# Documentation for Sensor and Actuator Control System

## Overview

This Arduino-based program implements a monitoring and control system for various environmental and operational parameters. It uses multiple sensors to collect data, processes the data, and sends it to a server for further analysis or action. The system also includes actuator controls to respond to environmental changes based on predefined thresholds.

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## Components and Libraries

### Libraries Used

1. **DFRobot_SHT20**: For reading temperature and humidity.
2. **Adafruit_TSL2561_U**: For light sensor readings.
3. **Adafruit_INA3221**: For power consumption monitoring.
4. **RTClib**: For real-time clock (RTC) functionality.
5. **WiFiS3**: For Wi-Fi connectivity.
6. **ArduinoHttpClient**: For HTTP communication.

7. **ArduinoJson**: For creating and parsing JSON data.

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# Pin Definitions

### Sensors

- **TDS Sensor**: `A3`
- **pH Sensor**: `A2`

### Actuators

- **Water Pump Relay**: `8`
- **Misting Relay**: `12`
- **pH Downer Relay**: `A1`
- **Fan Relay**: `A0`

### Stepper Motor

- **Step Pin**: `9`
- **Direction Pin**: `10`
- **Enable Pin**: `11`

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# Functional Blocks

## Wi-Fi Initialization

The `setupWifi` function connects to a specified Wi-Fi network. It retries 20 times before halting the program if the connection fails.

## Sensor Initialization

The `setupSensors` function initializes all connected sensors and displays their status. It checks for the following:

- SHT20 for temperature and humidity
- TSL2561 for light
- INA3221 for power consumption
- RTC for real-time clock

## Actuator Initialization

The `setupActuators` function sets the initial states of all actuators to ensure a safe startup state.

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# Core Features

## Data Acquisition

1. **Sensors:**
   - Light (lux): TSL2561
   - Temperature (°C) and Humidity (%): SHT20
   - pH: Analog sensor
   - TDS (ppm): Analog sensor
2. **Power Consumption:**
   - Solar panel, battery, and load: INA3221 (Channel 1)
   - Actuator consumption: INA3221 (Channel 2)

## Data Processing

- Filters out abnormal readings based on acceptable thresholds.
- Detects significant changes and sends data only when a threshold is crossed.

## Data Reporting

The `reportData` function sends all sensor readings and system status to the server. It uses the `sendSensorData`, `sendComponentStatus`, and `sendMetricData` functions for HTTP POST requests with JSON payloads.

## Actuator Control

1. **Misting System:**
   - Activates when temperature exceeds or humidity drops below acceptable limits.
2. **pH Downer:**

- Activates when pH value exceeds the maximum limit.

3. **Shade Net:**
    - Stepper motor rotates forward or backward to control the shade based on light intensity.

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# Thresholds and Limits

## Sensors

| Parameter | Minimum | Maximum |
|---|---|---|
| Temperature (°C) | 10.0 | 50.0 |
| Humidity (%) | 0.0 | 100.0 |
| pH | 5.0 | 8.0 |
| TDS (ppm) | 0.0 | 2000.0 |
| Light (lux) | 0.0 | 100,000.0 |

## Significant Change Detection

| Parameter | Threshold |
|---|---|

| | Change |
|---|---|
| Light (lux) | 200 |
| Temperature (°C) | 0.5 |
| Humidity (%) | 1.0 |
| pH | 0.1 |
| TDS (ppm) | 50 |

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# Periodic Tasks

1. **Sensor Readings:**
   - Processed every 2 seconds (`sensorReadInterval`).
2. **Data Reporting:**
   - Sends periodic reports to the server every 10 minutes (`REPORT_INTERVAL`).

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# Server Communication

### Endpoints

| Purpose | Endpoint |
| --- | --- |
| Sensor Data | `/api/sensor-data` |
| Component Status | `/api/component-status` |
| Power Consumption Metrics | `/api/save-metric` |

## JSON Payload Structure

**Sensor Data:**

json

Copy code


```
{
"sensor": "temp",
"output": "Temperature Sensor Output",
"parameter": "celsius",
"value": 25.0,
"timestamp": "2023-11-18T10:30:00Z"
}
```

**Component Status:**

json

Copy code

{

"component": "misting_process",

"status": "ON",

"timestamp": "2023-11-18T10:30:00Z"

}

**Power Metrics:**

json

Copy code

{

"metric_type": "battery_percentage",

"metric_value": "75",

"timestamp": "2023-11-18T10:30:00Z"

}

---

## Control Logic

### Light Sensor

- Rotates stepper motor to adjust shade when light exceeds `32,400 lux` or drops below `22,400 lux` for 5 seconds.

### Temperature and Humidity

- Activates misting system if:
  - Temperature exceeds `30°C`.
  - Humidity drops below `65%`.

### pH Sensor

- Activates pH downer relay for 3 seconds if pH exceeds `7.0`.

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## Key Functions

### Initialization

- `setupWifi`: Connects to Wi-Fi.
- `setupSensors`: Initializes all sensors.
- `setupActuators`: Initializes actuators.

### Sensor Processing

- `processLightSensor`: Adjusts shade based on light intensity.
- `processTempAndHumidity`: Controls misting system.
- `processPHSensor`: Adjusts pH level.
- `processTDSSensor`: Monitors TDS levels.

### Data Reporting

- `sendSensorData`: Sends sensor data.
- `sendComponentStatus`: Sends actuator status.
- `sendMetricData`: Sends power consumption metrics.

---

## Usage Example

### Setup

1. Configure Wi-Fi credentials (`ssid`, `password`).
2. Set the server's IP and port (`serverAddress`, `serverPort`).

### Execution

- The system continuously monitors sensors, processes data, and adjusts actuators as needed.
- Reports data periodically to the server.

# Troubleshooting

## Common Issues

1. **Wi-Fi Connection Fails:**
   - Ensure the correct `ssid` and `password`.
   - Check if the server is reachable.
2. **Sensor Initialization Errors:**
   - Verify sensor connections.
   - Check I2C addresses and configurations.
3. **Abnormal Readings:**
   - Check sensor calibration and placement.

The National Engineering University

Alangilan, Batangas City

Proponents:

**20-06252 | BAUTISTA, NIÑO LUIS BERNABE M.**

**20-06612 | CANTOS, WYNN ELDON P.**

**20-04390 | FACTOR, JOHN KENNEDY C.**

**20-08175 | SANDOVAL, JEREMY L.**

Group No. 4~ BSEE 4209

Submitted To:

**ENGR. MARJORIE M. SALVA**

EE 411 INSTRUCTOR

**AY - 2024**

## DECLARATION

This project study, entitled **"GREENHOUSE MANAGEMENT SYSTEM: AUTOMATED CONTROL OF SHADING, MISTING, WATER CIRCULATION, PH LEVEL, AND WATER TDS MONITORING,"** is a presentation of the proponents' original work. Wherever contributions from others are involved, every effort is made to indicate this clearly, with due reference to the literature and acknowledgement of collaborative research and discussions. This project study was done under the guidance of the project study adviser, **ENGR. MARA JESSA B. MACARAIG.**

Bautista, Nino Luis Bernabe M.

Cantos, Wynn Eldon P.

Factor, John Kennedy C.

Sandoval, Jeremy L.

## APPROVAL SHEET

The project study entitled **"GREENHOUSE MANAGEMENT SYSTEM: AUTOMATED CONTROL OF SHADING, MISTING, WATER CIRCULATION, PH LEVEL, AND WATER TDS MONITORING,"** was prepared and submitted by **Bautista, Nino Luis Bernabe M., Cantos, Wynn Eldon P., Factor, John Kennedy C., and Sandoval, Jeremy L.,** in partial fulfillment of the requirement for the degree of BSEE is hereby recommended for an oral examination.

**ENGR. MARA JESSA B. MACARAIG**

Approved by the Committee on Oral Presentation with a grade of ___________.

**PANEL OF EXAMINERS**

**ENGR. ELENOR M. REYES**
CHAIRMAN

**ENGR. DINDO T. ANI**
MEMBER

**ENGR. RICHARD DEAN M. BRIONES**
MEMBER

Accepted and approved in partial fulfillment of the requirements for the degree of **BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING.**

**DATE**

**DR. CRISTINA AMOR M. ROSALES**
DEAN, CoE

## CAPSULE PROPOSAL

Automation has a huge impact on society since it increases productivity and efficiency. This creates new opportunities for technology focused businesses as well as the displacement of jobs. Automation transforms industries by maximizing operations, guaranteeing precision, and fostering consistency while minimizing human interaction. A future where technology and human skills work together to create efficient operations begins to take shape as it spreads. Furthermore, agriculture is essential to international trade, the production of jobs, and economic growth since it combines innovation, expertise, and technological technology. To meet the increasing demand for food while automating difficult duties and reducing the impact on the environment, creative solutions are crucial.

The Greenhouse System creates ideal conditions for maximum plant growth and productivity, modernizing contemporary agriculture. It is perfect for typhoon-prone regions like the Philippines because it shields crops from bad weather and pests. When combined with hydroponics, which cultivates plants in nutrient solutions without soil, high-quality produce and decorative plants can be grown all year round. A important hydroponic crop, lettuce, grows well with greenhouse automation that regulates temperature, humidity, and ventilation precisely. Compared to conventional farming methods, this approach offers a significant gain in production and sustainability.

The purpose is to create an innovative greenhouse management system that supports a few Sustainable Development Goals and adheres with industry requirements. The practical significance of this research on expanding agricultural technology is

highlighted by the implementation of this advanced system at San Isidro, Batangas City. This research could lead to increased food efficiency, less human involvement, the development of sustainable communities, and a greater integration of technology in the agriculture sector.

**KEYWORDS:** Automation, Greenhouse System, Hydroponics, San Isidro, SIMCO

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We are sending our warmest gratitude to all of you.

## DEDICATION

The study is dedicated, first and foremost, to Batangas State University - The National Engineering University, our beloved University, for supplying us with the information that we have employed for this research.

We also dedicate this work to our project beneficiary, SIMCO, in the hope that this project will significantly benefit them.

Wholeheartedly, we dedicate the completion of this research to all of the people behind our success.

To our Almighty God, to our beloved families, to our skilled professor, Engr. Marjorie M. Salva, to the Chairman and panel members, to the evaluator, and to our friends and loved ones.

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**N.L.B.M.B**

**W.E.P.C**

**J.K.C.F**

**J.L.S**

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# CHAPTER I

# INTRODUCTION

This chapter presents the introduction, background to the study, statement of the problem, research objectives, research questions, significance of the study, scope and delimitation and definition of terms.

## 1.1 BACKGROUND OF THE STUDY

Automation impacts our society by increasing efficiency and production, resulting in job displacement while also creating new opportunities for technology-focused companies. It involves using technology to perform activities with minimal human intervention, resulting in a major change in the industries. The adoption of automation technologies, incorporating different methods and processes, improves the efficiency, reliability, and speed of tasks that were previously conducted by human workers. This shift not only optimizes operational workflows but also promotes precision and consistency across various sectors. As automation becomes more widespread, it emphasizes the potential of a future characterized by efficient and reliable operations, where human and technological expertise work together to improve productivity and overall performance. [1]

Agriculture is the practice of cultivating natural resources to sustain human life and provide economic gain. It combines the creativity, imagination, and skill involved in planting and raising animals with modern production methods and new technologies. Agriculture impacts global trade because it’s tied to other sectors of the economy, supporting job creation and encouraging economic development. Countries with strong

agricultural sectors experience employment growth in other sectors, according to the United State Agency for International Development (USAID). Countries with agricultural productivity growth and robust agriculture infrastructure also have higher per capita incomes, since producers in these countries innovate through technology and farm management practices to boost agricultural productivity and profitability. Innovative solutions are required to meet the world's growing food demand while reducing farming's environmental impact and automating manual processes.[2]

The Greenhouse System optimizes environmental conditions to increase plant growth with maximum yield possible time, which is one of the primary goals of the modern agricultural system. Greenhouses have long been recognized as a means of improving crop productivity and quality. They provide a controlled environment, protecting crops from adverse weather conditions, pests, and diseases. However, even within the protected confines of a greenhouse, maintaining optimal weather conditions remains a significant challenge due to the dynamic and unpredictable nature of external factors. [3]

Internet of Things (IoT) enables real-time monitoring and control of environmental factors such as temperature, humidity, water circulation, and nutrient levels, allowing farmers to optimize crop growth while minimizing resource waste. [4] IoT ensures that ideal growing conditions are consistently maintained by automating adjustments based on sensor data, resulting in improved crop yields and quality while significantly reducing the need for manual intervention.

Hydroponics is the cultivation of plants in a liquid nutrient solution with or without the use of artificial medium. Hydroponics has been recognized as a viable way

of producing vegetables (tomatoes, lettuce, cucumbers, pechay, and kangkong) as well as ornamental crops such as herbs, roses, freesia, and foliage plants. Because of the ban on methyl bromide in soil culture, the demand for hydroponically grown produce has risen significantly in recent years.[5]

Lettuce (Lactuca sativa) is the fourth most important vegetable crop grown hydroponically in greenhouses preceded by tomatoes, cucumbers and peppers. Although greenhouse production of lettuce is very small in comparison to field grown, it has a specific market niche as a gourmet, high-quality item. Hydroponic farming revolutionizes conventional farming practices and contributes to a greener future by providing a sustainable and effective technique for growing lettuce.[6]

Greenhouse automation, the focal point of the study, confronts the challenges in lettuce production head-on by effectively incorporating technology and automation into the hydroponic cultivation process within the greenhouse. This approach provides a complex method to regulate vital factors like: temperature, humidity, and ventilation, resulting in an environment that is perfectly suited to the particular requirements of lettuce throughout its entire growth cycle. In lettuce production, the significance of this technology becomes apparent when compared with traditional manual processes.

The Sustainable Development Goals (SDGs) represent a global commitment to addressing some of the most issues confronting humanity. Adopted by all United Nations Member States in 2015, these 17 goals serve as a universal call to action to end poverty, protect the planet, and ensure prosperity for all by the year 2030. By optimizing irrigation practices through automated hydroponic systems, the project contributes to SDG 6 (Clean Water and Sanitation), addressing the goal of ensuring sustainable water management.

Additionally, the adoption of sustainable farming practices and the reduction of carbon footprints align with SDG 13 (Climate Action). Furthermore, the research contributes to the preservation of terrestrial ecosystems, supporting SDG 15 (Life on Land) by promoting efficient and sustainable agricultural practices that minimize environmental impact on land and biodiversity. In addressing these SDGs collectively, the research aims to make a positive and comprehensive contribution to global sustainability efforts, tackling issues related to water, energy, climate change, and ecosystems.[7]

In the community of Brgy. San Isidro, Batangas City, the project beneficiaries are local farmers who have embraced innovative agricultural practices to enhance their productivity. Being the main implementation to their efforts is a greenhouse, which is an important asset that was intended to optimize crop growth and ensure year-round agricultural output.

This greenhouse is already powered by solar panels, representing a significant step towards farming by renewable energy to reduce operational costs and environmental impact. However, despite its potential, the greenhouse has been non-functional, making its advanced infrastructure for not being used. Revitalizing this facility not only promises to enhance the local economy but also aligns with the broader goals of sustainable development and energy efficiency within the community. The restoration and optimization of this greenhouse is to transform agricultural practices in Brgy. San Isidro, advocating both economic growth and environmental care.

The greenhouse measures 3.65 meters wide by 4.6 meters long, at a height of 2.3 meters. Its rectangular shape maximized the available growing space, allowing for efficient use of the 16.79 square meters of floor area. The structure's height provided

enough room for taller plants and allowed for proper air circulation, creating an ideal climate for nurturing lettuce. The greenhouse's dimensions were chosen to accommodate the specific needs of the plants being cultivated, ensuring optimal growing conditions and maximizing the potential for a successful harvest.

In this study, the implications of the technology extend well beyond the agricultural sector. Greenhouse automation not only ensures food security by allowing for consistent crop production, but it also has the potential to reduce agriculture's environmental impact. It aligns with the broader goals of environmental sustainability and resilience by minimizing resource use and waste. The design and development of the greenhouse management system represents agricultural innovation in this context. This research will provide insight into the various components of these systems, from their design principles to the incorporation of modern technologies, as well as their potential for altering agriculture's future. This study adds to a growing body of knowledge by addressing the pressing need for automated lettuce production.

## 1.2 STATEMENT OF THE PROBLEM

Greenhouses play an important role in modern agriculture by creating controlled environments optimal to the growth and yield of lettuce crops. However, the effectiveness of greenhouse operations relies heavily on maintaining precise weather conditions for optimal lettuce production. External factors such as temperature, humidity, TDS Level, pH level and changing light intensities pose significant challenges to greenhouse operators.

The primary issue facing the beneficiary in Brgy. San Isidro, Batangas City, is the non-functionality of their existing greenhouse, which is powered by solar panels. Despite

the significant investment in this advanced agricultural infrastructure, the greenhouse remains underutilized, preventing the farmers from producing crops with its potential benefits. The restoration and optimization of the greenhouse facility are essential steps toward achieving these goals.

Implementation of Internet of Things (IoT) can effectively address challenges in greenhouse management by enabling real-time monitoring and automated control of key environmental factors such as temperature, humidity, and nutrient levels. Sensors continuously gather data, providing farmers with immediate insights and allowing for automatic adjustments when conditions exceed set thresholds.[8]

Light serves as a fundamental catalyst for photosynthesis, the process crucial for the synthesis of essential nutrients and plant growth. Adequate light exposure is essential for healthy development, photosynthesis, and nutrient uptake all of which have an impact on overall plant health and nutritional status. Some studies have found that simultaneous increases of light intensity and temperature within a practical range could significantly facilitate lettuce's growth and nutritional value. Regular monitoring of light levels and adjustments based on plant response is key to achieving the best results in lettuce cultivation. [9]

Temperature and humidity play an important role in the successful cultivation of hydroponic lettuce. Lettuce is a cool-season crop that thrives in specific temperature ranges, with the optimal temperature for growth being between 20 to 24°C (68 to 75°F.[10] Maintaining the proper temperature is essential, as lettuce can bolt (rapidly shoot up to go to seed) when exposed to temperatures exceeding 80 to 85°F (26 to 29°C), making the lettuce unmarketable.[11]

Relative humidity (RH) is another factor in hydroponic lettuce production. The ideal RH range for lettuce is between 50 to 70 percent. High humidity, exceeding 70%, can lead to issues such as tip burn, a physiological disorder caused by a calcium deficiency. The higher the RH, the less transpiration occurs in the plant, resulting in inadequate calcium uptake. Conversely, RH lower than 50% can cause outer leaf edge burn, another physiological disorder.[12]

Water is the medium in which plants absorb nutrients, plants are grown in a nutrient-rich solution instead of soil. It is possible to attain great yields and high quality in hydroponics. When water and nutrients are supplied in the required quantities, characteristics emerge. The nutrients and water needed by the plants are calculable. However, the water quality given is as crucial, but the quality (the salt and nutrient content) is generally fixed. As a result, it is critical to understand the water quality being used and, as a result, what fertilization modifications are required. [13]

The Nutrient Film Technique (NFT) hydroponic system relies on a continuous flow of nutrient-enriched water to provide plants with the necessary moisture and nutrients. In a typical NFT setup, a submersible pump circulates the water from the reservoir, through the channels where the plants are situated, and back to the reservoir in a constant loop.

