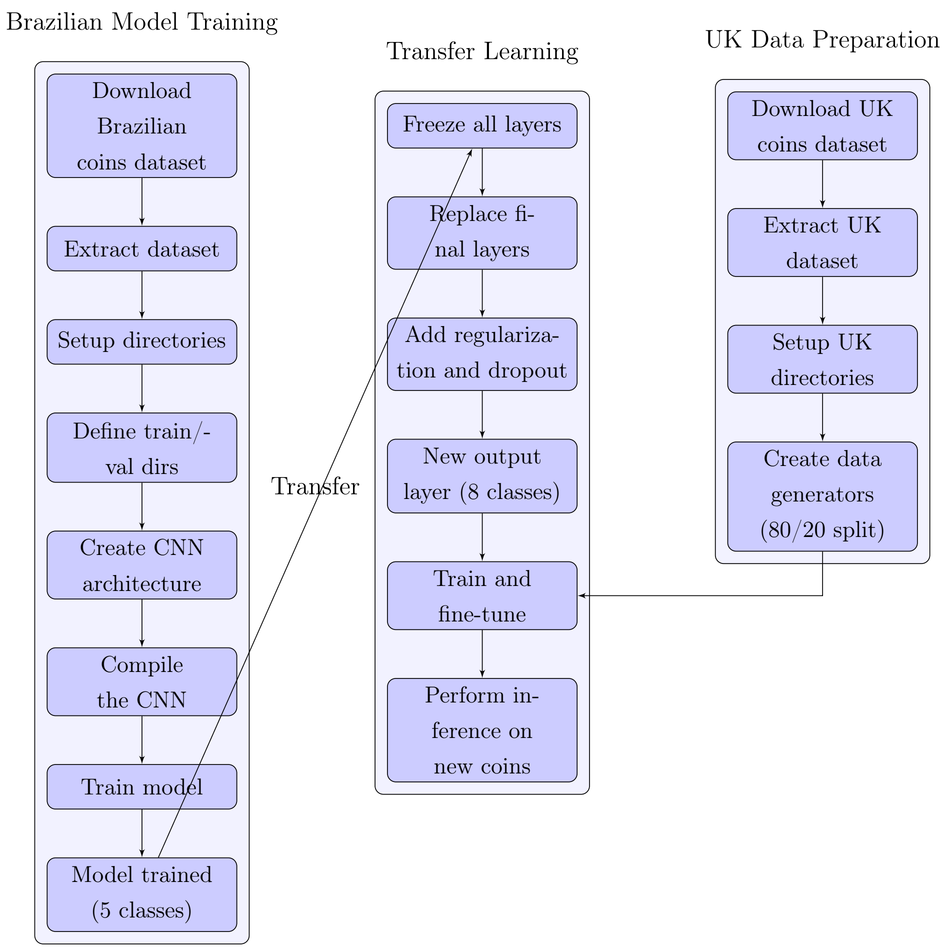

Figure 6.5: System Design Overview Flowchart

6.3.1 Functional Requirements

6.3.2 Design Approach

6.3.3 System Architecture

As shown in Figure 6.5 the system architecture consists of various components.

```
# Your code here
```

Listing 6.3: System Architecture Code Example

6.4 Enclosure Effectiveness

This section discusses the effectiveness of the Photodiode enlosure.

