A logo with a red design

Description automatically generated with medium confidence

# **MGMT-6134-24W: BIA CAPSTONE PROJECT**

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SmartGreenhouse: Revolutionizing Sustainable Agriculture with Cutting-Edge Technology

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# Project Summary

## Introduction

Embarking on a transformative journey from the previous "Farmsmart - Urban Smart Farming Platform Project," the mission is to drive forward the ongoing revolution in sustainable greenhouse agriculture by integrating advanced technologies. This initiative aims to amplify the impact of cutting-edge innovations within greenhouse systems, pushing boundaries in precision farming, resource optimization, and ecological sustainability. With a pragmatic focus on practical applications, the project seeks to bridge the gap between theory and implementation, leveraging state-of-the-art technologies to tackle real-world challenges faced by greenhouse operators.

At the heart of this enhancement project lies the exploration and refinement of smart sensors, automated climate control mechanisms, and data-driven management systems within greenhouse environments using microcontrollers. Through meticulous experimentation and hands-on implementation, the objective is to enhance the efficiency and effectiveness of these technologies, ultimately contributing to a more sustainable and resilient planting future. By incorporating microcontrollers, sensors, mobile applications, and programming, the project aims to develop predictive models that empower greenhouse operators with foresight, enabling them to preemptively manage environmental variables and optimize cultivation conditions. This initiative is poised to be a beacon of innovation, steering the trajectory of modern agriculture towards a harmonious coexistence with nature, promising a future where farmers can successfully navigate obstacles such as climate change, scarce resources, and mounting costs, ensuring a steady income stream, and contributing to global food security.

## Project Milestone Summary

The schedule for high-level milestone is:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Milestone | Description | Start Date | Completion Date | Status |
| 1 | Inception | January 19, 2024 | January 25, 2024 | Completed |
| 2 | Analysis of Deliverables | January 29, 2024 | February 15, 2024 | Completed |
| 3 | Design of Deliverables | February 19, 2024 | March 14, 2024 | Completed |
| 4 | Construction, Results and Discussion of Deliverables | March 18, 2024 | April 4, 2024 | Not Started |
| Final | Final Report & Evaluations | April 8, 2024 | April 11, 2024 | Not Started |

# System Architecture

The system architecture of the Greentech encompasses a comprehensive integration of hardware components, software tools, and communication protocols to achieve the project's objectives efficiently.

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| **System Architecture** |
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| **Activity Diagram** |
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## Hardware Components

**Sensors and Monitoring:**

1. **Temperature and Air Humidity Sensor – DHT11 Temperature Humidity Sensor**

A close-up of a blue and black device

Description automatically generated

This sensor measures both temperature and humidity levels in the air, providing essential data for controlling the greenhouse environment and ensuring optimal growing conditions for plants.

1. **Soil Moisture Sensor – Capacitive Soil Moisture Sensor**

A black rectangular electronic device with wires

Description automatically generated

Designed specifically for measuring soil moisture levels, this sensor helps in determining when and how much water plants need, allowing for precise irrigation control to prevent over or under-watering.

1. **Light Intensity Sensor – TSL25911FN Ambient Light Sensor**

A close-up of a circuit board

Description automatically generated

Capable of detecting ambient light intensity up to 88000 lux, this sensor enables the system to adjust artificial lighting within the greenhouse to supplement natural sunlight, ensuring that plants receive adequate light for photosynthesis.

**Control and Actuation:**

* + 1. **Board – Arduino R4 WIFI**

A blue circuit board with many small chips

Description automatically generated

Serving as the brain of the smart greenhouse system, this microcontroller board equipped with WiFi capabilities manages data from various sensors, controls actuators, and facilitates communication with other devices or systems.

* + 1. **Relay – DC 5V Relay Module, 230V Relay Shield**

A blue relay module with blue and black components

Description automatically generated with medium confidence

These relay modules are responsible for controlling high-voltage devices such as heaters, ventilation systems, or shading systems within the greenhouse, enabling the system to adjust environmental conditions based on sensor data.

* + 1. **Pump Motor – 12V DC Water Pump**

A black and red electrical device

Description automatically generated

This motorized pump moves water through irrigation systems based on data from soil moisture sensors, ensuring that plants receive the right amount of water at the right time to maintain optimal hydration levels.