However, it indicates that some NFT growers have found it beneficial to put the pumps on cycles, effectively flooding and draining the system, rather than running the pump continuously. This is done to address a key drawback of the NFT system, the constant submersion of the roots in the water film, which can limit aeration and lead to

issues like root rot and bacterial diseases.By cycling the water flow, the growers are able to provide the plants with intermittent periods of water and air exposure, which can improve oxygenation and overall plant health.[14]

Total Dissolved Solids (TDS) refers to the cumulative measurement of inorganic salts, minerals, and other dissolved substances present in the water and nutrient solution used in hydroponics. These substances include essential nutrients such as nitrogen, phosphorus, potassium, and micronutrients like calcium, magnesium, and iron. By measuring TDS, growers gain an overall understanding of the nutrient concentration in their hydroponic systems. The plant species, development stage, and nutrient solution formulation all affect the optimal TDS range. Most hydroponic crops do best with a TDS range of 800 to 1500 parts per million (ppm). [15]

In hydroponics, maintaining the right pH level is important for plant health and nutrient absorption. The pH scale ranges from 0 to 14, with 7 being neutral. Most plants survive in a slightly acidic to neutral range, between 5.5 and 6.5. Different plants have specific pH preferences, and maintaining the correct pH ensures they can access important nutrients. pH levels can change due to various factors, such as nutrient concentration, growing media, and organic matter like algae and bacteria. Regular testing and adjustments are necessary to keep pH levels stable.

There are several methods for testing and adjusting pH levels, including test strips, liquid kits, and digital pH meters. For consistent pH control, automatic pH controllers are recommended, especially in recirculating systems. Maintaining the right pH level in hydroponics ensures plants can absorb nutrients properly, leading to healthier

and more productive growth.[16]

These automation systems are specifically crafted to intelligently control and manage the overall lettuce production in real-time, ensuring a more efficient and consistent cultivation process. Despite the potential benefits they offer, greenhouse automation systems particular for hydroponic lettuce production face several critical problems and challenges that require careful investigation and resolution during the design and development phases.

## 1.3 RESEARCH QUESTIONS

1. What are the design standards, requirements, and considerations for automated control of shading, misting, water circulation, pH level, and TDS monitoring?
2. What are the methods and procedures needed for the fabrication, construction, and assembly of an automated control of shading, misting, water circulation, pH level, and TDS monitoring?
3. What tests are necessary to determine the machine's reliability and efficiency?

## 1.4 RESEARCH OBJECTIVES

The main objective of the study is to design and develop the automated control system of shading, misting, water circulation, pH Level, and TDS monitoring. Specifically, this aims to achieve the following:

1. To design the system in terms of:
   - 1.1 General Description of the Project
   - 1.2 Design Standards
   - 1.3 Design Computation and Analysis
   - 1.4 Design Layout

1.5 Circuit Diagram

1.6 Materials and Components

1.7 Programs and Its implementation

1.8 Bill of materials and specifications

2. To develop the System in terms of its methods of fabrication and assembly.

3. To evaluate the overall system performance in terms of:

3.1 Functionality Test

3.1.1 Shade Net Control Test

3.1.2 Climate Control & Misting Control Test

3.1.3 pH Level Control Test

3.2 Performance Testing

3.2.1 Growth Stage of Lettuce

## 1.5 SCOPE AND DELIMITATION OF THE STUDY

The research will be carried out at Brgy. San Isidro, Batangas City, Philippines. This venue is ideally suited due to its established infrastructure for hydroponic farming, providing a relevant setting for testing the proposed automated control system. The hydroponic greenhouse measures 3.65 by 4.6 meters with a height of 2.9 meters.

The study focuses on developing a smart greenhouse system that will control the environment inside the greenhouse. Innovating the greenhouse through the use of a retracting shading net that will automatically adjust the environment condition especially when excess sunlight is detected. According to the design, the proposed shade net will be string-pulled by a stepper motor that is automatically operated by a microcontroller. By implementing this shading net, the internal environment of the greenhouse can be optimized, ensuring that plants receive the right amount of sunlight without being exposed to excessive heat or light levels, ultimately enhancing their growth and

productivity.

Moreover, the study aims to develop a misting system for the greenhouse. The mister is mounted underneath the roof within the greenhouse railings. The water supply for the misting is directly connected to the water distribution utility and is automatically controlled by a microcontroller such as the Arduino Mega.

The study also involves designing the watering system. The goal is to implement automated controls of watering schedules based on real-time data related to crop needs and environmental conditions. The proposed watering system will operate every 15 minutes within an hour.

pH sensors will be installed in the greenhouse to continuously monitor the acidity and alkalinity of the water. These sensors will provide real-time data that can be used to adjust irrigation, fertilization, and other environmental factors as needed. The TDS sensor will only be used to monitor the dissolved combined contents in the water. By maintaining optimal pH and TDS levels, the greenhouse can provide ideal conditions for the plants.

To achieve precise control over the entire system, an automated controller, such as Arduino Mega, is necessary. The Arduino utilizes a simplified C++ language for its syntax, and its libraries are also simplified for ease of use.

The electrical system would be sourced from a 12VDC that was supplied by the solar panel that were stored by the battery. All components were operated thru DC voltage as per requirement of most of the electrical parts. The overall electrical system would be operated off-grid as it is a low power system.

The project will adhere to standards set by the Philippine Electrical Code (PEC)

and the National Electrical Manufacturers Association (NEMA) for all electrical installations and components. Additionally, the agricultural construction will follow best practices in greenhouse design, considering local climate conditions and agricultural standards required by the PEC to minimize the risk of accidents. A smart greenhouse system will be developed and tested in collaboration with a private individual who owns the greenhouse. Despite the fixed size of the greenhouse, it will serve as a practical testbed, providing valuable insights and feedback for refining the smart greenhouse system and exploring potential future applications in agriculture.

However, certain limitations are essential to the project. Budget constraints dictate the scale and complexity of the automation system, and technological limitations may affect the feasibility of advanced features. Time constraints also play a role, influencing the depth and span of research, experimentation, and analysis.

Therefore, all the other types of lettuce other than batavia lettuce would be disregarded to be used or simply not optimally designed to be raised in this specific kind of greenhouse. This automation is only the production and does not include the planting process of lettuce which is classified as the germination. Geographical considerations acknowledge that the applicability of the system may vary based on different climatic and geographical conditions.

## 1.6 IMPORTANCE OF THE STUDY

The research aims to establish a solar powered greenhouse that helps in automating the whole process of production of lettuce within the greenhouse. This study can create great impacts to the following people in particular:

**To Greenhouse Owners.** The study's findings will provide greenhouse owners

with insights into how to optimize their plant growth conditions, particularly regarding sunlight exposure. By incorporating the smart greenhouse system, they can expect improved plant health and productivity, ultimately leading to increased yields and profits.

**To the Local Community and Agricultural Sector.** The implementation of the smart greenhouse system has the potential to contribute to the local agricultural sector's sustainability and growth. By enhancing the efficiency and productivity of greenhouse operations, the study aims to create a positive ripple effect, benefiting not only individual greenhouse owners but also the broader agricultural community.

**To the Electrical Engineering Department of Batangas State University.** The study serves as a platform for the Electrical Engineering Department to showcase its expertise in developing innovative solutions for real-world problems. By collaborating with a private individual and focusing on the practical application of electrical engineering principles, the department can demonstrate its commitment to addressing societal needs through research and development.

**To the Researchers.** The study presents an opportunity for researchers to contribute to the advancement of knowledge in the field of smart greenhouse systems. By conducting thorough investigations, designing and implementing the system, and analyzing its performance, researchers can deepen their understanding of the complex interactions between technology and agriculture, paving the way for future research endeavors.

**To Future Researchers:** The study's findings and methodologies can serve as a valuable resource for future researchers interested in smart greenhouse systems or related fields. By documenting the challenges, solutions, and lessons learned, the study can

provide a foundation for further exploration and innovation in agricultural technology.

# CHAPTER II

# LITERATURE REVIEW

This chapter discusses the review of literature used in the study. The discussion of literature is divided into two parts: conceptual literature and related literature. A synthesis regarding how the following studies would be used as well as the discussions regarding the similarities and differences of the study to those existing publications is also presented.

## 2.1 CONCEPTUAL LITERATURE

This section is concerned with various concepts that will be useful for this study. The information provided in this chapter is derived from books, publications, and websites.

### Principles and Theories of Automation

Automation is a fundamental idea and principle in the engineering fields, as well as in industrial civilization (manufacturing, processes, industries, etc.). Automatic machines are used to increase a plant's output per worker in order to lower growing wages and the production expenses that go along with it. High productivity can be achieved using automatic systems without sacrificing accuracy and precision. Therefore, automation is the process of reducing human intervention in machine operation and directly replacing it with technologically advanced systems like computers, robotics, etc.[17]

Automated systems generally outperform manual systems in terms of productivity, speed of operation, accuracy, and precision. Automation is applicable to a wide range of systems, from simple household appliances to complex industrial activities.

The control systems might be as simple as ON/OFF buttons or as complex as multivariable high-level algorithms. Industrial automation employs control systems and information technology to manage a variety of machinery and processes. Automation has made manufacturing lines much more flexible, resulting in higher output quality and quantity.

**Principles and Theories of Greenhouse**

A greenhouse is an external structure for growing plants, primarily made of a transparent material like glass or polycarbonate panels. In order for a greenhouse to function, as much light as possible must be let in and then stored as heat energy. All of the daylight is able to enter the greenhouse due to its transparent roof and walls. The greenhouse's soil and plants both become warmer as a result of this light. However, because glass is an insulator as well, the heat is trapped inside the structure, maintaining a comfortable temperature throughout the day. Maintaining a steady temperature is a big advantage of greenhouses. Even after the sun sets, the greenhouse remains warm because materials like water and soil within it absorb thermal energy from sunlight and release it gradually. The greenhouse is enclosed, so there isn't a breeze to release the heated air. Your plants remain comfortable as a result of the consistent temperature, which is typically quite warmer than the sudden cold temperatures we experience outside. In addition to being protected from inclement weather, they receive all the sunshine required for wholesome growth. [18]

According to the Philippine Agricultural Engineering Standard (PAES), gable roof greenhouses are required to adhere to specific height guidelines. The standard stipulates that the eave height, which is the distance from the ground to the point where

the roof begins, should be a minimum of 1.70 meters. Additionally, the gable height, which is the vertical distance from the eave to the highest point of the roof, must not be less than 2.4 meters. These specifications ensure that gable roof greenhouses comply with established standards to meet structural and functional requirements in agricultural engineering.[19]

**History of Greenhouses Development**

Historically, people have been using greenhouses for protecting plants from harsh weather conditions since ancient times. Here, the history of greenhouse development has been discussed. The first notes about greenhouses can be traced to the reign of Tiberius, Roman emperor from 14 to 37 CE. The Roman emperor Tiberius ate a cucumber-like vegetable daily, requiring Roman gardeners to discover artificial methods, similar to a greenhouse system, to grow it year-round. The gardeners first tried to install cucumber plants on carts so they could drag them into sheds when it became too cold. But if the cold lasted more than a few days, the cucumbers would start to die from lack of light. But someone came up with the idea of covering the structures not with slate, but sheets of selenite, a transparent rock, to let the sun in.[20]

There are nine greenhouse farming in the Philippines: Albay, Bulacan, Cavite, Laguna, Leyte, Negros Occidental, Nueva Ecija and Pangasinan. The five major greenhouse in the country are located in Albay (1,000 hectares), Cavite (500 hectares), Laguna (1,000 hectares), Leyte (2,000 hectares), and Negros Occidental (1,000 hectares). With ample sunlight and fertile soil, the Philippines is perfect for greenhouse farming. Philippines is estimated to have a production capacity of 6-7 million plants per year. The main challenges facing the Philippines greenhouse industry is logistics, it’s difficult to get

produce from rural areas into urban centers where it can be sold and distributed to customers.[21]

### Types of Greenhouses Based on Covering Materials & Construction

### Glass Type Greenhouse

**Figure 2.1** Glass Greenhouses (Source: Gothic Arch Greenhouses)

Glass is used as covering material in glass greenhouses. As a covering material it has the advantage of greater interior light intensity, has a higher air infiltration rate, and leads to lower interior humidity and excellent disease prevention quality. Ridge and furrow, lean-to type, even span type of designs are used for construction of glass greenhouse.[22]

**Plastic Film Type Greenhouse**

**Figure 2.2** Polyethylene Plastic for Greenhouses

The covering materials of flexible plastic including polyvinyl chloride, polyethylene and polyester are used in this type of greenhouses. As a covering material for greenhouses, plastics are more popular, cheap and the heating cost as compared to glass greenhouses. Plastic lms have a short lifespan which is the main disadvantage of this covering material. For example, the best quality ultraviolet (UV) stabilized can last for four years only. Quonset design as well as gutter-connected design is suitable for using this covering material.[22]

**Shade Cloth Type Greenhouse**

**Figure 2.3** Perfect Shade Cloth for Your Greenhouse

Shading is a way of keeping the greenhouse cool during the hotter months. It reduces the temperature inside by minimizing the amount of light passing to the greenhouse. Shade clothes typically reduce the light level by 75% and turn it into heat. The temperature of the cloth rises as it acts as a solar collector. The temp of the cloth is higher than the temp of the air, so the heat energy goes up. As it goes up, the cool air draws from below in the process known as evaporative cooling. The most common materials for the cloth are polyethylene and polypropylene. You can find a variety of shade cloths of different densities and degrees of shade ranging from 5 to 95 per cent.[22]

**Principles and Theories of Greenhouse Management**

Greenhouse management is crucial for maximizing efficiency and productivity in commercial greenhouse plant production. It encompasses a comprehensive approach, addressing various aspects such as the design and structure of greenhouses, environmental control systems, heating and cooling mechanisms, selection and maintenance of growing media, effective fertilization strategies, optimal carbon dioxide supplementation, precise irrigation techniques, and diligent pest management.

Moreover, it also includes the production of container-grown crops, ensuring that all components work in harmony to create ideal growing conditions. This holistic approach not only enhances plant growth but also promotes sustainable agricultural practices, making it an essential element in the success of commercial greenhouse operations.[23]

**Application Automated Greenhouse Management**

The application of automation in greenhouse management has developed the agricultural industry by combining modern technology with traditional farming. This

ensures optimal growth conditions for plants, reduces labor costs, minimizes errors, and guarantees consistent production. With the challenges posed by environmental changes and global warming, these smart and automated systems offer sustainable solutions for future agriculture.[24]

**Figure 2.4** Automated Greenhouse System by the University of Arizona

At different growth stages, plants need varying light types and intensities. Utilizing plant-specific light modulators guarantees that they receive the appropriate light when needed.[24]

**Figure 2.5** Retractable Shade Net

Figure 2.5 shows the retractable shade net that protract and retract with the use of pulley and rope. The Filipino farmers call it “automatic” because the manual work for them is when the workers will pull the end of the shade net to the other side to stretch it.[25]

The irrigation approach varies based on the plant type and farming conditions. Although drip and flood irrigation are common, modern farming practices are increasingly favoring tidal irrigation. Essential tools for effective irrigation management include water flow sensors, flow meters, electromagnetic valve controllers, water temperature sensors, and liquid level sensors. By utilizing these devices, one can more accurately regulate and supervise the irrigation process to ensure plants receive adequate water.[24]

**Figure 2. 6** Commercial Greenhouse Irrigation

**Principles and Theories of Hydroponics**

The word hydroponics comes from Latin, where "hydro" means water, and "ponos" means work. In hydroponics, plants grow in water instead of soil. When plants grow, they use light and chlorophyll to turn carbon dioxide and water into sugar and

oxygen through a process called photosynthesis. The interesting thing is that you don't see the word "soil" in there. That's because plants can grow without it. What they really need is water and nutrients, usually found in the soil. But if they can get those things somewhere else, like standing in a solution full of nutrients, they can do without soil altogether. This fundamental idea forms the basis of hydroponics. While the literal interpretation of "hydroponics" implies growing plants in water (derived from Greek words meaning "water" and "toil"), the commonly accepted definition involves cultivating plants without the use of soil.[26]

**Hydroponics System**

Growing plants hydroponically involves utilizing a water-based nutrition solution in place of soil, together with an aggregate substrate or growing media like perlite, vermiculite, or coconut coir. Commercial enterprises, hobbyists, and small farmers all use hydroponic production systems.