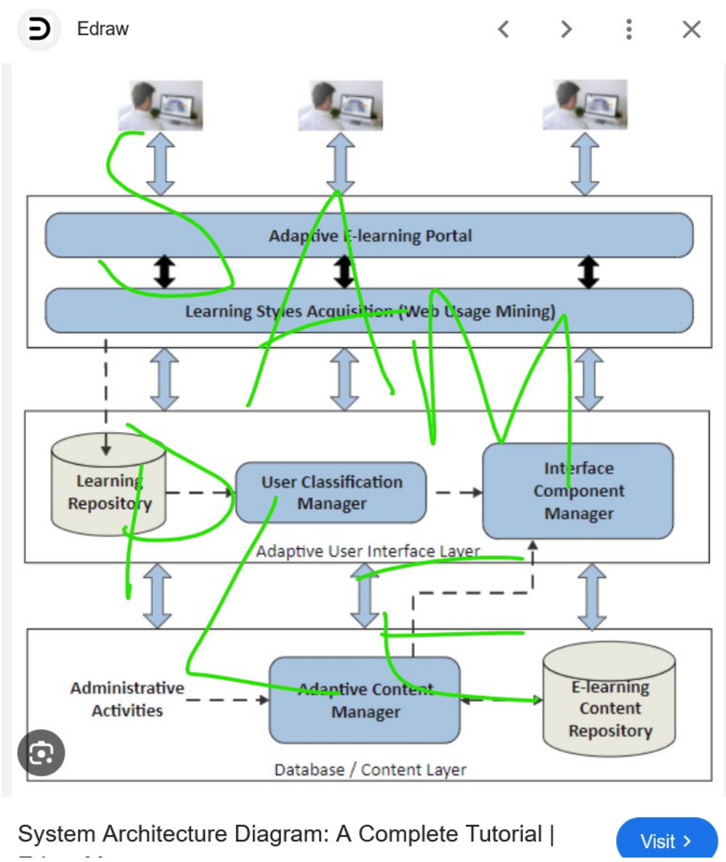

Figure 6.6: System Architecture Diagram

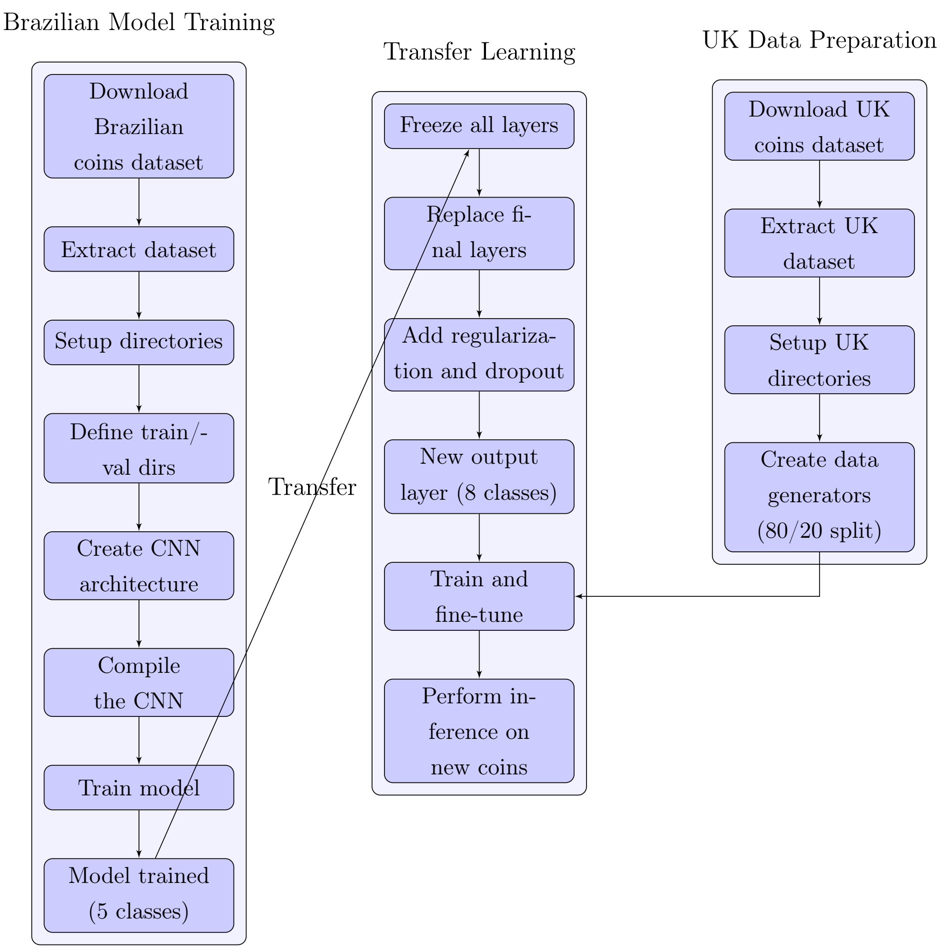

Figure 6.7: System Design Overview Flowchart

6.4.1 Functional Requirements

6.4.2 Design Approach

6.4.3 System Architecture

As shown in Figure 6.7 the system architecture consists of various components.

```
# Your code here
```