**Automation and Miscellaneous:**

1. **Mechanical Arm – Tinkerkit Braccio robot**

A close-up of a robotic arm

Description automatically generated

While not directly involved in environmental monitoring, this robotic arm can be used for various tasks such as plant maintenance, moving pots or trays for inspection or harvesting, enhancing automation within the greenhouse.

1. **Camera – Logitech C920**

A black webcam with a small lens

Description automatically generated

Used for remote monitoring and surveillance of the greenhouse, this high-definition webcam allows users to visually inspect plant health, detect pests or diseases, and monitor overall greenhouse conditions from anywhere with an internet connection.

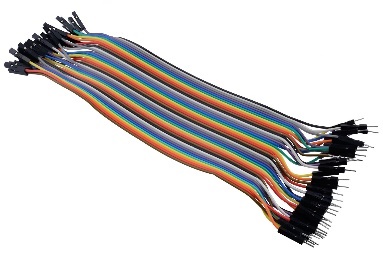
1. **Power Supply – 12V 2A Power Supply Adapter**

A black power supply with a box

Description automatically generated

Provides power to components such as the water pump, ensuring they operate efficiently to maintain the functionality of the smart greenhouse system.

1. **Interconnecting Sensors and Actuators – Jumper Wires**

 A bunch of wires with black and red and blue wires

Description automatically generated

Jumper wires are used to connect sensors such as temperature and humidity sensors, soil moisture sensors, and light intensity sensors to the microcontroller board. They allow for the transmission of data from the sensors to the controller, enabling real-time monitoring of environmental conditions within the greenhouse.

1. **Misting System – MIXC Drip Irrigation Kit**

A collage of a sprayer system

Description automatically generated

The misting system is connected to a humidity sensor within the greenhouse. This sensor continuously monitors the humidity levels in the air. When the humidity falls below a certain threshold, indicating dry conditions, the sensor triggers the misting system to activate.

1. **Water Irrigation System – Water Hose connected to a water pump.**

A black wire on a white background

Description automatically generated

The smart greenhouse system utilizes sensors, such as soil moisture sensors, to monitor the moisture levels in the soil. When the soil moisture drops below a certain threshold, indicating that the plants need watering, the system triggers the water pump to start irrigating**.**

1. **Lighting System – LED Grow Lights:**

A white circle with a black background

Description automatically generated

LED (Light Emitting Diode) grow lights are commonly used in smart greenhouse applications due to their energy efficiency, controllability, and ability to provide specific light spectra tailored to plant growth stages. These lights can emit wavelengths optimized for photosynthesis, promoting healthy plant growth, and maximizing yield.

## Software Components

**Data Processing**:

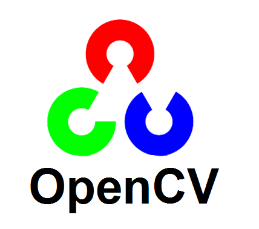
A screenshot of a computer

Description automatically generated 

Data collected from sensors is processed using software tools like Arduino IDE and Python IDE. This involves data filtering, aggregation, and analysis to extract meaningful insights about environmental conditions and plant health.

**Control Algorithms**:

A blue and green logo

Description automatically generated  A blue and white logo

Description automatically generated

Control algorithms are developed and implemented using programming languages supported by the chosen microcontroller platforms (C++), Open CV, and Python. These algorithms leverage sensor data to regulate environmental variables such as temperature, humidity, light, and soil moisture to maintain optimal growing conditions.

**User Interfaces**:

A green and white logo

Description automatically generated

User interfaces like Blynk Application to provide greenhouse operators with access to real-time data, control functionalities, and analytics dashboards. The interfaces are web-based or mobile applications, allowing remote monitoring and control of greenhouse operations. With Blynk, greenhouse operators can remotely monitor various parameters such as temperature, humidity, soil moisture, and light intensity using sensors placed throughout the greenhouse. They can also control devices like water pumps, fans, or heaters remotely based on real-time data.

## Communication Protocols

**Wireless Communication**:



**Wi-Fi (Wireless Fidelity):** Wi-Fi connectivity enables wireless communication between the central control unit (Arduino). It allows for remote monitoring, control, and data exchange over a local network or the internet.