**Types of Hydroponics System**

1. **Nutrient Film Technique (NFT)**

The NFT (nutrient film technique) is a widely used hydroponic method where plants' roots are suspended in the air above a growing medium like gravel or perlite. A nutrient solution is pumped through this medium, flowing over the roots, before returning to the reservoir. Coined by Allen Cooper in 1965, the technique involves a shallow stream of water, hence the name "nutrient film technique." It's favored by commercial growers due to its simplicity in maintenance and fewer potential complications.[27]

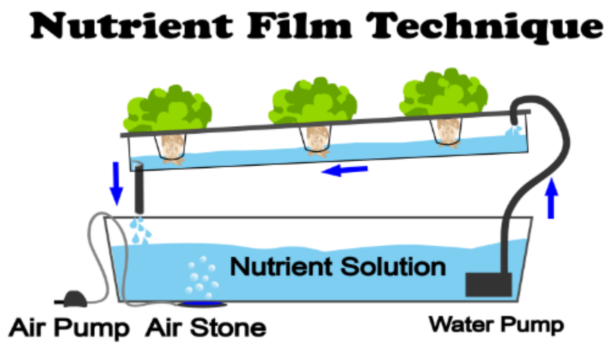


**Figure 2.7** Nutrient Film Technique

The fertilizer solution flows into channels that may support a variety of plant sizes in NFT hydroponics systems. Because the tubes are somewhat inclined, the nutritional solution runs through them, over the dangling roots of the plants, and then back into the hydroponic reservoir.[27]

2. **Deep Water Culture (DWC)**

Deep water culture (DWC) systems involve continuously immersing plant roots in a nutrient solution within a single basin, with an air stone at the bottom to aerate and oxygenate the water. Because it is simpler and easier to set up than more complex systems like aquaponics or aeroponics, this method is popular among new hydroponic gardeners. DWC is considered a passive system because it does not continuously recirculate water and nutrients. An air stone is required to improve oxygen circulation, which contributes to the system's success in maintaining suitable conditions for plant growth.[28]

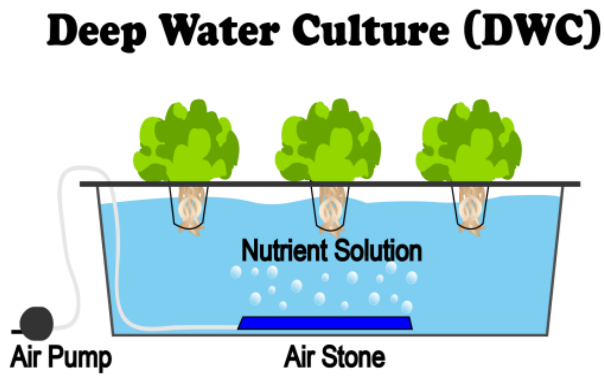


**Figure 2.8** Deep Water Culture

The roots of the plants in DWC hydroponic systems are suspended in the nutrient solution, and an air stone or diffuser delivers air straight to the roots. To help keep them secure, plants are placed in net pots filled with grow material.[28]

3. **Drip System**

Drip system hydroponics is a popular method in which nutrient solution is dripped onto plant roots and then recirculated back to the reservoir. It is an active hydroponic system that uses a pump to deliver nutrients and water to plants. Because of its drip mechanism, this system provides improved ecosystem control, allowing for precise management of the growing environment.[29]

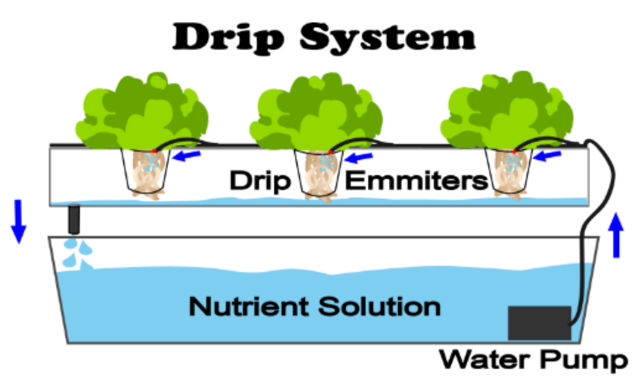


**Figure 2.9** Drip System

Drip hydroponic systems are perfect for people who frequently make adjustments because they are simple to use, set up, and adaptable in many ways. In these systems, the plant's base receives a direct supply of nutrients via tubes.[29]

**4. Aeroponics**

An improved form of hydroponics known as aeroponics involves suspending plants in the air and misting them with water on a regular basis using a timed sprinkler system that is linked to a primary nutrient reservoir. Because aeroponic roots aren't hindered by dense soil or thick growing media, this soilless growing technique is ideal for plants that require more oxygenation. Growing media is usually used sparingly or not at all by the grower, depending on the plant and type of aeroponics system.[30]

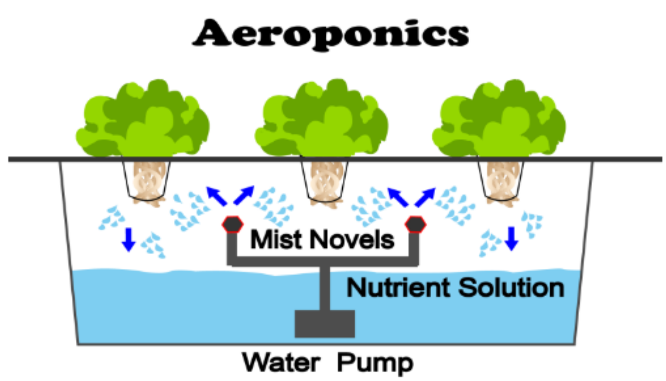


**Figure 2.10** Aeroponics

The piping that has mist nozzles installed is pumped with the nutrient solution. The solution returns to the reservoir as the pressure increases and the misters spray the plant's roots.[30]

**Significance of Light Intensity in Lettuce Cultivation**

Light intensity, or light quantity, refers to the total amount of light plants receive. This intensity drives photosynthesis, producing the carbohydrates that serve as the building blocks for plant growth. Unlike light quality, light intensity does not consider wavelength or color.[31]

Lux is a unit of measurement for illuminance, representing the amount of light that hits a surface. In the context of direct sunlight, understanding lux levels is essential for various applications, including agriculture, solar energy, and architectural design. On a clear day, direct sunlight typically ranges from 32,000 to 100,000 lux. Understanding sunlight lux helps optimize crop growth, ensuring plants receive adequate light for photosynthesis.[32]

**Conversion of Light Intensity to Lux**

Photosynthetic Photon Flux Density (PPFD) is a crucial unit used to measure the light that reaches a plant's canopy in the Photosynthetically Active Radiation (PAR) zone. This metric tells us the number of photosynthetically active photons falling on a given surface each second, expressed in µmol/s.m².[33]

$$Lux = PPFD\ x\ 54 \qquad \textbf{(Eq. 2.1)}$$

Where:

Lux = measurement of illuminance (lx)

PPFD = Photosynthetic Photon Flux Density

There are a few requirements that must be met while cultivating crops, tomatoes, lettuce, or cannabis in a big growing facility, our own backyard, or a grow tent. Enough air, water, and fertilizer are necessary for crops to grow well. Another thing to remember

is that everything grows in response to sunlight, and adequate light increases crop yields. When you have all of the above, your plants will grow healthily right away.

For most plants, the cold season is a difficult test of growth. Crops' metabolism will be significantly inhibited by low temperatures, which will postpone growth. We are all aware that sunshine is essential to plant growth and that sunlight influences plant growth in turn. As a result, plants cannot receive the optimal natural light during the day if they are placed in an interior dark space, and they will not grow normally and healthily. Nowadays, indoor planting is a highly popular option because it allows you to quickly adjust the growth environment to the crop's stage of development. This approach can be just as effective as the process of spontaneous growth if the right steps are done. Additionally, since grow light is a great alternative to sunshine for providing light supplementation to plants, you don't need to worry about the lack of light in the indoor setting.[34]

**Shade Net**

Shade net is a type of lightweight agricultural covering material that is primarily used for air permeability, wind proofing, heat and moisture preservation, and shading. An agricultural shade net may efficiently prevent excessive sunshine and high temperatures, lessen crop water evaporation, increase air humidity, and retain soil moisture all of which are favorable to crop growth. Furthermore, shade nets can operate as a windbreaker, lessening the effect of wind speed on crops while maintaining indoor air circulation, allowing for breathability, encouraging crop growth, and enhancing crop quality and yield.[35]

**Figure 2.11** Shade Net

The shade net regulates the amount of sunlight that enters, preventing overheating while maintaining optimal conditions for plant growth. Greenhouse shade nets work by blocking some sunlight, reducing intensity and minimizing temperature spikes within the enclosed space.[36]

**Pulley**


**Figure 2.12** Pulley

A pulley is a simple machine made up of a string (or rope) looped around a wheel (often with a groove), with one end connected to an object and the other to a human or a motor. Pulleys may appear basic, but they can provide a significant mechanical

advantage, making lifting duties much easier.[37]

**Shaft**

**Figure 2.13** Shaft

Shaft is basically the rotating component of any machine, which is round in the cross-section and is used for passing the power from one part to another or from the power producing machine to the power absorbing machine. A shaft is a rotating machine element, usually circular in cross section, which is used to transmit power from one part to another, or from a machine which produces power to a machine which absorbs power.[38]

**Determining the Allowable Stress of a Shaft**

The maximum allowable stress of a shaft depends on various factors, including material properties, loading conditions, and safety considerations.[39]

$$S_s = 30\% \ of \ S_y \qquad \textbf{(Eq. 2.2)}$$

Where:

$S_s = allowable\ stress\ for\ the\ shaft$ (MPa)

$S_y = yield\ strength\ for\ the\ material\ used\ for\ shaft$ (MPa)

**Determining Shaft Diameter**

Determining the correct diameter of a shaft is crucial for ensuring its strength, minimizing deflection, resisting fatigue, and maintaining safety and efficiency, all while balancing performance with cost and compatibility considerations. Proper sizing prevents mechanical failures, reduces vibration and noise, and ensure pps compliance with industry standards.[39]

$$D = \sqrt{\frac{8F}{\pi S_s}} \qquad \textbf{(Eq. 2.3)}$$

Where:

$D =$ diameter of the shaft (m)

$F =$ tension force from the shade net and the weight of the shaft itself. (N)

**Determining Shaft Torque**

Shaft torque is the amount of rotational force needed to drive a machine or carry out another planned function for a shaft. The force is influenced by factors such as the applied load and the required rotational speed of the shaft.[39]

$$T = \frac{\pi D^3 S_s}{16} \qquad \textbf{(Eq. 2.4)}$$

Where:

$T = torque\ (Nm)$

**Power Requirement**

The power requirement of a shaft involves calculating the power needed to perform a specific function, such as operating a machine or mechanical system. The calculation depends on the torque applied to the shaft and its rotational speed.[39]

$$P = 2\pi T N \quad \textbf{(Eq. 2.5)}$$

Where:

$P$ = power (W)

$N = rotational\ speed\ (RPM)$

**TSL 2561 Sensor**

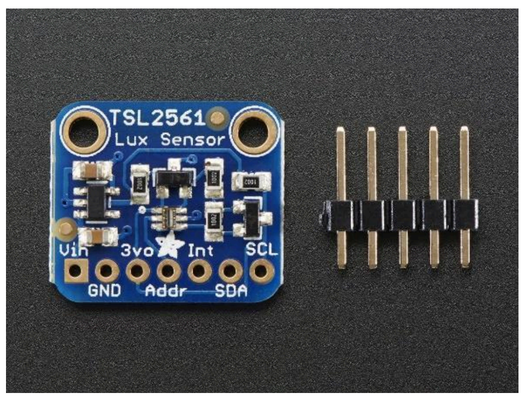


**Figure 2.14** TSL 2561 Sensor

The TSL2561 luminosity sensor is a digital light sensor that may be used in a variety of lighting conditions. Compared to low-cost CdS cells, this sensor is more precise, allowing for correct Lux metering, and it can be set for multiple gain/timing ranges to detect light levels ranging from 0.1 to 40,000+ Lux on its own. The best thing about this sensor is that it includes both infrared and full spectrum diodes! This means that you can measure infrared, full-spectrum, and visible light separately. Most sensors

can only detect one or the other, which does not exactly represent what human eyes see (since most photodiodes detect infrared light).[40]

**Importance of Misting System to maintain humidity and temperature**

The implementation of a misting system into farming practices brings about a significant improvement in managing plant growth. One of its main roles is to carefully regulate humidity, maintaining an optimal moisture level for plants. By releasing fine water droplets, the system strikes a balance, preventing issues caused by both too much and too little moisture. The precise control over humidity is crucial for ensuring the health and vitality of plants.

Misting system acts as a reliable protector against temperature fluctuations and excessive evaporation. When temperatures rise, the controlled mist cools the surroundings, shielding plants from the harmful effects of overheating. At the same time, it acts as a shield, reducing evaporation and preserving the necessary moisture levels. This dual function not only helps control temperature but also safeguards plants from the negative impacts of dehydration. [41]

**Determining Relative Humidity**

The amount of water vapor in the air is known as the "vapor pressure," wherein air can only hold a certain amount of water vapor at a given temperature before it starts condensing back to liquid in the form of rain. [42]

$$Relative\ Humidity\ =\ \frac{AVP}{SVP}\ X\ 100\% \qquad \textbf{(Eq. 2.6)}$$

Where:

$AVP\ =\ actual\ vapor\ pressure$

$SVP\ =\ saturation\ vapor\ pressure$

**Determining Flow Rate**

Flow rate refers to the quantity of fluid passing through a particular point in a system per unit of time. It is a key parameter for understanding and analyzing fluid behavior, as well as for designing and optimizing various systems and processes that involve the movement of fluids, such as pipelines, pumps, and ventilation systems. [43]

$$Q = \frac{V}{t} \qquad \textbf{(Eq. 2.7)}$$

Where:

$Q = flowrate\ (\frac{m^3}{s})$

$V = volume\ (m^3)$

$t = time\ (s)$

**Mist Maker**

Misting nozzles are used to cool outdoor spaces in all sorts of industries and for all kinds of purposes, from public venues and commercial establishments to industrial plants and agricultural environments. It is useful because they create drops of water that are around 15 millionths of a meter, or microns, in width. The size of the droplets is crucial because they are small enough that they evaporate quickly, rather than collecting on everything around them.[44]

**Figure 2.15** Misting Nozzles

Misting nozzles  consist of a series of nozzles placed in a line. When attached to high-pressure pumps, water is forced through nozzles, forming droplets which evaporate into mist when they reach the outdoor air. This can reduce the temperatures by 35 to 40 degrees Fahrenheit. If the misting system is in a confined indoor area, it will provide a cool mist but will also increase humidity.[44]

**Humidity and Temperature Sensor**

A sensor is typically defined as an input device that generates an output signal in response to a physical quantity detected. The term "input device" in this case implies that the sensor is part of a larger system, giving data to a central control unit such as a processor or microcontroller. A sensor can also be defined as a device that converts signals from various forms of energy into electrical signals.[45]

Humidity sensors, also called hygrometer, are devices that detect and measure the amount of water vapor or moisture that is contained in the air, which can not only influence the level of comfort that is experienced by people and animals but also plays an important role in the production of products and other manufacturing processes. Being able to sense and measure the level of humidity is necessary in order to exercise control over it, such as by turning on the air conditioner in the summertime or a humidifier in the winter.[46]

Temperature sensor is an instrument that is constructed to sense the condition of coolness or hotness in the target. The fundamental working of this sensor is based on the voltage in its diode. The temperature variation is directly related to the resistance of this diode. The resistance of the diode is detected and transformed into simple and readable values of temperature such as Fahrenheit, Kelvin, or Centigrade and demonstrated in

meaningful formats instead of readout values. These temperature sensors are employed to sense the internal temperature of various structures like power plants.[47]

The DHT11 sensor is a widely employed temperature and humidity sensor, known for its reliability and ease of use in various applications. This sensor is equipped with a dedicated Negative Temperature Coefficient (NTC) element to accurately measure temperature and an 8-bit microcontroller responsible for transmitting temperature and humidity data as serial data. Additionally, the DHT11 sensor is pre-calibrated at the factory, simplifying its integration with other microcontrollers.

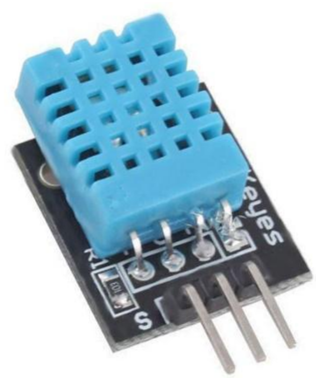


**Figure 2.16** DHT11-Temperature and Humidity Sensor

This versatile sensor is capable of measuring temperature within the range of 0°C to 50°C and humidity levels ranging from 20% to 90%. It boasts an impressive level of accuracy, with temperature readings accurate to within ±1°C and humidity readings accurate to within ±1%. If your research requires measurements within this temperature and humidity range, the DHT11 sensor stands as a suitable and dependable choice for your application.[48]

**Water Flow Rate & Volume Measurement**

**Figure 2.17** Water Flow Rate & Volume Measurement

A water flow sensor is made of a plastic valve through which water can pass. A water rotor and a hall effect sensor are present to sense water flow rate and monitor water volume. Water passes through the valve, causing the rotor to rotate. This allows the change in the motor's speed to be seen. The hall effect sensor calculates the change and outputs it as a pulse signal. Thus, the rate of flow of water may be determined.[49]

**Solenoid Valve**

**Figure 2.18** Solenoid Valves

Solenoid valves are control units which, when electrically energized or de-energized, either shut off or allow fluid flow. The actuator takes the form of an electromagnet. When energized, a magnetic field builds up which pulls a plunger or

pivoted armature against the action of a spring. When de-energized, the plunger or pivoted armature is returned to its original position by the spring action.[50]

### Solar Water Pump

A solar water pump operates by harnessing energy from the sun, which is converted into electricity by solar panels. These panels consist of photovoltaic cells that capture sunlight and transform it into direct current (DC) electricity.

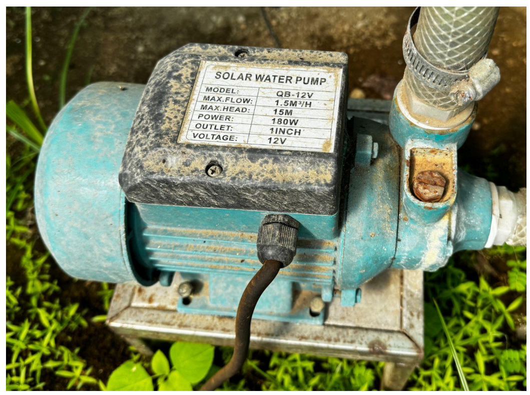


**Figure 2.19** Solar Water Pump

Solar water pump is used in a hydroponic system to circulate the nutrient and water to plants grown without soil. Solar panels convert sunlight into electricity, which then powers a surface pump to distribute the nutrient solution through the hydroponic setup.[51]

### Nutrient Solution

The nutrient solution is composed of key elements such as nitrogen, phosphorus, potassium, calcium, magnesium, and trace elements like iron, manganese, and zinc, all provided in precise concentrations to promote optimal plant growth. For example, the concentration of nitrogen might vary, presented in forms that plants can easily absorb,

such as nitrate and ammonium. The water quality used in preparing the nutrient solution is critical; it must be free from contaminants, and its pH and electrical conductivity (EC) must be maintained within specific ranges to ensure nutrient availability and uptake.

Moreover, the nutrient solution in hydroponics can be recycled in a closed system, reducing water and nutrient waste and minimizing environmental impact. The system continuously supplies nutrients to the plant roots, recirculates the runoff, and adjusts the composition based on the uptake and transpiration rates observed in the plants, which can be monitored through changes in EC levels. This recycling process not only conserves resources but also controls the growth conditions more precisely, enhancing overall plant health and yield.[52]

**Nutrient Flow Control**

Maintaining proper nutrition is one of the most important parts of growing greenhouse crops. There are two components of crop nutrition that growers must address. One component of nutrition is the total amount of nutrients accessible to the plant. The absolute amount of nutrients required by a plant increases as its size and fruit load rise. A key principle to understand about fertilization is that plant development is regulated by the mineral nutrient in the shortest supply, even when other nutrients are abundant. The second part of nutrition is the appropriate ratio or balance of nutrients accessible to the plant. Maintaining the right balance between vegetative growth and fruit load is critical to the crop's long-term output. When nutrients are not balanced, serious shortages or toxicities can emerge.