Listing 6.4: System Architecture Code Example

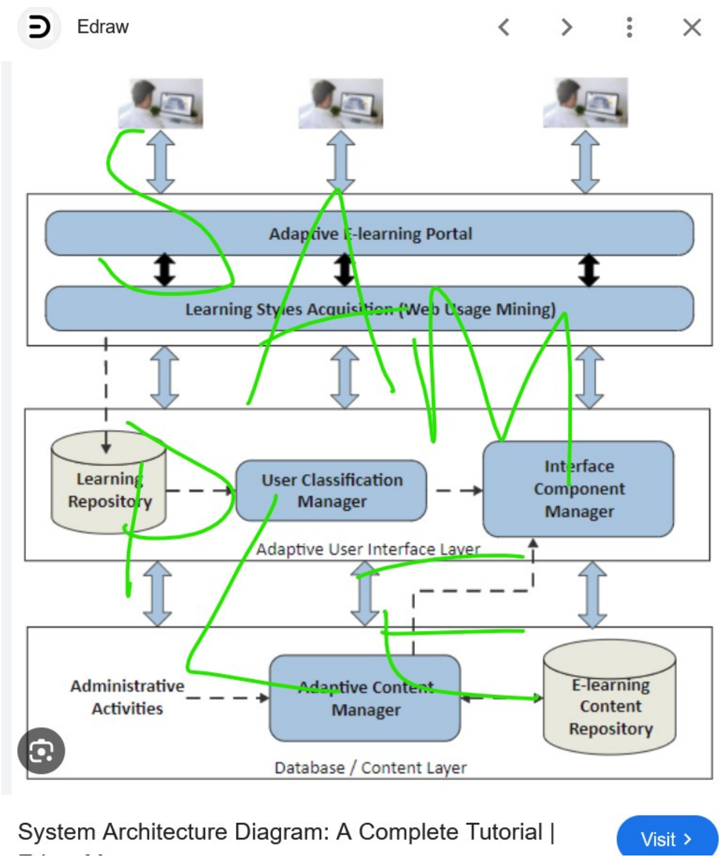

Figure 6.8: System Architecture Diagram

6.5 Data Acquisition System Evaluation

This section provides results related to the Arduino DAQ.