## Interaction and Integration

* Sensor data is continuously collected and transmitted to the microcontroller-based systems for processing.
* Control algorithms use processed data to make decisions and send commands to actuators for adjusting environmental conditions.
* User interfaces provide feedback to greenhouse operators, allowing them to monitor system status, adjust settings, and receive alerts or notifications.
* Communication protocols facilitate seamless interaction and integration between hardware components and software tools, ensuring efficient operation of the smart greenhouse system.

Overall, the system architecture facilitates a closed-loop control system where sensor data informs decision-making processes, leading to dynamic adjustments in greenhouse conditions to optimize plant growth while minimizing resource consumption and environmental impact.

# Prototypes

The Smart Greenhouse prototype is designed to efficiently utilize space while ensuring easy access for maintenance and monitoring. The layout consists of several key components arranged strategically within the greenhouse structure.

**Enclosure Design:**

* The Smart Greenhouse prototype utilizes a weatherproof enclosure to protect sensitive electronic components from environmental elements such as moisture, dust, and temperature fluctuations.
* The enclosure is constructed from a durable wood material chosen for its resistance to corrosion and durability in outdoor environments.
* Each sensor is wired according to its specified interface requirements, ensuring proper communication with the microcontroller for data acquisition.
* Power distribution panels are installed near the central control unit to manage the electrical connections for sensors, actuators, and other electronic components.

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| **Smart Greenhouse Front View** |
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| **Smart Greenhouse Right Side View** |
| A plant in a box  Description automatically generated |

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| **Smart Greenhouse Left Side View** |
| A plant in a pot  Description automatically generated |

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| **Smart Greenhouse Rear View** |
| A plant in a pot on a wooden deck  Description automatically generated |

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| **Smart Greenhouse Top View** |
| A plant in a box  Description automatically generated |

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| **Robot Arm** |
| A red robot with white gears  Description automatically generated   * The Robot Arm, equipped with grippers, is mounted on a sturdy frame positioned near the center of the greenhouse for optimal reach. * Robot Arm is connected to output ports on the microcontroller. |

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| **Arduino Board** |
| A circuit board with wires  Description automatically generated  **Central Control Unit:**   * The microcontroller or central processing unit (CPU) responsible for data processing and actuator control is housed in a weatherproof enclosure mounted near the center of the greenhouse. * The enclosure is positioned at a convenient height for maintenance access and features ventilation to prevent overheating. * Actuator control signals from the microcontroller are transmitted to the actuators to execute predefined actions based on sensor readings and system commands. |

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| **Light Intensity Sensor** |
| A wire on a wood post  Description automatically generated  Light Intensity sensor is strategically placed to measure light levels in both direct sunlight and shaded areas. |

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| **Temperature and Humidity Sensor** |
| A wooden post with wires attached to it  Description automatically generated  The Humidity / Temperature sensor is positioned at the greenhouse to capture accurate environmental data. |

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| **Soil Moisture Sensor** |
| A plant in a pot  Description automatically generated  Soil Moisture sensor is embedded in the soil bed to monitor moisture levels with a specific depth. |

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| **Misting System** |
| Actuators controlling misting systems are installed at strategic locations along the ceiling. |

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| **Water Irrigation System** |
| Actuators controlling irrigation mechanisms is installed at strategic location along the greenhouse walls. |

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| **Water Pump** |
| A black and red wires in a white tub  Description automatically generated  A water pump is an electromechanical device designed to move water from one location to another. The water pump is a DC (Direct Current) pump powered by a low voltage source such as a 12V power supply. These pumps are chosen for their efficiency, reliability, and ease of integration into automated systems. |

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| **Relay** |
| A circuit board with wires and a laser beam  Description automatically generated  A relay is an electromechanical switch used to control high-power devices or systems such as lighting, heating, ventilation, and irrigation systems. |

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| **Camera** |
| A black belt attached to a pole  Description automatically generated  A camera is a digital camera equipped with features suitable for capturing high-quality images or videos of plants and the surrounding environment. |

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| **Wire Management** |
| A wood frame with wires and a wood floor  Description automatically generated A wooden structure with wires and wires  Description automatically generated  Wiring runs neatly along the greenhouse walls or ceiling, secured with cable ties and conduits to prevent tangling or damage. |

# API Functions

Within our system, we used two kinds of API to separately control sensors and robot arm.

A diagram of a person

Description automatically generated

For sensors, we used pre-built libraries for data collecting and then we used map function to convert analog read value bit to percentage.