To control nutrition, growers must have a quick and dependable technique of monitoring the nutrient status of the cropping medium. A conductivity meter and a pH

meter are necessary tools. The pH of the medium influences the availability of individual nutrients. As a result, as the pH changes, so does the crop's nutrient balance. Understanding the nutrients needed to grow plants is simply one part of successful crop production. Optimum yield also necessitates understanding the rate to apply, the technique and timing of application, the source of nutrients to employ, and how the components are affected by substrate and greenhouse environmental conditions. [53]

**Hydroponic Solution**


**Figure 2.20** Solution A and B

Hydro A and Hydro B. This system divides essential nutrients into two separate solutions, allowing for optimized nutrient uptake and reduced interaction conflicts. Hydro A is enriched with calcium, crucial for enhancing plant structural strength and heat tolerance, while Hydro B provides magnesium, essential for chlorophyll production and energy transfer within the plant. This method facilitates precise control over the nutrient environment, crucial for maximizing plant health and productivity.[54]

**pH Down**

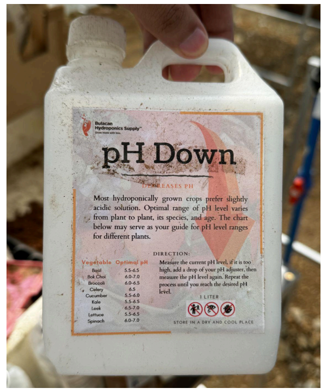


**Figure 2.21** pH Down Solution

pH Down is a phosphorus-based pH control additive that effectively reduces water pH levels, which is essential for hydroponics, aeroponics, sprinklers, and irrigation systems. Maintaining the proper pH is essential for efficient nutrient absorption, resulting in healthier and more vigorous plant development.[55]

**Importance of pH Level in Hydroponics**

The pH value in hydroponics refers to the acidity or alkalinity of the nutrient solution, with readings ranging from 0 to 14 (0-6 being acidic, 7 neutral, and 8-14 alkaline). For general hydroponic solutions, the recommended pH level falls between 6 and 6.5 (Nicholls, 63). Various factors can influence pH levels, including temperature, light intensity, evaporation, the quality of tap water, and the quantity of nutrients.

Given the numerous variables affecting pH, regular monitoring is important to maintain an optimal environment for plant growth. Adjusting the pH level can be achieved simply: to reduce acidity, add one tablespoon of baking soda to three gallons of solution, while to decrease alkalinity, add one tablespoon of white vinegar per four

gallons of solution. These adjustments help ensure a balanced pH level, which is vital for healthy plant development in hydroponic systems.[56]

**Water pH Level Sensor**

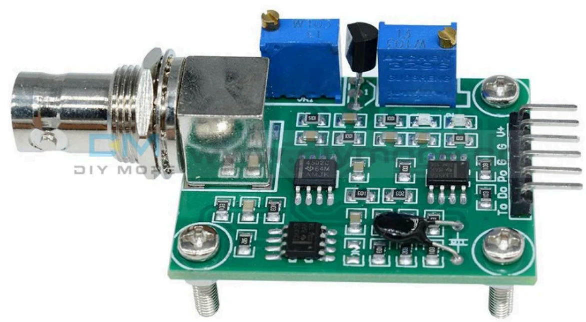

**Figure 2.22** PH4502C module

The PH4502C module features a working voltage of 5±0.2V (AC/DC) and a working current of 5-10mA, with a detection concentration range of pH 0-14 and a temperature detection range of 0-60 degrees Celsius. It has a quick response time of ≤ 5 seconds and stability time of ≤ 60 seconds, consuming ≤ 0.5W of power. Designed to operate in temperatures ranging from -10 to 50 degrees Celsius (with a nominal temperature of 20 degrees Celsius) and 95% relative humidity (with a nominal humidity of 65% RH), this sensor has a service life of 3 years. Its compact size measures 42mm x 32mm x 20mm, weighing 25g, and it provides an analog voltage signal output.[57]

**Figure 2.23** Analytical Surver Electrode pH Probe

The Analytical Surver Electrode pH Probe with a BNC (Bayonet Neill-Concelman) Plug Connector is designed for use with aquarium pH meters, controllers, and sensors. This pH electrode features a single cylinder for direct connection to BNC input terminals, ensuring accurate and reliable pH readings. With a pH range of 0-14, temperature range of 0-60°C, and zero-point of 7 ± 0.5 pH, this electrode minimizes alkali errors to 0.2 pH. Theoretical percentage slope exceeds 98.5%, ensuring precise measurements. With an internal resistance of less than or equal to 250MΩ and a response time of less than or equal to 1 minute, this electrode operates effectively in temperatures ranging from 0-60°C. The BNC plug connector is compatible with most pH meters and controllers, making it suitable for a wide range of applications, including aquariums, hydroponics, and laboratory settings.[58]

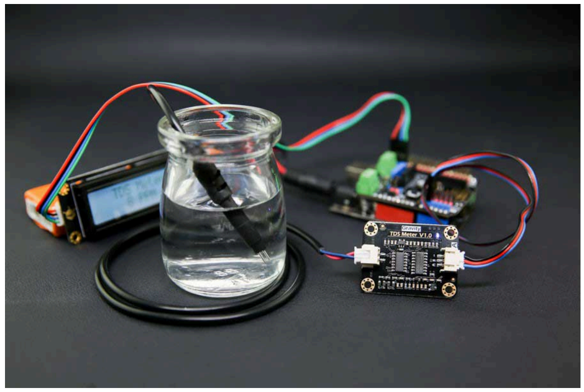

**Figure 2.24** DFRobot Gravity: Analog TDS Sensor/Meter

The DFRobot Gravity: Analog TDS Sensor/Meter for Arduino is a device that allows you to measure the total dissolved solids (TDS) in water using an Arduino microcontroller. This sensor can be used to monitor the water quality by detecting the TDS level, which is an important parameter for applications such as water filtration, aquaculture, and hydroponics. The sensor can be easily interfaced with an Arduino board and the TDS value can be displayed on a 16x2 LCD screen. The sensor comes with a calibration mode that allows you to calibrate it using a known TDS solution, ensuring accurate measurements. Overall, this TDS sensor provides a simple and cost-effective way to monitor water quality using an Arduino-based system. [59]

**ARDUINO BOARD**

Arduino serves as an accessible platform for electronics and programming enthusiasts. It features an open-source board used to create various electronics projects. The Arduino board, comprising an integrated development environment (IDE) and a microcontroller, enables users to write and upload code to the board via a simple USB cable, requiring no additional hardware. Its user-friendly interface, employing a simplified version of C++, makes it popular among beginners in electronics. The board's

conventional design encapsulates the microcontroller's functionalities in an easily manageable package, further enhancing its usability.[60]

**Types of Arduino board**

**Arduino Uno**

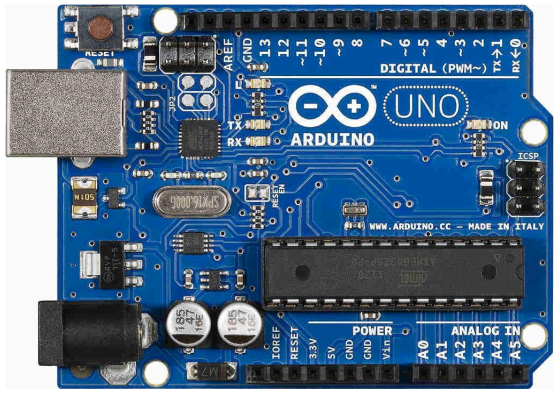


**Figure 2.25** Arduino Uno

Arduino Uno is a popular microcontroller development board based on the 8-bit ATmega328P microcontroller. Along with ATmega328P MCU IC, it consists other components such as crystal oscillator, serial communication, voltage regulator, etc. to support the microcontroller.[60]

**Arduino Due**


**Figure 2.26** Arduino Due

The Arduino Due is a microcontroller board that relies on the ARM Cortex-M3 architecture, marking the inaugural Arduino board of its kind. This board boasts an array of features, including 54 digital I/O pins, with 12 of them serving as PWM output pins, along with 12 analog pins, 4 UARTs, a clock speed of 84 MHz, USB OTG connectivity, 2 DACs, a power jack, 2 TWI (Two-Wire Interface) ports, a JTAG header, an SPI header, and two buttons for reset and erase functions.

Operable at 3.3V, the Arduino Due's input/output pins can tolerate a maximum voltage of 3.3V. Exceeding this voltage threshold can potentially damage the board. The board can be conveniently connected to a computer using a standard USB cable or powered through an AC to DC adapter. Moreover, the Arduino Due is compatible with all Arduino shields designed for 3.3V operation, further enhancing its versatility for various project applications.[60]

**Arduino Mega**

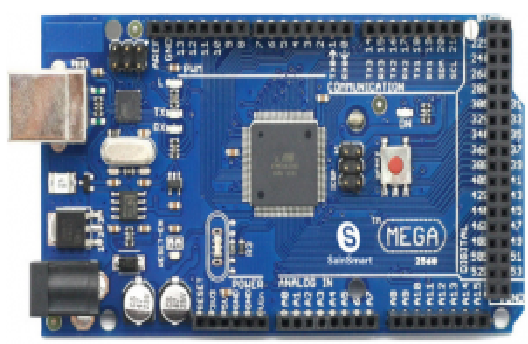


**Figure 2.27** Arduino Mega

The Arduino Mega (R3) Board can be likened to the bigger sibling of the UNO. It boasts numerous digital I/O pins, with 14 of them capable of functioning as PWM outputs. Additionally, it offers 6 analog input pins, a reset button, a power jack, and a

USB connection. This board provides all the essential components for supporting the microcontroller. Simply connect it to a computer via a USB cable and provide power through an AC-to-DC adapter or battery to kickstart your projects. The abundance of pins on the Arduino Mega board makes it exceptionally valuable for projects that require a multitude of digital inputs or outputs, such as applications involving numerous buttons.[60]

**Arduino Leonardo**

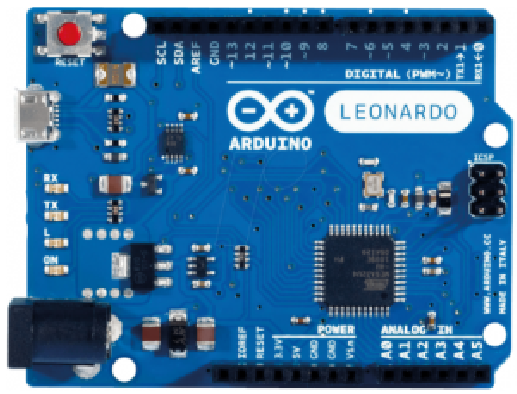


**Figure 2.28** Arduino Leonardo

The Arduino Leonardo board represents the initial iteration of Arduino development boards. It leverages a single microcontroller in conjunction with USB functionality, making it an economical and straightforward option. Due to its direct USB handling capabilities, various program libraries are accessible, enabling the Arduino board to emulate computer peripherals like keyboards and mice, thus enhancing its versatility.[60]

**Choosing the Right Arduino Board**

There is a wide variety of Arduino boards available in today's market, including options like Free Duino and NetDuino. The ideal approach for selecting the most suitable

Arduino board is to carefully examine and differentiate the brand names on the original boards. Finding affordable Arduino boards is easily achievable through online retailers and electronic stores. These boards come in various versions and specifications.

All these boards can be programmed using the Arduino IDE software, which enables anyone to write and upload code. However, each board differs in terms of inputs, outputs, speed, physical dimensions, voltage requirements, and more. The operational voltage for these boards typically ranges from 3.7V to 5V.[60]

**Raspberry Pi**

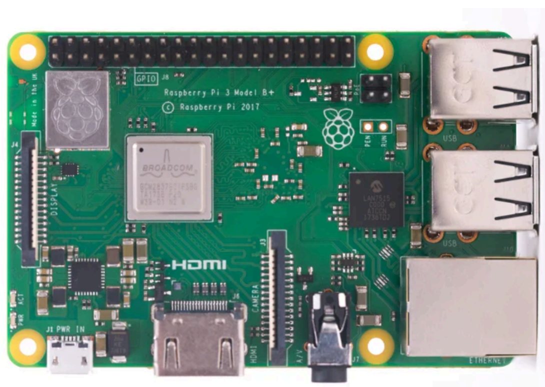


**Figure 2.29** Raspberry Pi

The Raspberry Pi is a single-board computer developed by the Raspberry Pi Foundation. Launched in 2012, the Raspberry Pi has seen several iterations with increasing processing power and memory, while maintaining an affordable price. These compact computers run Linux and provide GPIO (general-purpose input/output) pins, allowing users to control electronic components, explore the Internet of Things, and engage in physical computing projects. The Raspberry Pi is widely used for learning

programming, building hardware projects, home automation, and even industrial applications.[61]

**Power Supply**

**Figure 2.30** Power Supply

A power supply is a hardware component that supplies power to an electrical device. It receives power from an electrical outlet and converts the current from AC (alternating current) to DC (direct current), which is what the computer requires. It also regulates the voltage to an adequate amount, which allows the computer to run smoothly without overheating. The power supply an integral part of any computer and must function correctly for the rest of the components to work.[62]

**Circuit Breaker**

**Figure 2.31** Circuit Breaker

Circuit breaker is a type of switching mechanism used to regulate and protect an electrical power supply. It can be controlled manually or automatically. A fixed contact and a moving contact are its two primary contacts. Normally, the connections are closed, allowing current to pass through the system. A mechanism that releases accumulated potential energy separates the contacts in the event of a failure, such as an overload or short circuit. Circuit breakers protect electrical circuits from damage caused by overcurrent, short circuits, or overload. They interrupt the flow of current when a fault occurs and restore it when the fault is cleared.[63]

**ESP32**

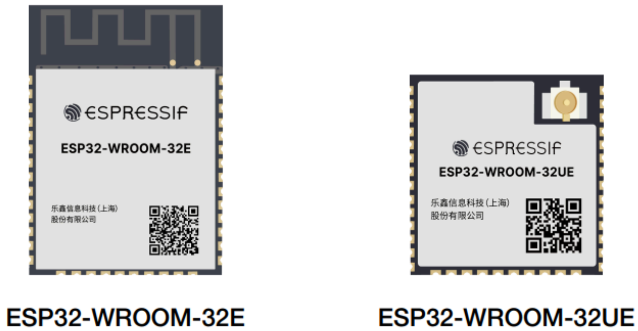


**Figure 2.32** ESP32

An ESP32 device in Arduino refers to a development board that uses the ESP32 chip, which is a powerful microcontroller with built-in Wi-Fi and Bluetooth capabilities. The ESP32 is often used in IoT (Internet of Things) projects due to its ability to connect to the internet and communicate wirelessly. When used with the Arduino IDE (Integrated Development Environment), the ESP32 can be programmed to perform various tasks, such as reading sensor data, controlling actuators, and sending/receiving data over the internet.[64]

**Relay Module**

**Figure 2.31** Relay

Relay is an electromechanical device that uses an electric current to open or close the contacts of a switch. The single-channel relay module is much more than just a plain relay, it is composed of components that make switching and connection easier and act as indicators to show if the module is powered and if the relay is active or not.[65]

**Jumping Wire**

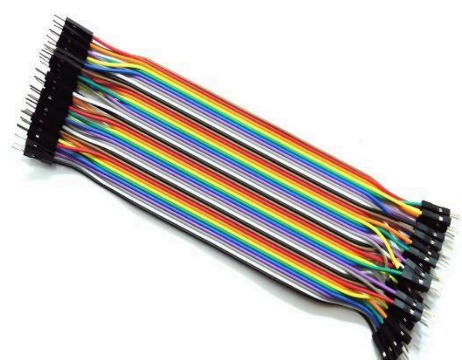

**Figure 2.34** Jumping Wire

Generally, jumpers are tiny metal connectors used to close or open a circuit part. They have two or more connection points, which regulate an electrical circuit board. Their function is to configure the settings for computer peripherals, like the motherboard. Suppose your motherboard supported intrusion detection. A jumper can be set to enable or disable it. Jumping wires are electrical wires with connector pins at each end. They are used to connect two points in a circuit without soldering.[66]

**Relay Board**

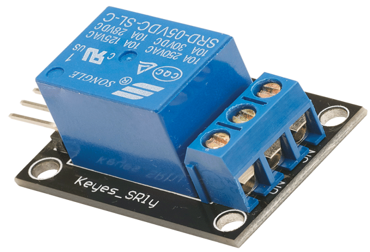

**Figure 2.35** Relay Board

A Relay is a simple electromechanical switch. While we use normal switches to close or open a circuit manually, a relay is also a switch that connects or disconnects two circuits. But instead of a manual operation, a relay uses an electrical signal to control an electromagnet, which in turn connects or disconnects another circuit.[67]

**Contactor**


**Figure: 2.36** Contactor

A contactor is an electrical device which is used for switching an electrical circuit on or off. It is considered to be a special type of relay. However, the basic difference between the relay and contactor is that the contactor is used in applications with higher current carrying capacity, whereas the relay is used for lower current applications. Contactors can be field mounted easily and are compact in size. Generally, these electrical devices feature multiple contacts. These contacts are in most cases normally open and provide operating power to the load when the contactor coil is energized. Contactors are most commonly used for controlling electric motors. [68]

**Stepper Motor**

**Figure 2.37** Stepper Motor

A stepper motor is an electric motor whose main feature is that its shaft rotates by performing steps, that is, by moving by a fixed amount of degrees. This feature is obtained thanks to the internal structure of the motor, and allows to know the exact angular position of the shaft by simply counting how many steps have been performed, with no need for a sensor. This feature also makes it fit for a wide range of applications.[69]

## 2.2 RELATED LITERATURE

The proponents to several studies related to the design of the present project. Different theories and principles related to the design of the greenhouse, ventilation, and hydroponic. In order to provide justification for the feasibility of the studies, the following research and studies related to the project design are presented and reviewed.

### FOREIGN STUDIES

The study of Miao, C. et al. (2023) was conducted to comprehensively understand the impact of light intensity on the growth and quality of different crops and to develop precise lighting schemes for specific cultivars. Lettuce and Spinach were used in this experiment, using a light-emitting diode (LED) under intensities of 300, 240, 180, and 120 μmol m−2 s−1 to gather information on growth and quality of the plants. The light intensity received by the plant changes as the plant grows taller; therefore, the computer-based LED plant supplementary lighting control system was adjusted to match the desired experimental light intensity after the measurement of growth parameters.