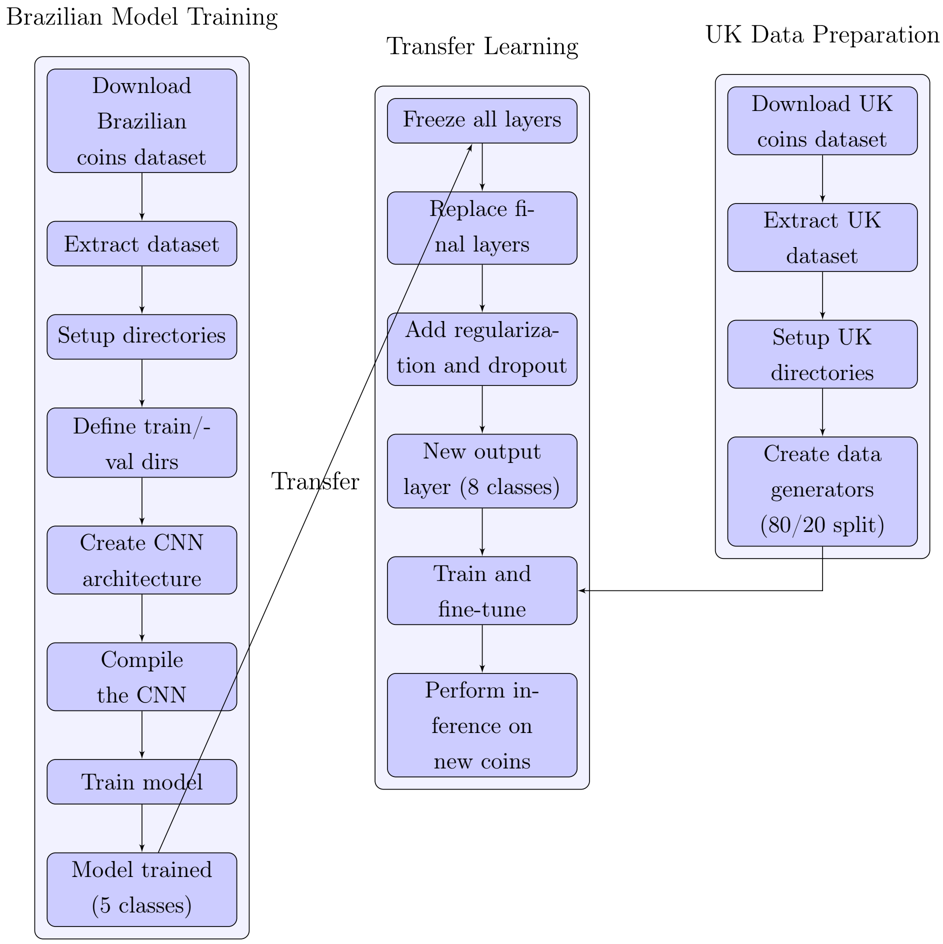

Figure 6.9: System Design Overview Flowchart

6.5.1 Functional Requirements

6.5.2 Design Approach

6.5.3 System Architecture

As shown in Figure 6.9 the system architecture consists of various components.

```
# Your code here
```

Listing 6.5: System Architecture Code Example

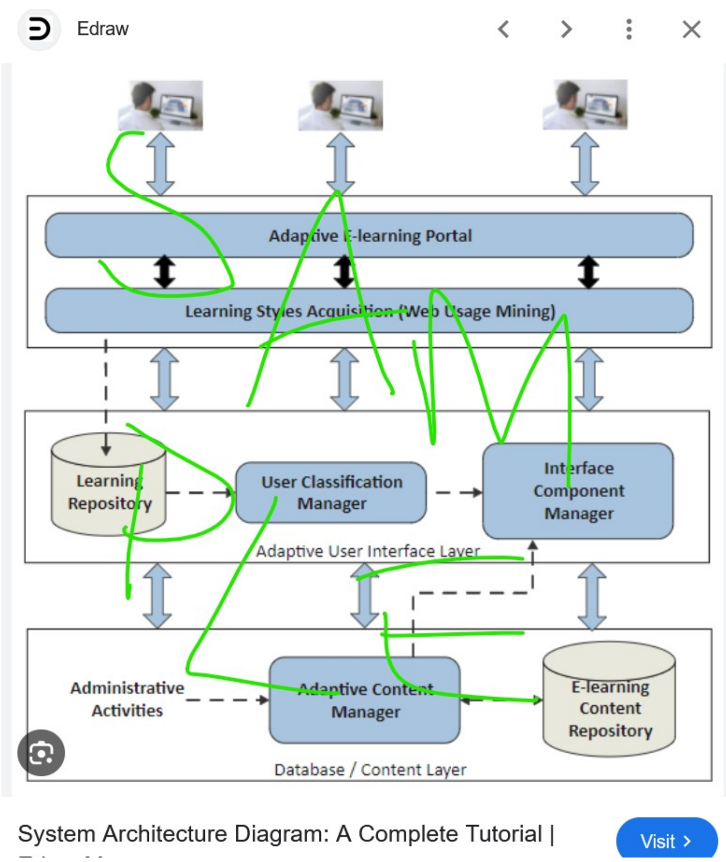

Figure 6.10: System Architecture Diagram

6.6 System Performance Analysis

6.6.1 Operational Constraints Identified

6.6.2 Environmental Factors Impact

```
// Environmental test results
// Temperature, ambient light, and vibration effects
```

Figure 6.11: Environmental Testing Results

6.6.3 System Stability and Repeatability

6.6.4 Recommendations for Improvement

6.7 Comparative Analysis

This section compares the simulation with the prototype results.