A diagram of a machine

Description automatically generated

The robot arm can be controlled by two kinds of methods. One was manually controlled from a mobile app and the other was by detecting ArUco markers. Both controlling methods moved the robot arm by giving final posture, which is a XYZ coordinate.

A diagram of a mathematical equation

Description automatically generated with medium confidence

The API was used to convert XYZ coordinate to degrees of angles for each joint by inverse kinematics.

A math equations on a white background

Description automatically generated

The degrees of angle were calculated by DH parameters.

# User Interface

The user interface (UI) serves as the front-end component of the smart greenhouse system, facilitating user interaction. It should prioritize intuitiveness, responsiveness, and visual appeal. Essential features may encompass real-time sensor data visualization, environmental parameter controls, historical data analysis, and notification management.

1. **Dashboard** –present users with a centralized dashboard offering an overview of the greenhouse system's status and crucial metrics. Display real-time sensor data, including temperature, humidity, light intensity, and soil moisture levels, through various visualizations like charts, graphs, or gauges.
2. **Control Panel** – incorporate controls for adjusting environmental parameters within the greenhouse, such as temperature setpoints, humidity levels, light schedules, and irrigation settings. Implement user-friendly sliders, toggles, and input fields for easy parameter modification.
3. **Sensor Data Visualization** – enable users to access detailed sensor data from different greenhouse areas. Utilize interactive charts and graphs to showcase historical sensor readings over time, enabling users to track trends and identify patterns.
4. **Alerts and Notifications ­**– establish a notification system to promptly alert users about critical events or deviations from preset thresholds. Allow users to personalize notification preferences and receive alerts via push notifications, email, or SMS.
5. **Historical Data Analysis** – provide tools for analyzing historical data to gain insights into greenhouse performance and optimize cultivation practices. Offer features like data filtering, trend analysis, and report generation for comprehensive analysis.
6. **User Profiles and Settings** – empower users to create personalized profiles and settings to tailor the app experience to their preferences. Enable the setup of multiple greenhouse configurations, saving favorite settings, and managing notification preferences.
7. **Remote Access and Control** – enable remote monitoring and control of the greenhouse system from anywhere via mobile devices. Implement secure authentication mechanisms, such as biometric authentication or two-factor authentication, to ensure data protection and secure access.
8. **Responsive Design** – design the UI to be responsive and adaptable to various screen sizes and orientations. Ensure proper sizing and spacing of UI elements to maintain a consistent user experience across different mobile devices.
9. **Feedback Mechanism** – incorporate feedback mechanisms like surveys, ratings, and user feedback forms to gather input from users and enhance the app based on their suggestions and preferences.
10. **User Onboarding and Tutorials** – Provide user-friendly onboarding tutorials and guides to help users familiarize themselves with the app's features and functionalities. Offer tooltips, walkthroughs, and instructional videos for effective app navigation.

## User Interface for Mobile Application

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| **Home Page** |
| A green and white logo  Description automatically generated |

Steps: Home Page

The Home Page serves as the entry point for users accessing the application. Upon their first visit, users are presented with the option to either Login or Sign Up. This initial interaction is crucial, setting the tone for their experience within the application. The Home Page is designed to be intuitive and user-friendly, guiding users seamlessly through the onboarding process. It is built using modern web technologies, ensuring compatibility across various devices and browsers. The page's layout is responsive, adapting to different screen sizes to provide a consistent experience. Interactive elements are strategically placed to encourage user engagement and exploration. Overall, the Home Page is designed to make a positive first impression and establish a strong foundation for users' interactions with the application.

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| **Sign Up** | |
| A screenshot of a email  Description automatically generated | A screenshot of a phone  Description automatically generated |

Steps: Home Page -> Sign Up

The Sign-Up page is where new users can create an account to access the application. During the Sign-Up flow, users must enter their email address and agree to the terms and conditions and the privacy policy. Once this information is submitted, a confirmation message is displayed, prompting users to verify their email address. An email containing a confirmation link is sent to the provided email address. Users must click on this link to verify their email and complete the Sign-Up process. After confirming their email, users can then log in to the application using their credentials. This process is designed to ensure the security and validity of user accounts and to comply with privacy regulations.