Crunchy (exhibiting the non-heading trait) developed tipburn when exposed to the light intensity of 300 μmol m−2 s−1, whereas tipburn and leaf shrinkage were observed in Deangelia (semi-heading lettuce cultivar) under both 240 μmol m−2 s−SS1 and 300 μmol m−2 s−1. The spinach cultivar, Shawen, exhibited leaf curling under all LED light intensities, impeding normal growth. These results indicated that although higher light intensity is beneficial for increasing yield and quality, the light intensity should be regulated as per the specific variety. Light intensity is an important factor and should be

optimized for specific crop species and cultivars to achieve healthy growth in plant factories.[70]

In the study of J. Zhou (2022), the interaction between light and temperature is crucial for the growth and development of lettuce. The optimal light range for photosynthesis and yield varies with temperature. At low temperatures (15 °C), a light intensity of 350–500 $\mu mol \cdot m^2 \cdot s^{-1}$ is recommended. For medium temperatures (23 °C), a light intensity of 350–600 $\mu mol \cdot m^2 \cdot s^{-1}$ is suggested. At high temperatures (30 °C), a light intensity of 500–600 $\mu mol \cdot m^2 \cdot s^{-1}$ is advisable. Additionally, light intensity should be reduced during the late growth stage for lettuce grown at medium and high temperatures. This study suggests that a balanced combination of light intensity and temperature can optimize lettuce photosynthesis and yield in greenhouses and plant factories.[9]

Based on the study of the Government of Newfoundland and Labrador (2020) that a lettuce plant is truly a crop that grows in a cold environment. The climate limitations for lettuce are focused on ensuring a suitable water supply throughout its growth stages and preventing exposure to temperatures exceeding 30°C. It is strongly recommended to maintain an environmental temperature below 30°C to prevent the occurrence of flowering or bolting, which imparts a bitter taste to the lettuce plant.[71]

The study of Sanders, C. (2018) stated that the cultivation of lettuce in greenhouses is negatively impacted by high temperatures, especially in hot climates. Therefore, developing an efficient method to regulate the internal temperature of greenhouses is crucial to maintaining crop productivity throughout the year. The optimal air temperature for lettuce plants, classified as cool-season vegetables, in a plant factory

or temperate zone is between 22 and 26 °C. However, it has been suggested that the ideal temperature for growing lettuce in tropical environments is between 22 and 30 °C, or even 33 °C for other leafy vegetables like mustard greens.[72]

Furthermore, it's crucial to note that the optimal temperature range for lettuce cultivation falls between 60 and 65°F according to the study of Kumsong, N. et al. in 2023, as this leafy green is inherently adapted to thrive in cool growing conditions. Despite its preference for cooler climates, lettuce exhibits a degree of resilience, demonstrating the ability to endure occasional temperature spikes of 80 to 85°F for short durations, provided that the nights maintain a refreshing coolness. This resilience underscores the adaptable nature of lettuce, allowing it to withstand temporary deviations from its ideal growing conditions while maintaining its overall health and vitality.[73]

The study of B. Frestya et al. 2021 entitled “The effect of hydroponics systems on the growth of lettuce”, used different kinds of experimental methods consisting of 5 treatments. A = Hydroponic Installation of the Nutrient Film Technique (NFT), B = Hydroponic Installation of Deep Film Technique (DFT), C = Hydroponic Installation of EBB and FLOW or Tidal Systems, D = Installation of Aeroponic Hydroponic Systems, and E = Installation of Floating Assembling Hydroponic System. They used these methods to measure the effectiveness of each system in increasing the growth of plant height, and leaf number. Different hydroponic systems affect the growth of lettuce, namely plant height and number of leaves. The NFT hydroponic system is 6% -10% more efficient in increasing the yield of lettuce. The NFT and RFS systems are recommended for use in hydroponic lettuce production.[74]

The study of G. M. Barbade, et al. (2021), entitled “Automatic Water Tank Filling System with Water Level Indicator” primary goal is to conserve water by using an automatic water level controller and indicator. The water level controller works by using the fact that water can conduct electricity due to minerals in it. This allows it to control circuits, turning them on or off as the water level changes. The carbon sensor also plays a role, sensing water without direct contact to trigger the LED light and turn off the pump once the tank is full. There have been several approaches to constructing an automatic water level control with a switching device, but all of them require human intervention. This project uses electrical control to build an automatic water level control system with a switching device for both overhead and underground tanks to replace the water without human intervention. When the water tank falls below a certain level, the system turns off the electric pump and shuts down the water pump. When the tank is full, the system turns off the electric pump and shuts down the water pump.[75]

The study of Demi, et. al, 2019, proposed a system that utilizes sensors to measure pH and TDS levels in the nutrient film technique (NFT) to maintain the quality of hydroponic plants. This system monitors the nutrient solution's pH (acidity or basicity) and total dissolved solids (TDS) using pH and TDS sensors. A control system is employed to manage nutrition controllers such as pH down, pH up, and AB nutrition by turning them on or off. Depending on the specific conditions, various pumps (for pH up/down, TDS up/down, and nutrition A/B) and a chiller are activated or deactivated to maintain optimal conditions. This approach aims to ensure plants grow in the best possible environment, resulting in healthier and more robust crops..[76]

The study of Danita, et.al, 2018, used Internet of Things (IoT) for monitoring the temperature and humidity to ensure the good yield of plants. The sensors used here are YL69 moisture sensor and DHT11 (Temperature & Humidity sensor). From the data received, Raspberry PI3 automatically controls Moisture, Temperature, Humidity efficiently inside the greenhouse by actuating an irrigating pipe, cooling fan, and sliding windows respectively according to the required conditions of the crops to achieve maximum growth and yield. The recorded temperature and humidity are stored in a cloud database (Thing Speak), and the results are displayed in a webpage, from where the user can view them directly.[77]

The study of Ardiansah et al, 2020. conducted research in the field of agriculture. They used IoT for crop management as a media for monitoring and controlling, especially in greenhouses and is called Precision Farming. In the Internet of Things, the data that has been acquired by the hardware will then be transmitted wirelessly. The wireless connections used are Bluetooth, ZigBee Protocol, and Wi-Fi, where Bluetooth and Zigbee connections have a short distance between 10 - 100 meters, while Wi-Fi has a longer distance especially when connected to the Internet.[78]

**LOCAL STUDIES**

The article of Semilla et al. (2018) entitled "Indoor production of loose-leaf lettuce (Lactuca sativa L.) using artificial lights and cooling system in tropical lowland" used controlled environment agriculture (CEA) for farming set-up in the Philippines. It is a controlled environment developed using locally available materials, light emitting diodes (LED) as sole-source of light and cooling system for temperature manipulation.

This study was conducted to determine the optimal temperature and light intensity requirements for growing loose-leaf lettuce in lowland tropics.[79]

In addition, the study constructed three chambers with an area of 2.5m 2.5m x 6.0m and ceiling height of 2.5m. Each chamber was equipped with two 1hp window-type air-conditioning units (AC) operated alternately for 12 hours, two 70-watt circulating fans, and two sprinkler foggers. They employed ECOLUM LED T8 tube lights with a daylight color temperature of 6500K were used to produce PPF. Light intensities of 50, 100 and 150 μmol m-2 s-1 were tested under temperature settings of 25 °C and 18 °C. Carbon dioxide and relative humidity were maintained at recommended levels. No significant difference in productivity was observed under 25 °C and 18 °C. Also, no significant difference in productivity was observed between plants in two temperature settings and plants outside.[79]

The study of D. Jose (2020) stated that lettuce plant lettuce plants demonstrate a remarkable ability to adapt in areas with relative humidity that ranges from 65% to 85%. The study suggests lettuce varieties can be carefully selected based on their tolerance to specific environmental conditions.[80]

The study of Albius, J et. al, 2018. "Solar-Powered Multi-Network Greenhouse: Automated Mushroom Monitoring and Management System Using Microcontrollers and IoT-Based Applications". utilized microcontrollers and Internet of Things applications to power the Solar Powered Multi-Network Greenhouse and create an automated system for managing and monitoring mushrooms. Due to the fact that mushrooms are more susceptible to temperature changes, particularly in tropical nations like the Philippines, this study creates an automated system whose composition is managed by a greenhouse

monitoring device utilizes an Arduino IDE microcontroller several extremely powerful sensors that provide precise metrics for monitoring systems and improved agricultural control management. There was discussion of the many approaches that could be used to regulate variables and preserve stability values appropriate for mushroom farming. To guarantee the device's accuracy and operation, a number of experiments and testing were conducted on the prototype. Similarly, performance tests were carried out to regulate and track the requirements of the mushroom with regard to temperature, relative humidity, and light. The equipment is accurate, functional, and capable, according to the results. According to the study, installing a CCTV system to continuously monitor the greenhouse's exterior and interior would improve it. In addition to being in a more isolated location, the greenhouse might also enhance some application functions.[81]

The study of Mastul, A et, al, 2023, “The Use of IoT on Smart Agriculture in the Philippines”. The study examines the advantages of using Internet of Things (IoT) technologies with modern agriculture, with a particular focus on the Philippines to evaluate the effects of IoT on precision steering, automated irrigation, field mapping, weather monitoring, livestock tracking, greenhouse automation, and crop monitoring. They used IoT-based livestock tracking to guarantee the welfare of the animals and effective breeding methods. Making educated decisions for crop protection and risk management is made easier with the help of IoT-based weather monitoring. IoT-enabled automated irrigation lowers water waste while enhancing crop health. During planting and harvesting, resource management is improved by precision steering systems. Automation in greenhouses minimizes manual labor while optimizing growing conditions for plants. IoT-based field mapping enables site-specific management, increasing

sustainability and yield. Comprehensive plans for IoT integration in Philippine agriculture are necessary regardless of the benefits because problems like internet connectivity and early investment are still present.[82]

The study of J. Anthony (2018) entitled “Auto GMS: An Automated Greenhouse Monitoring System of Abiotic Factors for Leafy Vegetables Production” conducted at Oriental Mindoro, shows that they were able to automate greenhouse processes by using multiple highly sensitive sensors to monitor the current working condition of their greenhouse. Additionally, they added SMS functionality to their system to provide real time updates to the end user about their system. These integrations were powered by the wifi module installed and the LCD screen display to provide information to the user. Internet of things (Iot) was greatly showcased as the integration of a user's GSM phone to the system for monitoring. Arduino uno were used to monitor and automate processes together with solenoid valves controlled by the relays to switch on or off for water intake to the irrigation system.[83]

The study of R. Amy (2020) entitled “Automated pH Monitoring and Controlling System for Hydroponics under Greenhouse Condition” conducted at Tarlac, Philippines, demonstrate a system for automatic monitoring and controlling was created in order to regulate the pH level of the water in the system by adding acid and base solution. A minimum pH of 6.0 and a maximum pH of 6.54 were observed. The pH level of the nutrient solution was maintained at a range of 6.0-6.8 level which is the recommended range for hydroponic lettuce production. It was determined that the automated pH monitoring and controlling system was effective after a performance evaluation and

validation finished. By lowering labor costs and enabling real-time pH monitoring, this device helps farmers produce more crops and make more revenue.[84]

## 2.3 SYNTHESIS

The comprehensive review of the literature presented in Chapter 2 underscores the transformative potential of automation and advanced technologies in the field of agriculture, with a particular focus on greenhouse management systems. This synthesis brings together key findings from the studies reviewed, demonstrating both the current state and future possibilities of technology-enhanced agriculture.

The development of automated control systems in greenhouse management is supported by many studies that look at how automation, hydroponics, and IoT technologies can work together to improve farming efficiency. A key part of this research is the use of automation in agriculture, which cuts down on the need for manual labor while boosting productivity.

### Foreign Studies

The experiment of C. Miao et al, aimed to study how light intensity affects the growth and quality of lettuce and spinach in a plant factory. They used LED lights at different intensities and controlled the light using a computer-based system. Results showed that high light intensity can be good for yield and quality, but it needs to be managed carefully. They used crunchy lettuce and it had tipburn at 300 µmol $m^{-2}$ $s^{-1}$, while Deangelia lettuce had tipburn and leaf shrinkage at 240 and 300 µmol $m^{-2}$ $s^{-1}$. Shawen spinach had leaf curling at all intensities, which affected its growth. This study

highlights the importance of optimizing light intensity for different crops and varieties. By doing so, planting facility can ensure healthy growth and better-quality produce.

The study of J. Zhou et al, highlights the critical role of temperature over light intensity in influencing lettuce photosynthesis and growth. Optimal lettuce cultivation requires prioritizing temperature management, with specific light intensity recommendations tailored to varying temperatures. At lower temperatures (15 °C), a light intensity of 350–500 μmol·m−2·s−1 is beneficial, while medium temperatures (23 °C) require 350–600 μmol·m−2·s−1, and higher temperatures (30 °C) are best supported by 500–600 μmol·m−2·s−1. Additionally, reducing light intensity during the late growth stage for medium and high-temperature conditions is advantageous. The study emphasizes that a strategic balance of light and temperature can enhance lettuce photosynthesis and yield in controlled environments.

The study by the Government of Newfoundland and Labrador (2020) emphasizes that lettuce thrives in cold environments. The primary climate considerations for cultivating lettuce involve maintaining a consistent water supply and avoiding temperatures above 30°C. Keeping the environmental temperature below 30°C is crucial to prevent flowering or bolting, which can cause the lettuce to develop a bitter taste. Ensuring these conditions supports optimal growth and quality of lettuce crops.

The study of Sanders, C. discussed the efficient methods to regulate greenhouse temperature are crucial for maintaining crop productivity year-round. Lettuce is classified as a cool-season vegetable, with the optimal air temperature for growth in a plant factory or temperate zone being between 22 and 26 °C. However, in tropical environments, the

ideal temperature for lettuce cultivation is suggested to be between 22 and 30 °C. The findings provide insights to the researchers on optimizing temperature according to the type of lettuce being grown in the greenhouse.

The study by Kumsong, N. et al., stated that lettuce is adapted to thrive in cool growing conditions, with an optimal temperature range for cultivation between 16°C and 19°C. Despite this preference, lettuce can withstand occasional temperature spikes of 27°C to 30°C for short durations, as long as the nights remain cool. This resilience allows lettuce to adapt to temporary deviations from its ideal growing conditions while maintaining its health and vitality.

The study of Frestya et al. compared five hydroponic systems (NFT, DFT, EBB and FLOW, Aeroponic, Floating Assembling) to see which is best for lettuce growth. They measured plant height and leaf number to determine effectiveness. Plant height is mainly influenced by water and light availability. This study shows ways to reduce water usage and enhance nutrient delivery, highlighting their potential to improve greenhouse practices by creating optimal growth conditions with minimal resource waste. Water shortage can slow growth and reduce yields. By using these advanced methods, greenhouse management can become more efficient and sustainable, demonstrating the significant benefits of automated control systems and hydroponic techniques. This study becomes a reason for the proposed study to choose the NFT system in hydroponics.

The study of G. M. Barbade et al, entitled "Automatic Water Tank Filling System with Water Level Indicator," focuses on conserving water by implementing an automatic water level controller and indicator. Utilizing water's conductivity due to minerals, the

system controls circuits to turn them on or off as the water level fluctuates. A carbon sensor detects water levels without direct contact, activating an LED light and stopping the pump when the tank is full. However, the study above uses carbon sensor to measure the water level, while the proposed study will be using water flow sensor and float switch.

The study of Demi, et. al, proposed a system for measuring pH and TDS in the nutrient film technique (NFT) using sensors to maintain the quality of hydroponic plants. They used a control system to turn on or off the nutrition controllers, such as pH down, pH up and AB nutrition. Depending on the specific condition, various pumps (pH up/down, TDS up/down, nutrition A/B) and the chiller are activated or deactivated to maintain the desired conditions. The study helps the researchers in using pH and TDS sensors and adapting the process of turning valves on or off.

The research by Ardiansah et al. (2020) explores the application of IoT in agriculture, particularly in greenhouse settings, under the concept of Precision Farming. This approach leverages IoT for real-time monitoring and control of crop management. The study highlights the use of various wireless technologies for data transmission, including Bluetooth, ZigBee, and Wi-Fi. Bluetooth and ZigBee are effective for short-range communication (10-100 meters), whereas Wi-Fi enables longer-range connectivity, especially with Internet access. This integration of IoT in agriculture facilitates enhanced precision and efficiency in crop management practices.

The study of M. Danita et al., implemented IoT sensors, specifically the YL69 moisture sensor and DHT11 temperature & humidity sensor, to monitor and ensure

optimal conditions for plant growth. A Raspberry Pi3 was used to control irrigation, cooling, and ventilation systems based on the sensor data. The system recorded temperature and humidity data, which were stored in a cloud database (ThingSpeak) and displayed on a webpage for user access. The study becomes a guide for the proposed study to use DHT11 to measure temperature and humidity.

**Local Studies**

The study of M.G. Semilla et al, in the Philippines utilized Controlled Environment Agriculture (CEA) for indoor lettuce production, focusing on identifying optimal temperature and light intensity conditions for cultivating loose-leaf lettuce in tropical lowlands. The CEA setup used locally available materials, LED lights as the main light source, and a cooling system for temperature control. They constructed three chambers, each equipped with air conditioning units, circulating fans, and sprinkler foggers. The findings suggests that the temperature setting is play a significant role in cultivation of lettuce, highlighting the potential of CEA for year-round lettuce production in tropical climates.

D. Jose's 2020 study emphasized the adaptability of lettuce plants to areas with relative humidity ranging from 65% to 85%. The research suggests that lettuce varieties can be chosen based on their tolerance to specific environmental conditions. This indicates that farmers can select lettuce types suited to their region's humidity levels, potentially enhancing crop productivity and resilience.

The study by Albius et al. focuses on creating a Solar-Powered Multi-Network Greenhouse with an automated system for managing and monitoring mushrooms, which are particularly sensitive to temperature changes, especially in tropical regions like the

Philippines. The system utilizes microcontrollers and Internet of Things (IoT) applications to regulate variables and maintain stable conditions ideal for mushroom farming. The greenhouse monitoring device, managed by an Arduino IDE microcontroller, integrates several powerful sensors to provide precise metrics for monitoring and improving agricultural control management. Performance tests were also carried out to regulate and monitor temperature, relative humidity, and light requirements for mushrooms Additionally, the study suggests installing a CCTV system to continuously monitor the greenhouse's exterior and interior, which could further enhance its functionality, especially in isolated locations. The study helps the researchers to adapt only the utilization of IoT application and Arduino as microcontroller to the system.

The study by Mastul et al. focuses on the use of Internet of Things (IoT) in smart agriculture in the Philippines, aiming to evaluate its effects on various aspects such as precision steering, automated irrigation, field tracking, and weather monitoring, greenhouse automation, and crop monitoring. The study found that IoT technologies can significantly enhance agricultural practices in the Philippines. The study emphasizes the need for comprehensive plans for IoT integration in Philippine agriculture to overcome these challenges and fully realize the benefits of IoT technologies. This study helps the researchers to produce an IoT application in managing hydroponics that can adapt to the generation and to keep the quality of the product.

The study by JE. Anthony in 2018, titled "Auto GMS: An Automated Greenhouse Monitoring System of Abiotic Factors for Leafy Vegetables Production," conducted at Oriental Mindoro, focused on automating greenhouse processes using highly sensitive sensors to monitor the greenhouse's working conditions. The system included SMS

functionality to provide real-time updates to users and was powered by a wifi module and an LCD screen display for user information. The study focuses on the application of integration of Internet of Things (IoT) technology, specifically a user's GSM phone, for monitoring. Arduino Uno microcontrollers were used to monitor and automate processes, including controlling solenoid valves via relays for water intake to the irrigation system. The researchers considered the utilization of Arduino Uno and IoT for monitoring the whole process of the system.

The study of R. Amy (2020) entitled “Automated pH Monitoring and Controlling System for Hydroponics under Greenhouse Condition” demonstrates a system for automatic monitoring and controlling of hydroponics to regulate the pH level of the water in the system by adding acid and base solution. A minimum pH of 6.0 and a maximum pH of 6.54 were observed. The pH level of the nutrient solution was maintained at a range of 6.0-6.8 level which is the recommended range for hydroponic lettuce production. This study provides researchers with valuable insights into the optimal pH levels needed to ensure high-quality lettuce cultivation in the Philippines.

# CHAPTER III

# DESIGN AND METHODS

This chapter discusses the design and methods that have been improved for this project study. It includes the conceptual framework along with the technical design and procedure. Further discussed are the equipment, facilities, and programs used, the data collection and treatment, as well as the required budget to conduct the project study. Also presented are the expected output and a tabulated Gantt chart for the duration of this project study.