6.7.1 Breadboard vs. Stepboard Results

6.7.2 Iteration Improvements Analysis

6.7.3 Performance Against Design Requirements

The performance ...

6.7.4 Design Evolution Assessment

The what now?

6.8 System Limitations And Considerations

This section discusses the limitations and future work.

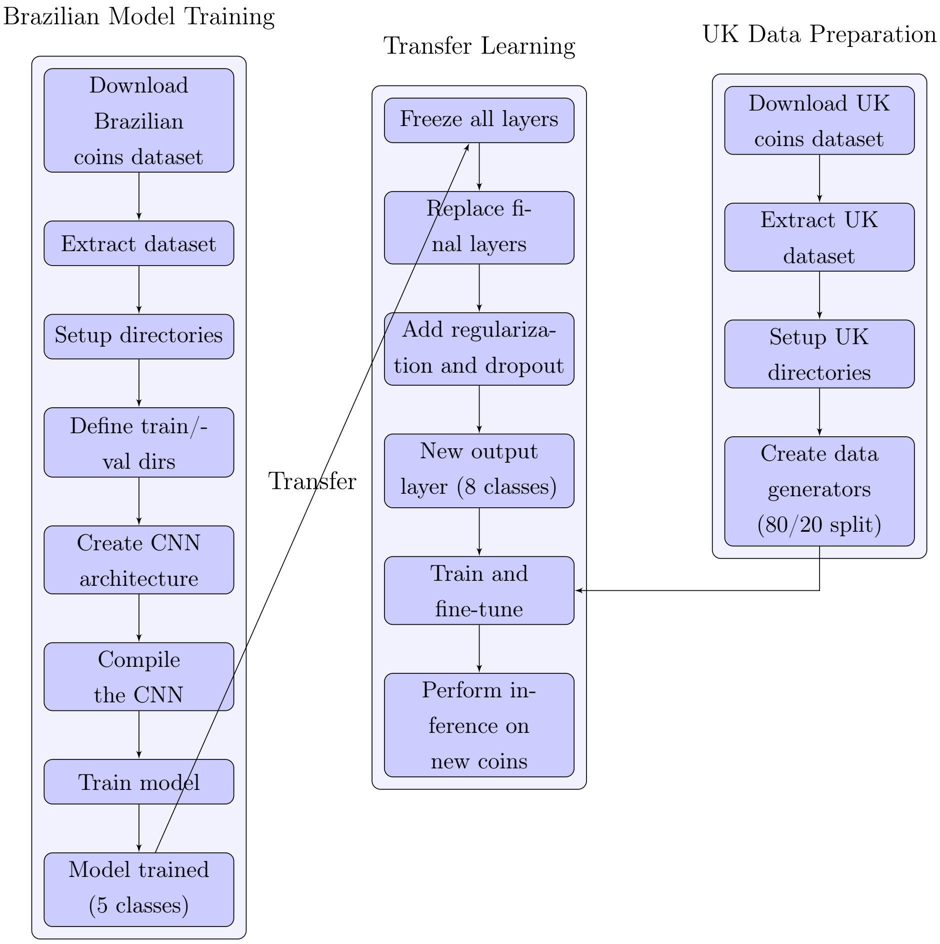

Figure 6.14: System Design Overview Flowchart

6.8.1 Functional Requirements

6.8.2 Design Approach

6.8.3 System Architecture

As shown in Figure 6.14 the system architecture consists of various components.

```
# Your code here
```