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| **Sign In** |
| A screenshot of a phone  Description automatically generated |

Steps: Home Page -> Sign In

The Sign In page is the gateway to the main application interface, where users can access their accounts by entering their email address and password. Upon entering their credentials, users must click the Log In button to initiate the authentication process. The system validates the entered email and password against the database records. If the credentials match, the user is granted access to the application. This process ensures that only authorized users can access the application's features and data.

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| **Main Menu** |
| A screenshot of a phone  Description automatically generated |

Steps: Home Page -> Sign In -> Main Menu

The main menu provides users with access to various sections of the application, offering a streamlined navigation experience. Users can choose from options such as notifications & alerts, dashboard, automation, profile, and more. This menu serves as a central hub, allowing users to easily navigate between different features and functionalities within the application. It is designed to enhance user productivity and efficiency by providing quick access to key areas of interest.

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| **Profile** |
| A screenshot of a phone  Description automatically generated |

Steps: Home Page -> Sign In -> Main Menu -> Profile

The profile menu provides users with access to various sections related to their accounts and settings. Within this menu, users can navigate to My Profile, where they can view and edit their personal information. They can also access My Organization to manage organizational settings and information. The Billing section allows users to manage their payment methods and view billing information. The Settings menu provides access to account settings, where users can customize their preferences. The Help section offers resources and assistance for using the application. The About menu provides information about the application and its version. Finally, the Log Out option allows users to securely log out of their account.

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| **Dashboard - Sensors** |
| A screenshot of a device  Description automatically generated |

Steps: Home Page -> Sign In -> Main Menu -> Dashboard Sensors

The Dashboard Sensors feature enables users to visualize the data received from sensors deployed on the robot. These sensors provide real-time measurements of various environmental parameters, including Light Intensity, Soil Moisture Level, Temperature, and Humidity Level. Users can view this data in a graphical format, allowing them to monitor and analyze the robot's surroundings. The Dashboard Sensors feature provides valuable insights that can help users make informed decisions and optimize the robot's performance.

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| **Dashboard – History Data** |
| A screenshot of a computer  Description automatically generated |

Steps: Home Page -> Sign In -> Main Menu -> History Data

The History Data feature allows users to visualize sensor data in real-time and access historical data from different time intervals: 1 hour, 6 hours, 1 day, 1 week, and 1 month ago. This feature provides users with a comprehensive view of past data, enabling them to track changes and trends over time. Users can analyze historical data for parameters such as Light Intensity, Soil Moisture Level, Temperature, and Humidity Level, gaining valuable insights into environmental conditions and trends.

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| **Dashboard – Robot Arm** |
| A white background with black dots  Description automatically generated |

Steps: Home Page -> Sign In -> Main Menu -> Robot Arm

The Robot Arm menu enables users to control the robot arm directly from their device. This functionality allows users to perform tasks such as picking up objects and executing predefined plans. Users can interact with the robot arm through the menu, providing commands and instructions for its operation. This feature enhances the usability of the robot arm, allowing users to perform complex tasks with ease and precision.

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| **Timeline** |
| A screenshot of a phone  Description automatically generated |

Steps: Home Page -> Sign In -> Main Menu -> Timeline

The Timeline feature allows users to verify the most recent connection between the application and the robot. It displays the date and time of the last connection, providing users with real-time information about the status of their connection. This feature helps users stay informed about the connectivity status of the application and the robot, ensuring they have the most up-to-date information available.

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| **Notifications & Alerts** |
| A screenshot of a phone  Description automatically generated |

Steps: Home Page -> Sign In -> Main Menu -> Notifications & Alerts

The Notifications and Alerts feature enables users to receive real-time notifications about system events, updates, and changes made to the application. Users can stay informed about important events and updates, ensuring they are always up-to-date with the latest information. This feature enhances user engagement and helps users stay informed about changes that may affect their use of the application.

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| **Automations** | |
| A screenshot of a phone  Description automatically generated | A screenshot of a phone  Description automatically generated |

Steps: Home Page -> Sign In -> Main Menu -> Automations

The Automations menu allows users to automate various functionalities within the application. Users can define specific actions to be performed and set the conditions for when these actions should occur. This feature enables users to streamline processes and improve efficiency by automating repetitive tasks. Users can customize their automations to suit their specific needs, enhancing the overall usability and functionality of the application.