## 3.1 CONCEPTUAL FRAMEWORK

This project study focuses on the design and construction of a Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, pH level and TDS monitoring. This framework will guide the research to understand and show how the greenhouse management system can help make farming more sustainable and efficient. Moreover, it was constructed and improved the greenhouse considering the environment of the greenhouse that will affect the crops, such as the temperature, relative humidity and monitoring system. The position, size of the land, temperature, and pH level at the location of the control system installation were also taken into consideration due to its impact to the automated systems performance in the greenhouse.

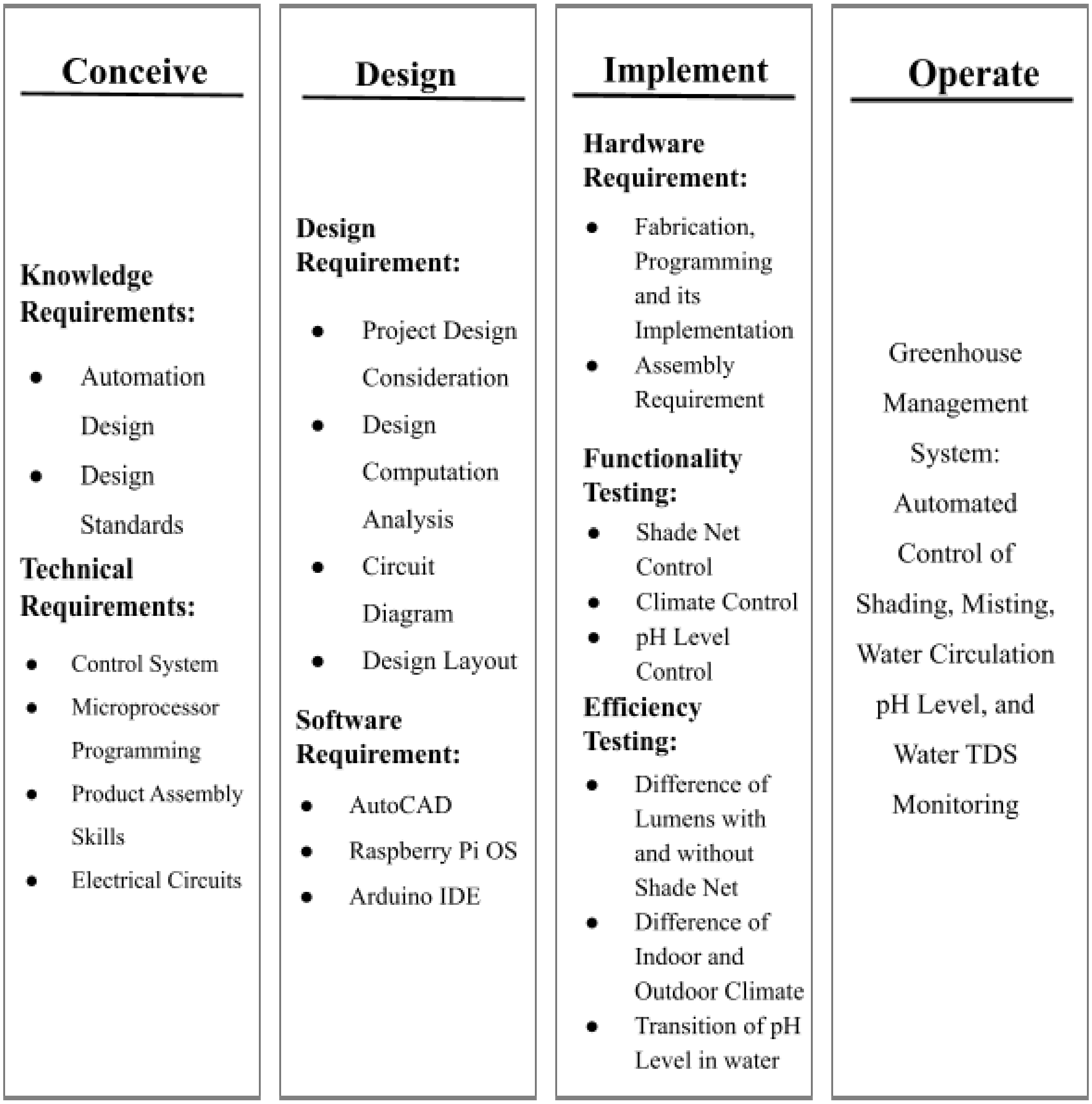


**Figure 3.1** Conceptual Paradigm of the Study

The Conceive Stage's purpose is to acquire essential knowledge for an automated greenhouse management system involving a thorough evaluation of the collaboration between software and hardware. This includes establishing a comprehensive monitoring and control system. Proficiency in programming is crucial for connecting the various elements of the automated system. Expertise in understanding the ideal environmental conditions within the greenhouse, including temperature, humidity, nutrient solution level

and light intensity. Recognizing that any changes in these parameters can have a direct impact on crops indicates the need of taking a comprehensive approach in implementing and managing an efficient automated greenhouse management system.

During the Design Stage, the design and software requirements are determined. The project study contains different design requirements, material specifications and system components, the general description of the project, design standard, design computation and Analysis, design layout, circuit diagram, materials and components, programs and complementation, bills of materials and specification of the study. The monitoring and control system automatic function hinges upon considering the factors mentioned. These factors have been taken to ensure the effective operation of the system.

The implementation of the project construction and programming as well as the fabrication of the output. Functionality testing was also included, which was divided into Climate control test, Nutrient solution monitoring control test, Shade net control test of greenhouse management and the efficiency testing which contains: Difference of outdoor and indoor climate, Flowrate of water outflow & inflow, and Difference of lumens with & without shade net is considered. Lastly, the operation stage was presented as the output of the project study. This project study entitled Greenhouse Management System: Automated Control of Shading, Misting, and Nutrient Monitoring for Sustainable Agriculture.

Furthermore, the materials and equipment used are considered to achieve the effectivity and purpose also the expected output of the project study. To enhance comprehension of the study core principles, the research team crafted a conceptual model encompassing the necessary expertise, as well as the design criteria and prerequisites.

Additionally, the scope covers the construction and programing, along with the architectural planning and physical build of the Greenhouse Management System for sustainable agriculture.

## 3.2 TECHNICAL DESIGN AND PROCEDURE

### I. Designing Stage

In order to collect the existing information and foundation parts of the prototype, its focus is on the comprehensive development of an automated control system for shading, misting, water circulation, pH level, and TDS monitoring. The design process begins with determining the specific components required for each subsystem, ensuring the system meets the environmental needs of the greenhouse. The computation phase involves calculating necessary parameters such as light intensity, water flow rates, nutrient concentrations, and the power requirements of the solar-powered system. Additionally, material identification is critical to select durable and efficient components like sensors, pumps, microcontrollers, and shading mechanisms that ensure system reliability. A thorough cost analysis is performed to estimate the total expenses for materials, labor, and installation, ensuring that the project remains within budget while achieving the desired functionality. This holistic approach to design not only aligns with automation and greenhouse principles but also addresses the project's efficiency, practicality, and sustainability objectives.

### II. Fabrication Stage

In this phase, the development and specifications of the machine are built in accordance with the goals of the research. When choosing materials that satisfy the requirements, a number of variables will be taken into account, such as cost, accessibility

locally, and material specifications. The nearby machine shop will be the location of real manufacture, with materials sourced locally employed in the fabrication process. The many parts of the Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, Water TDS and pH level monitoring control equipment will then be assembled and integrated over time. The final inspection will assess how well the machine operates and how well it follows the standards.

**III. Preliminary Testing Stage**

The tests will focus on evaluating the core components of the system, such as the shading mechanism, misting system, water circulation, pH level control, and TDS monitoring. These tests aim to confirm that each subsystem functions as expected under real-world conditions. Specifically, the tests will measure the responsiveness of the shading system, the efficiency of the misting and water circulation systems, and the accuracy of the pH and TDS sensors. Preliminary testing is an essential phase after the manufacture of the system, designed to assess its overall operational capabilities and identify any issues. Key parameters, including system response time, resource efficiency, and accuracy, will be evaluated during this stage. Any detected problems will be corrected before proceeding with further testing and integration.

### 3.3 EQUIPMENT / FACILITIES / PROGRAMS

The content outlines the key elements involved in project planning and implementation, with a focus on the necessary equipment and infrastructure. It emphasizes the importance of choosing appropriate software for both programming and designing the system, which is critical in defining aspects such as layout, size, block diagrams, and control mechanisms. The passage also mentions the use of various

software tools for demonstrating the capabilities of the software and displaying the project's results. This indicates a systemic approach to project management, combining both physical and digital resources to achieve project objectives.

## EQUIPMENT

A complete set of equipment is required for the assembly of the automated system within the greenhouse. This includes:

### 1. Fabrication Tools for Mechanical Components

- Welding Machine: For assembling metal parts of the greenhouse structure and mechanical supports for components like the shade net and misting system.
- Cutting Tools: For cutting metal sheets, pipes, and other structural components.

### 2. Electrical and Wiring Tools

- Soldering Station: Essential for connecting electronic components, such as control boards, sensors, and wiring for the automation system.
- Multimeter: For checking voltage, current, and continuity in the electrical system to ensure proper connections.
- Crimping Tools: For connecting wires securely with terminals when installing the greenhouse's electrical and control systems.

### 3. Hydraulic and Plumbing Equipment

- PVC Pipe Cutters and Joiners: For the installation of water circulation and misting systems.

- Nozzle Installers: To install misting nozzles that regulate humidity and cooling within the greenhouse.

**4. Control and Automation Tools**

- Arduino Kit (with compatible sensors and actuators): For the control system of shading, misting, water circulation, and environmental monitoring.
- Relay Modules and Stepper Motors: For automating functions like opening/closing the shade net or adjusting water circulation based on environmental data.

**5. Precision Measuring Instruments**

- Digital Calipers: For precise measurement of fabricated parts and ensuring proper fits, especially in components like shafts or mounting brackets.
- Temperature and Humidity Sensors: To monitor the environment and calibrate the automated control systems for maintaining optimal greenhouse conditions.
- pH and TDS Meters: To measure and regulate the water quality in the hydroponic system, ensuring the proper nutrient balance.

**6. Programming and Debugging Tools**

- Computer with Arduino IDE (or Raspberry Pi setup): For coding and testing the software that will automate the shading, misting, and circulation systems.

## FACILITY

SIMCO, located in San Isidro Batangas City, serves as the primary facility for the research, equipped with two previous advanced hydroponic greenhouse systems. These greenhouses, built with study materials suitable for the local climate, feature automated controls for temperature, humidity, and watering to create optimal growth conditions for lettuce crops. They also have an efficient irrigation system for water and nutrient management in hydroponics. The researchers chose this location to allow convenient access. Another reason for selecting it is because of the support from the beneficiary who will provide a fabricator to help the researcher complete the prototype.

## PROGRAM

Different software and programs were used to achieve the study's results. The layout of the study was presented using AutoCAD software, while data was organized using spreadsheet programs such as Google Sheets during system testing. The Arduino IDE was the programming software that was used to program the Arduino board. It consists of a text editor for writing code, a message area, a text console, a toolbar with buttons for common functions, and a series of menus. To connect the Arduino to the computer, a cable converter and Ethernet cable were used as communicators. As a result, a laptop computer was required, as well as a greenhouse where the automated system was installed.


**Figure 3.1** AutoCad Software

AutoCAD (Computer-Aided Design) is a computer application that is very useful for project layout, design, and taking complex measurements of various lengths and angles in modeling 2D and 3D. The application is extremely useful for idea visualization and dimensioning, especially during the project's planning and design stages. The design was most likely done in 3D in order to view the output in isometry as well as observe the actual construction while using some of the parameters mentioned.


**Figure 3.2** Google Sheet

Spreadsheet programs, such as Google Sheets and Microsoft Excel, are powerful computer applications that can be used for data organization, computation, analysis, and

storage. Users can create, edit, and format spreadsheets in Google Sheets, as well as import and export data from other sources.

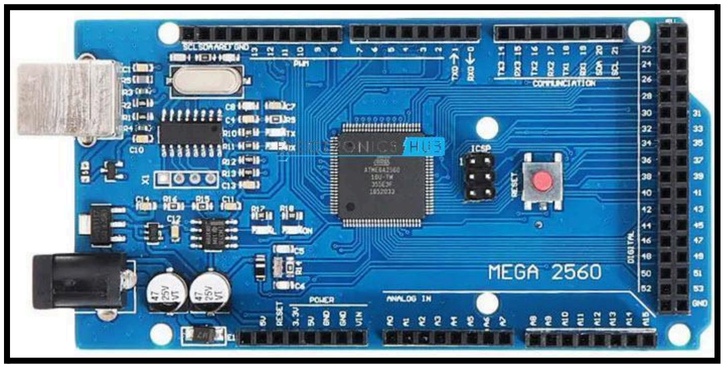


**Figure 3.3** Arduino Mega

The Arduino Mega is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It's a powerful board that's great for projects requiring a lot of I/O pins or complex functionality.


**Figure 3.4** Arduino IDE (Integrated Development Environment)

The Arduino IDE (Integrated Development Environment) is free and open-source software that simplifies code compilation, particularly for those with no prior technical knowledge. It was created by Arduino.cc and is compatible with a variety of operating systems, including MAC, Windows, and Linux. It is based on the Java platform and includes built-in functions and commands for debugging, editing, and compiling code. The Arduino modules available include the Arduino Uno, Arduino Mega, Arduino Leonardo, and Arduino Micro, each of which has a microcontroller on the board that is programmed in the form of code. The editor for writing the code and the IDE are the two main components of the IDE. Code and the compiler are required for compiling and uploading the code.

### 3.4 DATA COLLECTION AND TREATMENT

The proponents employed design and development research which entails the implementation of procedures and methodologies to create a functional prototype. In obtaining necessary information, the researchers gathered data through various methods. The researchers conducted a comprehensive review of related literature and previous studies as the foundation for the project design. Methods such as Internet and E-library research, interviews, and consultation were used to complete this project study.

## Functionality Test

### a) Shade Net Control

**Table 3.1** Shade Net Control Functionality Testing

| Shade Net Control Testing | | | |
|---|---|---|---|
| Trial | Temperature (°C) | Luminous Flux (lm) | Shadi S (O |
| 1 | | | |
| 2 | | | |
| 3 | | | |

This test assesses the effectiveness of the automated shade net control system in the greenhouse. The system is designed to adjust the deployment of the shade net based on real-time monitoring of light intensity and temperature to optimize plant growth conditions. The test involves monitoring the response of the shade net system to changes in external light and temperature conditions. Given its location within a resort, nearby artificial light may trigger the luminous sensor. Therefore, considering temperature is crucial when activating the shading system. The shade net control system operates by deploying and retracting the net with precision based on predefined light and temperature thresholds. A "PASSED" remark is noted if the shading motor starts to take action when temperature is on 30°C and luminous intensity reaches beyond 600 $\mu mol \cdot m^2 \cdot s^{-1}$ or 32,400 lux [9], ensuring that plants receive the optimal temperature and luminous flux for the lettuce plant. Otherwise, the test result is marked as "FAILURE".

**Table 3.2** Shade Net Control Efficiency Test

| Difference of Lumens with and without Shade Net |
|---|

| Trial | Lumens with Shade Net | Lumens without Shade Net | Required Luminous Flux | Remarks (Passed/ Failure) |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

This test is designed to determine the effectiveness of the shade net in managing light exposure within the greenhouse. It involves recording the lumens, a measure of light intensity, inside the greenhouse with the shade net installed and without it. Measurements are taken using a luminosity sensor during multiple trials to ensure reliability of the data. Each trial will note the lumens with the shade net and compare it to the lumens recorded without the shade net. The system is deemed efficient if the light intensity with the shade net falls within the optimal range for plant growth, avoiding both underexposure and harmful overexposure. A "PASSED" remark is noted if the desired luminous flux is achieved, ensuring that plants receive the correct amount of light for healthy photosynthesis without excess stress from over-illumination. Otherwise, the test result is marked as "FAILURE".

### b) Climate Control Testing

**Table 3.3** Humidity and Temperature Functionality Testing

| Humidity and Temperature Functionality Testing | | | | |
|---|---|---|---|---|
| Trial | Humidity (%) | Temperature (°C) | Misting Element Status (On/Off) | Remarks (Passed/ Failure) |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

The method of determining the functionality of the humidity and temperature sensor will be evaluated. These evaluations are intended to provide crucial information to advocates, allowing them to make adjustments and improvements. This assessment comprises three trials under humidity and temperature conditions, where the misting element will activate when the sensors reach any of the set values for humidity and temperature. A "PASSED" remark will be assigned if the misting element activates when the temperature rises beyond 30°C [71] and the humidity drops to 65%[73]. Also testing if the mister shuts down when the 27°C[71] temperature and 85%[73] of humidity were met. However, if not, it will be considered "FAILURE".

**Table 3.4** Humidity and Temperature Efficiency Test

| Difference of Indoor and Outdoor Climate | | | | |
|---|---|---|---|---|
| Trial | Indoor (Temperature & Humidity) | Outdoor (Temperature & Humidity) | Required Humidity & Temperature | Remarks (Passed/ Failure) |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

This test assesses the efficiency of the greenhouse management system in stabilizing indoor climate conditions compared to the fluctuating outdoor environment. The evaluation involves measuring and comparing the temperature and humidity levels inside and outside the greenhouse across multiple trials. Each trial will record the temperature and humidity data from sensors located inside the greenhouse and in the external environment. The result is marked as "PASSED" if the indoor climate remains within the desired data, otherwise, it is noted as "FAILURE".

c) **pH Level Control Test**

**Table 3.5** pH Level Control Functionality Testing

This test evaluates the functionality of pH Level Control in the greenhouse management system. The test specifically assesses the control mechanism’s ability to maintain the pH condition at predetermined levels. During the test, the pH levels are closely monitored to ensure that the concentrations stay within the required value. For each trial, the pH sensor detects the nutrient level, triggering the pH downer pump to attain the optimal ph level. A "PASSED" remark is assigned if the system successfully activates the pH downer pump when pH level rises to 7 and stops when the pH level is 6. However, if the system fails to activate the valves despite meeting the requirement, a “FAILURE” is noted.

| pH Level Control Testing | | |
|---|---|---|
| Trial | pH Level | pH Downer Pump (On/Off) |
| 1 | | |
| 2 | | |
| 3 | | |

**Table 3.6** Transition of pH Level Efficiency Test

| Transition of pH Level in water | | | | |
|---|---|---|---|---|
| Trial | Initial pH Level | New pH Level | Required pH Level | Remarks (Passed/Failure) |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

The evaluation method of pH level control will involve a series of tests to assess the stability and accuracy of the system's ability to maintain optimal pH level concentration. This examination will focus on the system's response under various conditions to ensure consistent pH level. The test consists of three trials. In each trial, we will record the initial pH level and new pH level reading to control whether the valve will activate or deactivate based on the current reading. The pH downer valve will activate once the minimum required pHlevel has been met, and it will deactivate once the maximum required pH level has been attained. A "PASSED" remark will be assigned if the new pH level met the required pH level; otherwise, it will be marked as "FAILURE".