Listing 6.6: System Architecture Code Example

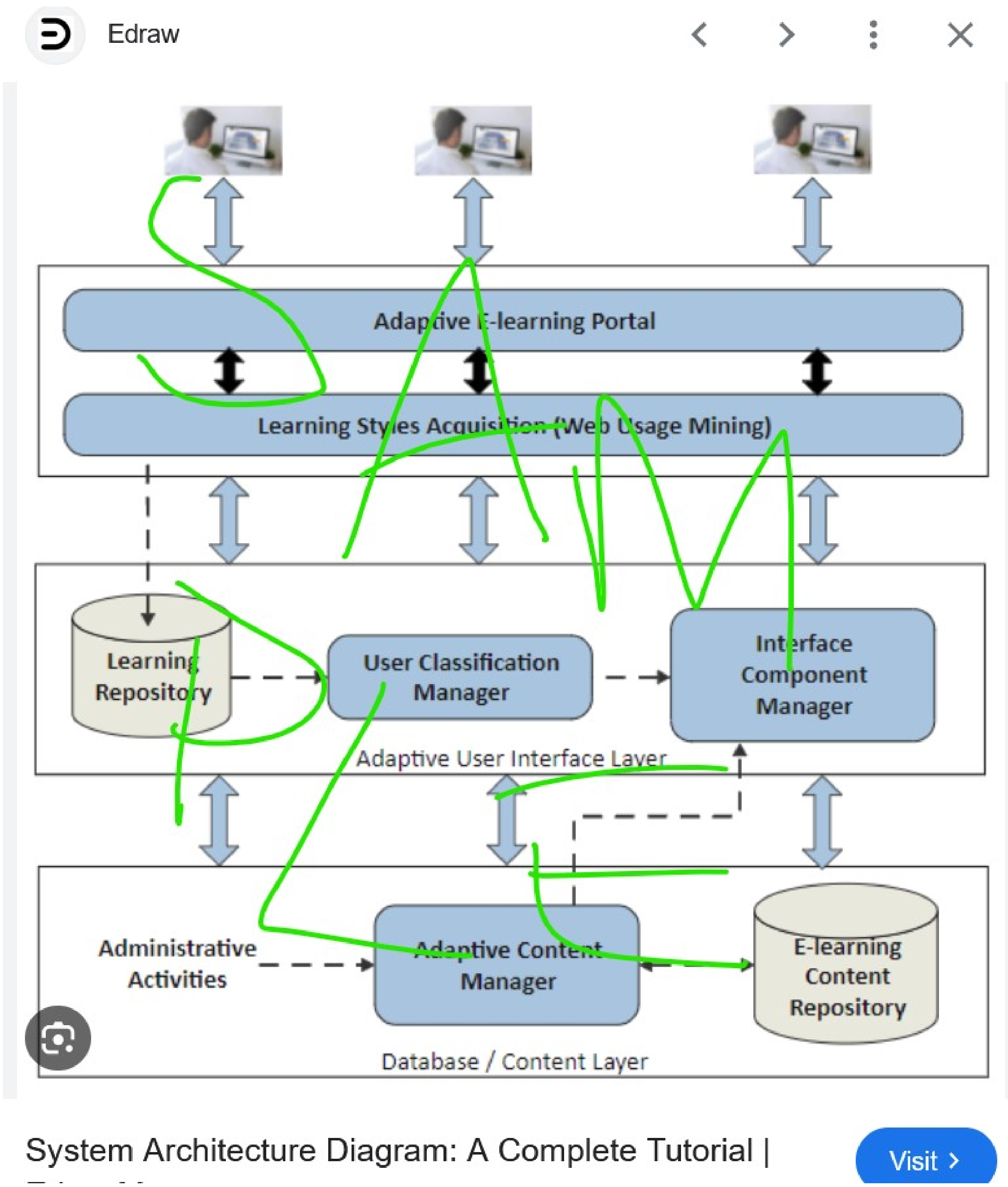

Figure 6.12: Overall System Performance Analysis

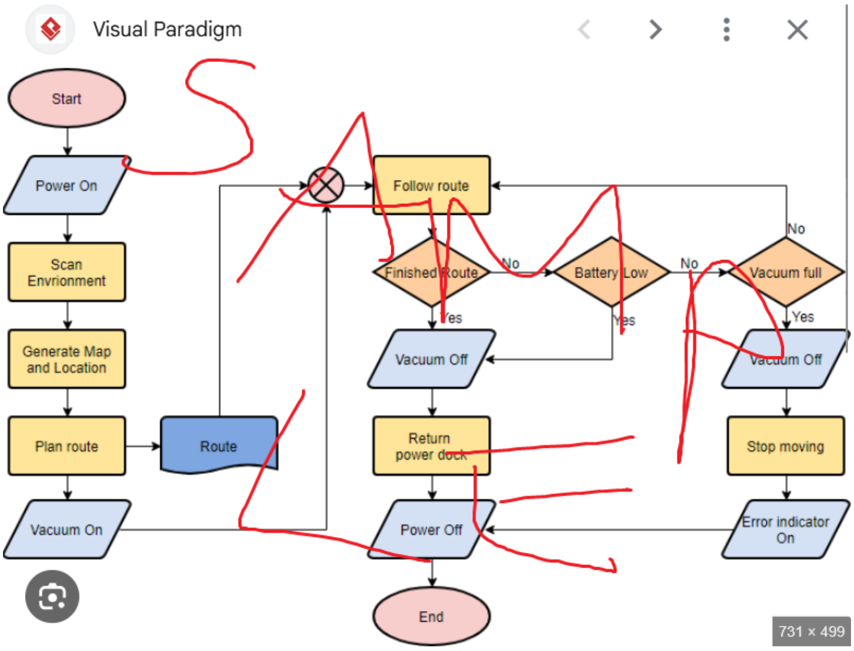

Figure 6.13: Prototype Iteration Comparison