## User Interface for Web Application

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| **Main Menu** |
| A screenshot of a chat  Description automatically generated |

Steps: Home Page -> Login -> Main Menu

The main menu on the website offers users a comprehensive view of all available components and navigation panels, enhancing the user experience. Positioned on the left panel, it presents the following options for navigation: Devices, Automation, Users, Organizations, and Locations. Additionally, the Devices screen is directly accessible from this menu, allowing users to efficiently manage their devices without navigating through multiple pages.

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| **Devices - Dashboard** |
| A screenshot of a computer  Description automatically generated |

Steps: Home Page -> Login -> Main Menu -> Devices -> Dashboard

The Dashboard feature provides users with a visual representation of sensor data, allowing them to monitor real-time information and access historical data from various time intervals: 1 hour, 6 hours, 1 day, 1 week, and 1 month ago. Additionally, the website allows users to customize the time range for data visualization, providing flexibility in data analysis. This feature offers users a comprehensive view of past data, enabling them to track changes and trends over time. Users can analyze historical data for parameters such as Light Intensity, Soil Moisture Level, Temperature, and Humidity Level, gaining valuable insights into environmental conditions and trends.

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| **Devices - Timeline** |
| A screenshot of a computer  Description automatically generated |

Steps: Home Page -> Login -> Main Menu -> Devices -> Timeline

The timeline feature on the website enables users to view the most recent connection between the application and the robot. It displays the date and time of the last connection, offering users real-time information about their connection status. This feature is designed to help users stay informed about the connectivity status of the application and the robot, ensuring they have the most up-to-date information available.

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| **Devices – Device Info** |
| A screenshot of a computer  Description automatically generated |

Steps: Home Page -> Login -> Main Menu -> Devices -> Device Info

The Device Info section on the website provides users with a comprehensive overview of information related to the device. This includes details such as the device's model, serial number, firmware version, and status.

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| **Devices – Metadata** |
| A screenshot of a computer  Description automatically generated |

Steps: Home Page -> Login -> Main Menu -> Devices -> Metadata

The Metadata section on the website offers users detailed information about their device, including manufacturing date, warranty details, operational history, and certifications. Users can also access technical documentation, user manuals, and troubleshooting guides. This section enhances users' understanding of their device, aiding in informed decision-making regarding its use and maintenance.

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| **Devices – Datastreams** |
| A screenshot of a computer  Description automatically generated |

Steps: Home Page -> Login -> Main Menu -> Devices -> Datastreams

The Datastreams section on the website allows users to access and analyze streams of data generated by the device. Users can view real-time and historical data for various parameters such as temperature, humidity, light intensity, and soil moisture level. This section provides valuable insights into the performance and behavior of the device over time, aiding in data-driven decision-making and optimization.

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| **Automations** |
| A screenshot of a computer  Description automatically generated  A screenshot of a computer  Description automatically generated |

Steps: Home Page -> Login -> Main Menu -> Automations

The Automation menu on the website allows users to automate various functionalities within the application. Users can define specific actions to be performed and set the conditions for when these actions should occur. This feature enables users to streamline processes and improve efficiency by automating repetitive tasks. Users can customize their automation to suit their specific needs, enhancing the overall usability and functionality of the website.

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| **Users** |
| A screenshot of a computer  Description automatically generated |

Steps: Home Page -> Login -> Main Menu -> Users

The Users menu on the website allows users to view members of the same organization. It displays information such as name, email, status, role, and actions for each user. This feature helps users manage and interact with members of their organization efficiently.