**Performance Test**

**Table 3.7** Weekly Growth Stage of Lettuce

| | Weekly Growth Stage | | | |
|---|---|---|---|---|
| | Week 1 | Week 2 | Week 3 | Week 4 |
| Greenhouse 1 | | | | |
| Greenhouse 2 | | | | |

Table 3.7 presents the growth characteristics of lettuce at different growth stages under two greenhouse systems: Greenhouse 1, which operates with a manual system, and Greenhouse 2, which uses an automatic system. The performance testing is designed to compare these two approaches in managing the growth conditions. The growth conditions will be monitored on a weekly basis from week 1 to week 4 to collect a detailed progression of the lettuce's growth over time. The results will provide valuable insights into the advantages of automation in maintaining optimal conditions for lettuce cultivation compared to manual control.

## 3.5 BUDGET REQUIREMENTS

The researchers make sure that the resources are widely accessible and available in order to properly carry out this study and construct the Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, Water TDS and pH level monitoring control. The financial requirements are also based on the theoretical framework and findings of the researchers. The table below shows the estimated costs for the components, materials and production output.

**Table 3.8** Bill of Materials

| Description | Specification | Quantity | Unit | Unit/Price | Total |
|---|---|---|---|---|---|
| Arduino Mega | ATmega2560/ 6-20V | 1 | pc | ₱ 1,145.00 | ₱ 1,145.00 |
| Contactor | 9-32 A AC | 1 | pc | ₱ 395.00 | ₱ 395.00 |
| DFRobot Gravity | 3.3-5.5 V | 1 | pc | ₱ 2,499.00 | ₱ 2,499.00 |
| DHT11 sensor | 5.5 V/0.2 mA | 2 | pc | ₱ 125.00 | ₱ 1125.00 |
| ESP32 | 78.32 mW | 1 | pc | ₱ 631.00 | ₱ 631.00 |
| Float Switch | 10W | 2 | pcs | ₱ 199.50 | ₱ 399.00 |
| Jumping Wire | Male 20cm | 3 | pcs | ₱ 35.00 | ₱ 105.00 |
| Pulley | 36kN high grade alloy | 1 | pc | ₱ 298.00 | ₱ 298.00 |
| PH4502C module | 5±0.2 V | 1 | pc | ₱ 999.00 | ₱ 999.00 |
| Raspberry Pi | 3.7-5 V | 1 | pc | ₱ 4,720.00 | ₱ 4,720.00 |
| Relay Module | 5V Single | 3 | pcs | ₱ 42.00 | ₱ 126.00 |
| Relay Board | 12V Single Channel | 3 | pcs | ₱ 50.00 | ₱ 150.00 |
| Shaft | 12mm | 2 | pcs | ₱ 353.00 | ₱ 706.00 |
| Shade Net | Anti UV | 1 | pcs | ₱ 499.00 | ₱ 499.00 |
| Solenoid Valve | 2 way/NC | 3 | pcs | ₱ 330.00 | ₱ 990.00 |
| Stepper Motor | 12 V/ 1.7 A | 1 | pcs | ₱ 699.00 | ₱ 699.00 |
| Water Pump | 12 V | 1 | pc | ₱ 1,499.00 | ₱ 1,499.00 |
| TSL2561 Sensor | 3.3V – 5V | 2 | pcs | ₱ 499.00 | ₱ 998.00 |
| Misting Nozzle | 3-12 kg | 1 | set | ₱ 541.00 | ₱ 541.00 |
| Water Flow Sensor | 1-25L/min | 1 | pcs | ₱ 184.00 | ₱ 552.00 |
| | | | | **Total Amount** | ₱ 25,993.00 |

**Table 3.7** shows the list of the expenses of the automated greenhouse management system, which includes the necessary equipment for the automated greenhouse management system and other electronic components. The total required budget for the said prototype amounted to ₱ 25,993.00.

**Table 3.9** Bill of Labor Costs

| Description | Costs (Php) |
|---|---|
| Construction Labor | ₱ 15,000.00 |
| Fabrication Labor | ₱ 30,000.00 |
| Programming Labor | ₱ 15,000.00 |
| Total Amount | ₱ 60,000.00 |

**Table 3.8** shows the list of the expenses of the development and installation of the Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, Water TDS and pH level monitoring control, which includes the programming, construction and fabrication of the prototype. The total required budget for the laborer and fabricator amounted to ₱ 60,000.00.

## 3.6 EXPECTED OUTPUT

The expected output is a fully functional greenhouse that can automatically water and harvest lettuce. It is also expected that it can regulate the temperature within the building to maintain the optimal growing condition for lettuce.

**Perspective View**

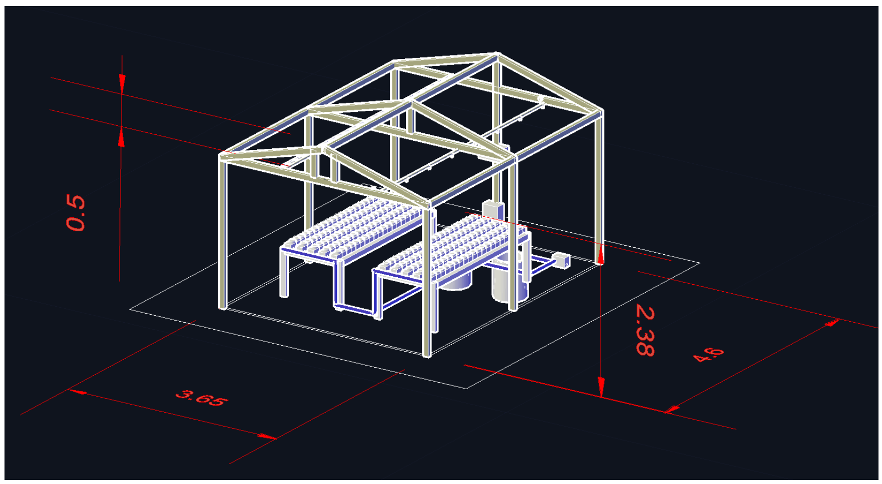


**Figure 3.5** Expected Output with Overall Dimension

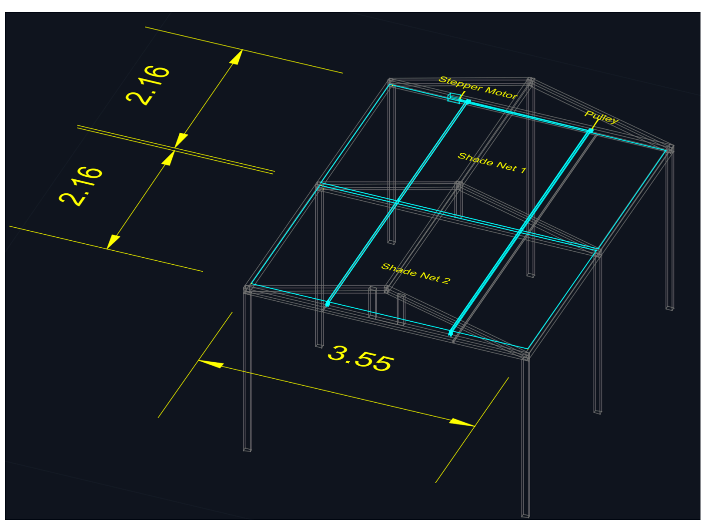


**Figure 3.6** Shading System

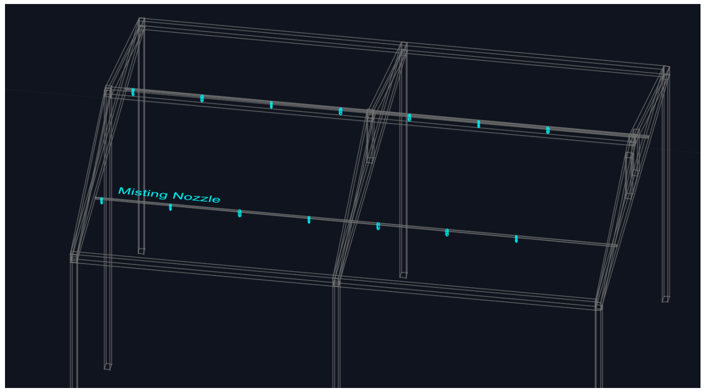


**Figure 3.7** Misting System

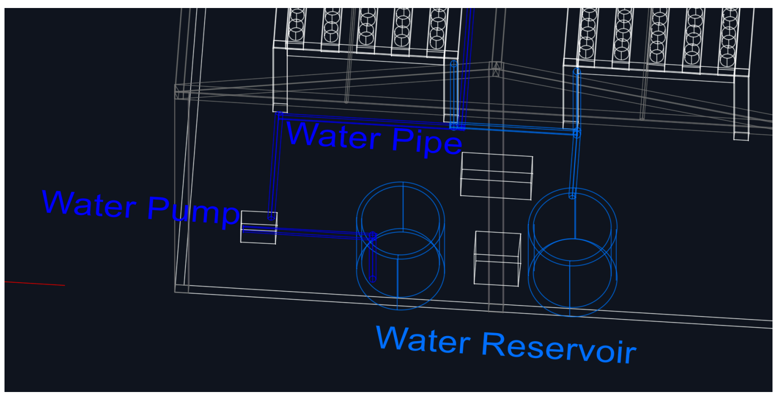


**Figure 3.8** Watering System

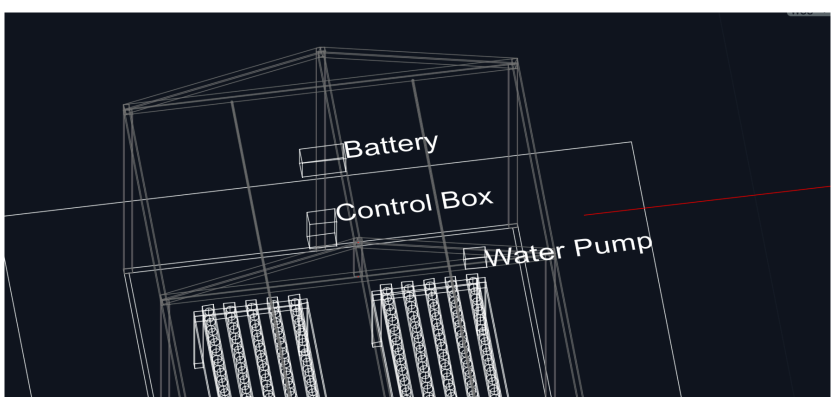


**Figure 3.9** Electronics System

The research aims to design an automated greenhouse management system for sustainable agriculture, specifically focusing on shading, misting, watering, and nutrient monitoring. This project aligns with the objectives of the DOST 6Ps Project by contributing to several key outputs. The innovative aspects of the automated control system could lead to potential patents, indicating an innovation. This would be evaluated based on the progress of the patent application process.

Overall, the research aligns with the goals of the DOST 6Ps Project by not only contributing to the advancement of knowledge in sustainable agriculture but also by potentially leading to practical innovations and solutions that benefit society and the environment.

Creating a greenhouse system positively impacts the economy by increasing crop yields, improving crop quality, creating jobs, and enabling year-round production, which expands market opportunities and can lead to higher profits. Efficient resource use and potential energy savings further enhance economic benefits.

### 3.7 GANTT CHART

The Gantt chart illustrates the work sequence of activities and corresponding duration in designing of the project "Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, Water TDS and pH level monitoring control". It begins with groupings, conceptualization and title proposal in January and February, followed by construction of Chapter I in February to March, and then Chapter II in the month of March. After that if we have a revision of Chapter I and II we will do it in March, Canvassing and Chapter III through the month of April, and the month of May is allotted for manuscript revisions and proposal defense.

**Table 3.10** Gantt Chart

| | January | February | March | April | May |
|---|---|---|---|---|---|
| **Groupings** | | | | | |
| **Conceptualizing** | | | | | |
| **Title Proposal** | | | | | |
| **Chapter I** | | | | | |
| **Chapter II** | | | | | |
| **Revision of Chapter I and II** | | | | | |
| **Canvassing** | | | | | |
| **Chapter III** | | | | | |
| **Revisions** | | | | | |
| **Proposal Defense** | | | | | |

The Table Gantt chart shows the progress of the researchers in every month and what month we started and finished each part of the chapter within the 1st week up to 18th week of Second Semester Academic year 2023-2024.

# CHAPTER 4

# PRODUCT DEVELOPMENT

This chapter encompasses the technicalibes in the construction of the product prototype. This Includes the Product Specification, Product Development, and Simulation and Testing. Design bases are specified in the Product Specification. Methods undertaken in the creation of the prototype are inscribed in the Product Development section, The testing procedures and summary of testing carried out is presented by simulation and testing.

**4.1 PRODUCT SPECIFICATION**

**4.1.1. General Description of the Project**

**4.1.2. Design Standards**

**4.1.3. Design Computation and Analysis**

**4.1.4. Design Layout**

**4.1.5. Circuit Diagram**

**4.1.6. Materials and Components**

**4.1.7. Software Program and Implementation**

**4.1.8. Bill of Materials and Specification**

**4.2. METHOD OF FABRICATION**

**4.3. METHODS OF TESTING**

## 4.1 PRODUCT SPECIFICATIONS

**Wire Sizing**

25 – 50 Feet Extension Cords

16 Gauge(1-13 Amps)

14 Gauge (14-15 Amps)

12-10 Gauge (16-20 Amps)

100 Feet Extension Cords

16 Gauge (1-10 Amps)

14 Gauge (11-13 Amps)

12 Gauge (14-15 Amps)

10 Gauge (16-20 Amps)

150 Feet Extension Cords

14 Gauge (1-7 Amps)

12 Gauge (8-10 Amps)

10 Gauge (11-15 Amps)

**[85]**

**SHADING**

**L298N motor driver**

The L298N motor driver is an affordable and straightforward option for controlling stepper motors, particularly suited for small to medium-sized bipolar stepper motors like the NEMA 17. It enables control over both the speed and direction of the motor. The L298N provides the necessary power and control to handle the NEMA 17's requirements, supporting up to 2A per channel and operating between 5V and 35V. [86]

**NEMA 17 stepper motor**

NEMA 17 stepper motors, which are characterized by 1.7 x 1.7-inch faceplate. These motors are distinguished by high torque, which is designed to maximize efficiency while minimizing vibration and noise, making it ideal for precise applications. The availability of customized windings allows these motors to be perfectly designed to specific voltage, current, and torque requirements.

Additionally, the NEMA standard, set by the National Electrical Manufacturers Association, ensures compatibility and safety across a wide range of electrical products, promoting consistency and reliability in power generation and transmission applications.[87]

**TSL2561 [40]**

**MISTING AND WATER CIRCULATION**

Misting Nozzle

Water Pump

**WATER TDS**

DFRobot Gravity: Analog TDS Sensor/Meter

**PH LEVEL MONITORING**

PH4502C module

Analytical Surver Electrode pH Probe

4.2 PRODUCT DEVELOPMENT

I2C is critical for enabling devices like sensors and displays to communicate over a two-wire interface (SDA and SCL). This protocol is essential for the development of products that require efficient, low-cost, and minimal wiring communication between

multiple devices. I2C is particularly valuable in complex systems where numerous sensors and components need to interact seamlessly.

### 4.3 SIMULATION AND TESTING

# CHAPTER 5

# RESULTS AND DISCUSSION

## 5.1 DISCUSSION OF RESULTS

## 5.2 SUMMARY OF FINDINGS

## 5.3 CONCLUSIONS

## 5.4 RECOMMENDATION

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# APPENDIX

## APPENDIX A

## LETTER FROM THE BENEFICIARY

BatStateU @120

BATANGAS STATE UNIVERSITY
The National Engineering University

*Propelling Transformations and Accelerating Reforms for National Development*

**College of Engineering – Department of Electrical Engineering**

**San Isidro Multi-Purpose Cooperative (SIMCO)**
Brgy. San Isidro, Batangas City
October 02, 2024

To Whom It May Concern,

Greetings!

We, the researchers, are submitting a proposal for the implementation of a Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, Ph Level and TDS Monitoring at San Isidro Multi-Purpose Cooperative (SIMCO) located in Barangay San Isidro, Batangas city. As providers of agricultural resources, we hold a strong conviction that the incorporation of hydroponics techniques into cultivation practices will significantly improve the well-being of our farmers and enhance the overall quality of their crops.

The implementation of this automated system, which controls essential greenhouse functions like shading, misting, and nutrient and water monitoring, will improve the overall efficiency of crop cultivation. By addressing key challenges such as maintaining optimal environmental conditions, monitoring pH and TDS levels, and automating watering schedules, the system aims to ensure a sustainable and high-yield operation, benefiting your crops, particularly in hydroponic lettuce farming.

Our approach aligns with sustainable agricultural practices and is designed to contribute to the achievement of your long-term productivity goals while minimizing environmental impact. We are confident that this innovative system will not only restore the functionality of your greenhouse but also contribute to the prosperity of your community's agricultural sector.

We sincerely seek your partnership and approval for this initiative and are grateful for your consideration.

Thank you.

Sincerely,

______________________________
Signature and Name of Representative

**APPENDIX B**

**CIRCUIT DIAGRAMS**

- DETAILED CIRCUIT DIAGRAMS SHOWING THE ELECTRICAL WIRING, SENSORS, MICROCONTROLLER CONNECTIONS, AND AUTOMATION CONTROL SYSTEMS FOR SHADING, MISTING, WATER CIRCULATION, AND PH/TDS MONITORING.

**APPENDIX C**

**TECHNICAL SPECIFICATIONS**

- SPECIFICATION SHEETS OF THE EQUIPMENT AND COMPONENTS USED (E.G., SENSORS, PUMPS, ARDUINO BOARDS, MOTORS). THIS INCLUDES POWER REQUIREMENTS, DIMENSIONS, AND PERFORMANCE RATINGS.

Computation:

Pumps

Electrical Loads

**APPENDIX D**

**PROGRAMMING CODE**

- FULL SOURCE CODE FOR THE CONTROL SYSTEM, TYPICALLY WRITTEN FOR ARDUINO OR OTHER MICROCONTROLLERS USED TO MANAGE SHADING, MISTING, AND WATER CIRCULATION.

**APPENDIX E**

**FABRICATION DRAWINGS**

- MECHANICAL DRAWINGS OR CAD DESIGNS THAT SHOW THE DIMENSIONS AND ASSEMBLY STEPS OF FABRICATED PARTS, SUCH AS

THE GREENHOUSE FRAME, SHADE NET MECHANISM, OR MISTING SYSTEM.

**APPENDIX F**

**TEST DATA**

- RAW DATA COLLECTED FROM FUNCTIONALITY AND EFFICIENCY TESTS, SUCH AS TEMPERATURE, HUMIDITY, LIGHT INTENSITY READINGS, OR PH AND TDS LEVELS DURING THE TRIAL RUNS.