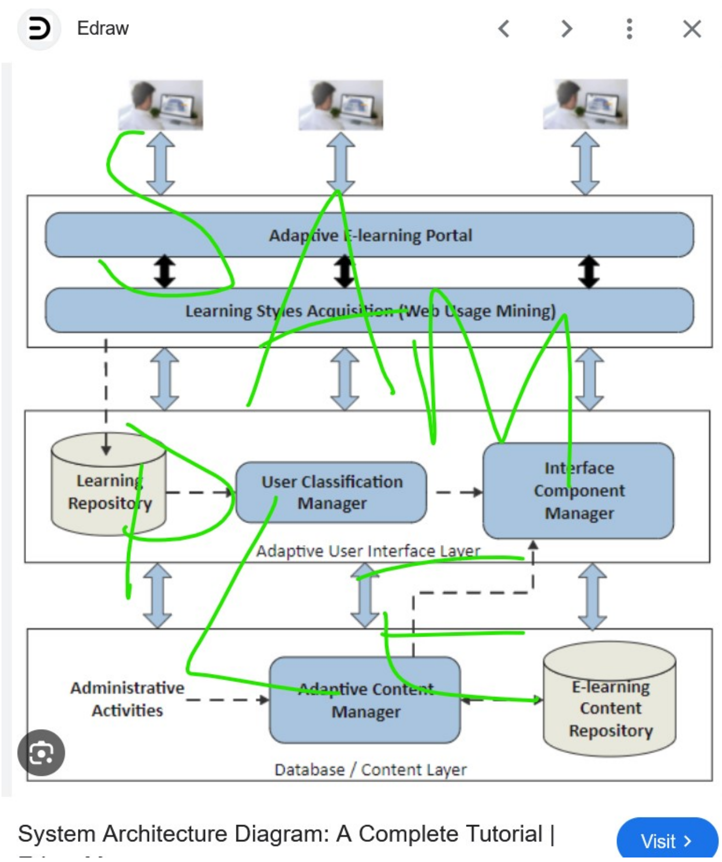

Figure 6.15: System Architecture Diagram

7. Conclusions

8. FutureWork

Bibliography

[1] J. Puig-Suari and C. Turner, "Development of the standard cubesat deployer and a cubesat class picosatellitel."