# Test Cases

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Test Case ID | Test Scenario | Test Case | Pre-Condition | Test Steps | Test Data | Expected Result | Post Condition | Actual Result | Status (Pass/Fail) |
| TC001 | Light Sensor Calibration Test | Verify the accuracy of the light sensor | Greenhouse setup with power supply, light sensor installed | 1. Place a calibrated light source at a known distance from the light sensor. | Calibrated light source value | Light sensor reading matches the calibrated light source value | Light sensor calibrated | Light sensor reading matched the calibrated value. | Pass |
| TC002 | Light intensity < (1000-1300) lux | Light ON | Light intensity sensor installed | 1. Set light intensity to 900 | Light intensity = 900 | Light should be ON | Light is ON | Light is ON | Pass |
| TC003 | Light intensity < (1000-1300) lux | Light OFF | Light intensity sensor installed | 1. Set light intensity to 1000 | Light intensity = 1000 | Light should be OFF | Light is OFF | Light is OFF | Pass |
| TC004 | Light intensity < (1000-1300) lux | Light OFF | Light intensity sensor installed | 1. Set light intensity to 1300 | Light intensity = 1300 | Light should be OFF | Light is OFF | Light is OFF | Pass |
| TC005 | Light intensity < (1000-1300) lux | Light OFF | Light intensity sensor installed | 1. Set light intensity to 1400 | Light intensity = 1400 | Light should be OFF | Light is OFF | Light is OFF | Pass |
| TC006 | Temperature Sensor Accuracy Test | Check temperature sensor accuracy | Greenhouse setup with power supply, temperature sensor | 1. Place a thermometer in the same environment as the sensor. | Thermometer reading | Temperature sensor reading matches thermometer reading | Temperature sensor calibrated | Temperature sensor reading was within 0.5°C of the thermometer reading. | Pass |
| TC007 | Temperature < (23–26°C) | Fan ON | Temperature sensor installed | 1. Set temperature to 22°C | Temperature = 22°C | Fan should be ON | Fan is ON | Fan is ON | Pass |
| TC008 | Temperature < (23–26°C) | Fan OFF | Temperature sensor installed | 1. Set temperature to 23°C | Temperature = 23°C | Fan should be OFF | Fan is OFF | Fan is OFF | Pass |
| TC009 | Temperature < (23–26°C) | Fan OFF | Temperature sensor installed | 1. Set temperature to 26°C | Temperature = 26°C | Fan should be OFF | Fan is OFF | Fan is OFF | Pass |
| TC010 | Temperature < (23–26°C) | Fan OFF | Temperature sensor installed | 1. Set temperature to 27°C | Temperature = 27°C | Fan should be OFF | Fan is OFF | Fan is OFF | Pass |
| TC011 | Soil Moisture Sensor Calibration Test | Calibrate soil moisture sensor | Greenhouse setup with power supply, soil moisture sensor | 1. Place soil with known moisture content under the sensor probe. | Known moisture content | Soil moisture sensor reading matches known moisture content | Soil moisture sensor calibrated | Soil moisture sensor reading matched the known moisture content. | Pass |
| TC012 | Soil Moisture < (75-80%) | Watering ON | Soil Moisture sensor installed | 1. Set soil moisture to 70% | Soil Moisture = 70% | Watering should be ON | Watering is ON | Watering is ON | Pass |
| TC013 | Soil Moisture < (75-80%) | Watering OFF | Soil Moisture sensor installed | 1. Set soil moisture to 75% | Soil Moisture = 75% | Watering should be OFF | Watering is OFF | Watering is OFF | Pass |
| TC014 | Soil Moisture < (75-80%) | Watering OFF | Soil Moisture sensor installed | 1. Set soil moisture to 80% | Soil Moisture = 80% | Watering should be OFF | Watering is OFF | Watering is OFF | Pass |
| TC015 | Soil Moisture < (75-80%) | Watering OFF | Soil Moisture sensor installed | 1. Set soil moisture to 85% | Soil Moisture = 85% | Watering should be OFF | Watering is OFF | Watering is OFF | Pass |
| TC016 | Humidity Sensor Accuracy Test | Verify humidity sensor accuracy | Greenhouse setup with power supply, humidity sensor | 1. Create a controlled humidity environment with a humidity chamber. | Humidity sensor reading | Humidity sensor reading matches controlled environment | Humidity sensor calibrated | Humidity sensor reading was within 5% of the controlled environment. | Pass |
| TC017 | Humidity < (60-65%) | Mist ON | Humidity sensor installed | 1. Set humidity to 55% | Humidity = 55% | Mist should be ON | Mist is ON | Mist is ON | Pass |
| TC018 | Humidity < (60-65%) | Mist OFF | Humidity sensor installed | 1. Set humidity to 60% | Humidity = 60% | Mist should be OFF | Mist is OFF | Mist is OFF | Pass |
| TC019 | Humidity < (60-65%) | Mist OFF | Humidity sensor installed | 1. Set humidity to 65% | Humidity = 65% | Mist should be OFF | Mist is OFF | Mist is OFF | Pass |
| TC020 | Humidity < (60-65%) | Mist OFF | Humidity sensor installed | 1. Set humidity to 70% | Humidity = 70% | Mist should be OFF | Mist is OFF | Mist is OFF | Pass |
| TC021 | Verification of Robot Arm Calibration | Ensure robot arm is properly calibrated | Robot arm is installed and powered on | Check calibration settings of the robot arm | Robot arm calibration data | Calibration settings match the physical configuration of the robot arm | Robot arm remains calibrated | Calibration settings match physical configuration | Pass |
| TC022 | Basic Movement Test | Test the basic movement capabilities of the robot arm | Robot arm is installed and calibrated | Issue commands to the robot arm to move in various directions and angles | Movement commands | Robot arm moves as per the specified commands | Robot arm remains operational | Robot arm moves as expected | Pass |
| TC023 | Precision Movement Test | Test the precision and accuracy of the robot arm movement | Robot arm is installed and calibrated | Command the robot arm to perform precise movements and reach specific targets | Target coordinates | Robot arm reaches the specified targets with high accuracy | Robot arm remains operational | Robot arm reaches specified targets | Pass |
| TC024 | Payload Capacity Test | Test the robot arm's ability to handle different loads | Robot arm is installed and calibrated | Attach loads of varying weights to the robot arm and observe its performance | Load weights | Robot arm can handle the specified loads without malfunctioning or dropping them | Robot arm remains operational | Robot arm handles loads as expected | Pass |
| TC025 | Light Sensor Failure Test | Verify system response to a failed light sensor | Greenhouse setup with power supply, light sensor installed | 1. Disconnect or simulate failure of the light sensor | Light sensor status | System should detect the absence or failure of the light sensor and alert the user | System logged an error message and alerted the user | Light sensor failure was detected, and system responded accordingly. | Pass |
| TC026 | Temperature Sensor Failure Test | Verify system response to a failed temperature sensor | Greenhouse setup with power supply, temperature sensor | 1. Disconnect or simulate failure of the temperature sensor | Temperature sensor status | System should detect the absence or failure of the temperature sensor and alert the user | System logged an error message and alerted the user | Temperature sensor failure was detected, and system responded accordingly. | Pass |
| TC027 | Soil Moisture Sensor Failure Test | Verify system response to a failed soil moisture sensor | Greenhouse setup with power supply, soil moisture sensor | 1. Disconnect or simulate failure of the soil moisture sensor | Soil moisture sensor status | System should detect the absence or failure of the soil moisture sensor and alert the user | System logged an error message and alerted the user | Soil moisture sensor failure was detected, and system responded accordingly. | Pass |
| TC028 | Humidity Sensor Failure Test | Verify system response to a failed humidity sensor | Greenhouse setup with power supply, humidity sensor | 1. Disconnect or simulate failure of the humidity sensor | Humidity sensor status | System should detect the absence or failure of the humidity sensor and alert the user | System logged an error message and alerted the user | Humidity sensor failure was detected, and system responded accordingly. | Pass |
| TC029 | Robot Arm Failure Test | Verify system response to a failed robot arm | Greenhouse setup with power supply, robot arm installed | 1. Disconnect or simulate failure of the robot arm | Robot arm status | System should detect the absence or failure of the robot arm and alert the user | System logged an error message and alerted the user | Robot arm failure was detected, and system responded accordingly. | Pass |

# Deployment Diagram

A deployment diagram is a visual representation of how a software system is physically arranged and executed across different devices or servers. It shows where software components run, how they interact, and what hardware supports them. It also facilitates effective communication and decision-making regarding infrastructure requirements, scalability, and system performance.

The significance of a deployment diagram lies in its ability to bridge the gap between the abstract design phase and the tangible implementation of a software system. It highlights the runtime environment, illustrating the connections between software and hardware components, allowing for the identification of potential bottlenecks, optimization of resource utilization, and ensuring an efficient and reliable deployment.

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| **High Level Deployment Diagram** |
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| **Detailed Deployment Diagram** |
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1. **User (Computer/Mobile):** Starts the process by purchasing a pre-built bundle and downloading the necessary code from the GitHub source.
2. **GitHub Repository:** Contains the codebase, including C++ files for Arduino and Python files for operating the robot arm.
3. **Arduino Board:** Receives uploaded C++ files to control sensors and the robot arm.
4. **Integrated Development Environment (IDE):** Executes Python files to provide accurate and easy control of the robot arm. This may include an API for controlling the robot arm.
5. **Mobile Device (Mobile):** Uses the Blynk mobile app to monitor and operate the greenhouse system.