**APPENDIX G**

**GANTT CHART**

- A DETAILED PROJECT TIMELINE OR GANTT CHART OUTLINING THE STAGES OF DESIGN, FABRICATION, AND TESTING OF THE GREENHOUSE MANAGEMENT SYSTEM.

**APPENDIX H**

**USER MANUAL/INSTRUCTIONS**

- INSTRUCTIONS OR A USER MANUAL FOR OPERATING THE AUTOMATED SYSTEM, INCLUDING HOW TO CALIBRATE SENSORS, ADJUST SETTINGS, AND MAINTAIN THE EQUIPMENT.

**APPENDIX I**

**SAFETY GUIDELINES**

- SAFETY PROTOCOLS FOLLOWED DURING THE FABRICATION AND INSTALLATION OF ELECTRICAL, PLUMBING, AND MECHANICAL SYSTEMS IN THE GREENHOUSE, PARTICULARLY RELATING TO HIGH-VOLTAGE COMPONENTS AND HANDLING CHEMICALS.

**"GREENHOUSE MANAGEMENT SYSTEM: AUTOMATED CONTROL OF SHADING, MISTING, WATER CIRCULATION, PH LEVEL, AND WATER TDS MONITORING"**

A Project Study Presented to the Faculty of Electrical Engineering

College of Engineering

Batangas State University

The National Engineering University

Alangilan, Batangas City

Proponents:

**20-06252 | BAUTISTA, NIÑO LUIS BERNABE M.**

**20-06612 | CANTOS, WYNN ELDON P.**

**20-04390 | FACTOR, JOHN KENNEDY C.**

**20-08175 | SANDOVAL, JEREMY L.**

Group No. 4~ BSEE 4209

Submitted To:

**ENGR. MARJORIE M. SALVA**

EE 411 INSTRUCTOR

**AY - 2024**

## DECLARATION

This project study, entitled **"GREENHOUSE MANAGEMENT SYSTEM: AUTOMATED CONTROL OF SHADING, MISTING, WATER CIRCULATION, PH LEVEL, AND WATER TDS MONITORING,"** is a presentation of the proponents' original work. Wherever contributions from others are involved, every effort is made to indicate this clearly, with due reference to the literature and acknowledgement of collaborative research and discussions. This project study was done under the guidance of the project study adviser, **ENGR. MARA JESSA B. MACARAIG.**


Bautista, Nino Luis Bernabe M.

Cantos, Wynn Eldon P.

Factor, John Kennedy C.

Sandoval, Jeremy L.

## APPROVAL SHEET

The project study entitled **"GREENHOUSE MANAGEMENT SYSTEM: AUTOMATED CONTROL OF SHADING, MISTING, WATER CIRCULATION, PH LEVEL, AND WATER TDS MONITORING,"** was prepared and submitted by **Bautista, Nino Luis Bernabe M., Cantos, Wynn Eldon P., Factor, John Kennedy C., and Sandoval, Jeremy L.,** in partial fulfillment of the requirement for the degree of BSEE is hereby recommended for an oral examination.

______________________________

**ENGR. MARA JESSA B. MACARAIG**

Approved by the Committee on Oral Presentation with a grade of __________.

**PANEL OF EXAMINERS**

______________________________

**ENGR. ELENOR M. REYES**
CHAIRMAN

______________________________ ______________________________

**ENGR. DINDO T. ANI**
MEMBER

**ENGR. RICHARD DEAN M. BRIONES**
MEMBER

Accepted and approved in partial fulfillment of the requirements for the degree of **BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING.**

______________________________ ______________________________

**DATE**

**DR. CRISTINA AMOR M. ROSALES**
DEAN, CoE

## CAPSULE PROPOSAL

Automation has a huge impact on society since it increases productivity and efficiency. This creates new opportunities for technology focused businesses as well as the displacement of jobs. Automation transforms industries by maximizing operations, guaranteeing precision, and fostering consistency while minimizing human interaction. A future where technology and human skills work together to create efficient operations begins to take shape as it spreads. Furthermore, agriculture is essential to international trade, the production of jobs, and economic growth since it combines innovation, expertise, and technological technology. To meet the increasing demand for food while automating difficult duties and reducing the impact on the environment, creative solutions are crucial.

The Greenhouse System creates ideal conditions for maximum plant growth and productivity, modernizing contemporary agriculture. It is perfect for typhoon-prone regions like the Philippines because it shields crops from bad weather and pests. When combined with hydroponics, which cultivates plants in nutrient solutions without soil, high-quality produce and decorative plants can be grown all year round. A important hydroponic crop, lettuce, grows well with greenhouse automation that regulates temperature, humidity, and ventilation precisely. Compared to conventional farming methods, this approach offers a significant gain in production and sustainability.

The purpose is to create an innovative greenhouse management system that supports a few Sustainable Development Goals and adheres with industry requirements. The practical significance of this research on expanding agricultural technology is

highlighted by the implementation of this advanced system at San Isidro, Batangas City. This research could lead to increased food efficiency, less human involvement, the development of sustainable communities, and a greater integration of technology in the agriculture sector.

**KEYWORDS:** Automation, Greenhouse System, Hydroponics, San Isidro, SIMCO

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## DEDICATION

The study is dedicated, first and foremost, to Batangas State University - The National Engineering University, our beloved University, for supplying us with the information that we have employed for this research.

We also dedicate this work to our project beneficiary, SIMCO, in the hope that this project will significantly benefit them.

Wholeheartedly, we dedicate the completion of this research to all of the people behind our success.

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**N.L.B.M.B**

**W.E.P.C**

**J.K.C.F**

**J.L.S**

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# CHAPTER I

# INTRODUCTION

This chapter presents the introduction, background to the study, statement of the problem, research objectives, research questions, significance of the study, scope and delimitation and definition of terms.

## 1.1 BACKGROUND OF THE STUDY

Automation impacts our society by increasing efficiency and production, resulting in job displacement while also creating new opportunities for technology-focused companies. It involves using technology to perform activities with minimal human intervention, resulting in a major change in the industries. The adoption of automation technologies, incorporating different methods and processes, improves the efficiency, reliability, and speed of tasks that were previously conducted by human workers. This shift not only optimizes operational workflows but also promotes precision and consistency across various sectors. As automation becomes more widespread, it emphasizes the potential of a future characterized by efficient and reliable operations, where human and technological expertise work together to improve productivity and overall performance. [1]

Agriculture is the practice of cultivating natural resources to sustain human life and provide economic gain. It combines the creativity, imagination, and skill involved in planting and raising animals with modern production methods and new technologies. Agriculture impacts global trade because it’s tied to other sectors of the economy, supporting job creation and encouraging economic development. Countries with strong

agricultural sectors experience employment growth in other sectors, according to the United State Agency for International Development (USAID). Countries with agricultural productivity growth and robust agriculture infrastructure also have higher per capita incomes, since producers in these countries innovate through technology and farm management practices to boost agricultural productivity and profitability. Innovative solutions are required to meet the world's growing food demand while reducing farming's environmental impact and automating manual processes.[2]

The Greenhouse System optimizes environmental conditions to increase plant growth with maximum yield possible time, which is one of the primary goals of the modern agricultural system. Greenhouses have long been recognized as a means of improving crop productivity and quality. They provide a controlled environment, protecting crops from adverse weather conditions, pests, and diseases. However, even within the protected confines of a greenhouse, maintaining optimal weather conditions remains a significant challenge due to the dynamic and unpredictable nature of external factors. [3]

Internet of Things (IoT) enables real-time monitoring and control of environmental factors such as temperature, humidity, water circulation, and nutrient levels, allowing farmers to optimize crop growth while minimizing resource waste. [4] IoT ensures that ideal growing conditions are consistently maintained by automating adjustments based on sensor data, resulting in improved crop yields and quality while significantly reducing the need for manual intervention.

Hydroponics is the cultivation of plants in a liquid nutrient solution with or without the use of artificial medium. Hydroponics has been recognized as a viable way

of producing vegetables (tomatoes, lettuce, cucumbers, pechay, and kangkong) as well as ornamental crops such as herbs, roses, freesia, and foliage plants. Because of the ban on methyl bromide in soil culture, the demand for hydroponically grown produce has risen significantly in recent years.[5]

Lettuce (Lactuca sativa) is the fourth most important vegetable crop grown hydroponically in greenhouses preceded by tomatoes, cucumbers and peppers. Although greenhouse production of lettuce is very small in comparison to field grown, it has a specific market niche as a gourmet, high-quality item. Hydroponic farming revolutionizes conventional farming practices and contributes to a greener future by providing a sustainable and effective technique for growing lettuce.[6]

Greenhouse automation, the focal point of the study, confronts the challenges in lettuce production head-on by effectively incorporating technology and automation into the hydroponic cultivation process within the greenhouse. This approach provides a complex method to regulate vital factors like: temperature, humidity, and ventilation, resulting in an environment that is perfectly suited to the particular requirements of lettuce throughout its entire growth cycle. In lettuce production, the significance of this technology becomes apparent when compared with traditional manual processes.

The Sustainable Development Goals (SDGs) represent a global commitment to addressing some of the most issues confronting humanity. Adopted by all United Nations Member States in 2015, these 17 goals serve as a universal call to action to end poverty, protect the planet, and ensure prosperity for all by the year 2030. By optimizing irrigation practices through automated hydroponic systems, the project contributes to SDG 6 (Clean Water and Sanitation), addressing the goal of ensuring sustainable water management.

Additionally, the adoption of sustainable farming practices and the reduction of carbon footprints align with SDG 13 (Climate Action). Furthermore, the research contributes to the preservation of terrestrial ecosystems, supporting SDG 15 (Life on Land) by promoting efficient and sustainable agricultural practices that minimize environmental impact on land and biodiversity. In addressing these SDGs collectively, the research aims to make a positive and comprehensive contribution to global sustainability efforts, tackling issues related to water, energy, climate change, and ecosystems.[7]

In the community of Brgy. San Isidro, Batangas City, the project beneficiaries are local farmers who have embraced innovative agricultural practices to enhance their productivity. Being the main implementation to their efforts is a greenhouse, which is an important asset that was intended to optimize crop growth and ensure year-round agricultural output.

This greenhouse is already powered by solar panels, representing a significant step towards farming by renewable energy to reduce operational costs and environmental impact. However, despite its potential, the greenhouse has been non-functional, making its advanced infrastructure for not being used. Revitalizing this facility not only promises to enhance the local economy but also aligns with the broader goals of sustainable development and energy efficiency within the community. The restoration and optimization of this greenhouse is to transform agricultural practices in Brgy. San Isidro, advocating both economic growth and environmental care.

The greenhouse measures 3.65 meters wide by 4.6 meters long, at a height of 2.3 meters. Its rectangular shape maximized the available growing space, allowing for efficient use of the 16.79 square meters of floor area. The structure's height provided

enough room for taller plants and allowed for proper air circulation, creating an ideal climate for nurturing lettuce. The greenhouse's dimensions were chosen to accommodate the specific needs of the plants being cultivated, ensuring optimal growing conditions and maximizing the potential for a successful harvest.

In this study, the implications of the technology extend well beyond the agricultural sector. Greenhouse automation not only ensures food security by allowing for consistent crop production, but it also has the potential to reduce agriculture's environmental impact. It aligns with the broader goals of environmental sustainability and resilience by minimizing resource use and waste. The design and development of the greenhouse management system represents agricultural innovation in this context. This research will provide insight into the various components of these systems, from their design principles to the incorporation of modern technologies, as well as their potential for altering agriculture's future. This study adds to a growing body of knowledge by addressing the pressing need for automated lettuce production.

## 1.2 STATEMENT OF THE PROBLEM

Greenhouses play an important role in modern agriculture by creating controlled environments optimal to the growth and yield of lettuce crops. However, the effectiveness of greenhouse operations relies heavily on maintaining precise weather conditions for optimal lettuce production. External factors such as temperature, humidity, TDS Level, pH level and changing light intensities pose significant challenges to greenhouse operators.

The primary issue facing the beneficiary in Brgy. San Isidro, Batangas City, is the non-functionality of their existing greenhouse, which is powered by solar panels. Despite

the significant investment in this advanced agricultural infrastructure, the greenhouse remains underutilized, preventing the farmers from producing crops with its potential benefits. The restoration and optimization of the greenhouse facility are essential steps toward achieving these goals.

Implementation of Internet of Things (IoT) can effectively address challenges in greenhouse management by enabling real-time monitoring and automated control of key environmental factors such as temperature, humidity, and nutrient levels. Sensors continuously gather data, providing farmers with immediate insights and allowing for automatic adjustments when conditions exceed set thresholds.[8]

Light serves as a fundamental catalyst for photosynthesis, the process crucial for the synthesis of essential nutrients and plant growth. Adequate light exposure is essential for healthy development, photosynthesis, and nutrient uptake all of which have an impact on overall plant health and nutritional status. Some studies have found that simultaneous increases of light intensity and temperature within a practical range could significantly facilitate lettuce's growth and nutritional value. Regular monitoring of light levels and adjustments based on plant response is key to achieving the best results in lettuce cultivation. [9]

Temperature and humidity play an important role in the successful cultivation of hydroponic lettuce. Lettuce is a cool-season crop that thrives in specific temperature ranges, with the optimal temperature for growth being between 20 to 24°C (68 to 75°F.[10] Maintaining the proper temperature is essential, as lettuce can bolt (rapidly shoot up to go to seed) when exposed to temperatures exceeding 80 to 85°F (26 to 29°C), making the lettuce unmarketable.[11]

Relative humidity (RH) is another factor in hydroponic lettuce production. The ideal RH range for lettuce is between 50 to 70 percent. High humidity, exceeding 70%, can lead to issues such as tip burn, a physiological disorder caused by a calcium deficiency. The higher the RH, the less transpiration occurs in the plant, resulting in inadequate calcium uptake. Conversely, RH lower than 50% can cause outer leaf edge burn, another physiological disorder.[12]

Water is the medium in which plants absorb nutrients, plants are grown in a nutrient-rich solution instead of soil. It is possible to attain great yields and high quality in hydroponics. When water and nutrients are supplied in the required quantities, characteristics emerge. The nutrients and water needed by the plants are calculable. However, the water quality given is as crucial, but the quality (the salt and nutrient content) is generally fixed. As a result, it is critical to understand the water quality being used and, as a result, what fertilization modifications are required. [13]

The Nutrient Film Technique (NFT) hydroponic system relies on a continuous flow of nutrient-enriched water to provide plants with the necessary moisture and nutrients. In a typical NFT setup, a submersible pump circulates the water from the reservoir, through the channels where the plants are situated, and back to the reservoir in a constant loop.

However, it indicates that some NFT growers have found it beneficial to put the pumps on cycles, effectively flooding and draining the system, rather than running the pump continuously. This is done to address a key drawback of the NFT system, the constant submersion of the roots in the water film, which can limit aeration and lead to

issues like root rot and bacterial diseases.By cycling the water flow, the growers are able to provide the plants with intermittent periods of water and air exposure, which can improve oxygenation and overall plant health.[14]

Total Dissolved Solids (TDS) refers to the cumulative measurement of inorganic salts, minerals, and other dissolved substances present in the water and nutrient solution used in hydroponics. These substances include essential nutrients such as nitrogen, phosphorus, potassium, and micronutrients like calcium, magnesium, and iron. By measuring TDS, growers gain an overall understanding of the nutrient concentration in their hydroponic systems. The plant species, development stage, and nutrient solution formulation all affect the optimal TDS range. Most hydroponic crops do best with a TDS range of 800 to 1500 parts per million (ppm). [15]

In hydroponics, maintaining the right pH level is important for plant health and nutrient absorption. The pH scale ranges from 0 to 14, with 7 being neutral. Most plants survive in a slightly acidic to neutral range, between 5.5 and 6.5. Different plants have specific pH preferences, and maintaining the correct pH ensures they can access important nutrients. pH levels can change due to various factors, such as nutrient concentration, growing media, and organic matter like algae and bacteria. Regular testing and adjustments are necessary to keep pH levels stable.

There are several methods for testing and adjusting pH levels, including test strips, liquid kits, and digital pH meters. For consistent pH control, automatic pH controllers are recommended, especially in recirculating systems. Maintaining the right pH level in hydroponics ensures plants can absorb nutrients properly, leading to healthier

and more productive growth.[16]

These automation systems are specifically crafted to intelligently control and manage the overall lettuce production in real-time, ensuring a more efficient and consistent cultivation process. Despite the potential benefits they offer, greenhouse automation systems particular for hydroponic lettuce production face several critical problems and challenges that require careful investigation and resolution during the design and development phases.

## 1.3 RESEARCH QUESTIONS

4. What are the design standards, requirements, and considerations for automated control of shading, misting, water circulation, pH level, and TDS monitoring?
5. What are the methods and procedures needed for the fabrication, construction, and assembly of an automated control of shading, misting, water circulation, pH level, and TDS monitoring?
6. What tests are necessary to determine the machine's reliability and efficiency?

## 1.4 RESEARCH OBJECTIVES

The main objective of the study is to design and develop the automated control system of shading, misting, water circulation, pH Level, and TDS monitoring. Specifically, this aims to achieve the following:

4. To design the system in terms of:
   - 1.1 General Description of the Project
   - 1.2 Design Standards
   - 1.3 Design Computation and Analysis
   - 1.4 Design Layout

1.5 Circuit Diagram
1.6 Materials and Components
1.7 Programs and Its implementation
1.8 Bill of materials and specifications

5. To develop the System in terms of its methods of fabrication and assembly.
6. To evaluate the overall system performance in terms of:

3.1 Functionality Test
3.1.1 Shade Net Control Test
3.1.2 Climate Control & Misting Control Test
3.1.3 pH Level Control Test
3.2 Performance Testing
3.2.1 Growth Stage of Lettuce

**1.5 SCOPE AND DELIMITATION OF THE STUDY**

The research will be carried out at Brgy. San Isidro, Batangas City, Philippines. This venue is ideally suited due to its established infrastructure for hydroponic farming, providing a relevant setting for testing the proposed automated control system. The hydroponic greenhouse measures 3.65 by 4.6 meters with a height of 2.9 meters.

The study focuses on developing a smart greenhouse system that will control the environment inside the greenhouse. Innovating the greenhouse through the use of a retracting shading net that will automatically adjust the environment condition especially when excess sunlight is detected. According to the design, the proposed shade net will be string-pulled by a stepper motor that is automatically operated by a microcontroller. By implementing this shading net, the internal environment of the greenhouse can be optimized, ensuring that plants receive the right amount of sunlight without being exposed to excessive heat or light levels, ultimately enhancing their growth and

productivity.

Moreover, the study aims to develop a misting system for the greenhouse. The mister is mounted underneath the roof within the greenhouse railings. The water supply for the misting is directly connected to the water distribution utility and is automatically controlled by a microcontroller such as the Arduino Mega.

The study also involves designing the watering system. The goal is to implement automated controls of watering schedules based on real-time data related to crop needs and environmental conditions. The proposed watering system will operate every 15 minutes within an hour.

pH sensors will be installed in the greenhouse to continuously monitor the acidity and alkalinity of the water. These sensors will provide real-time data that can be used to adjust irrigation, fertilization, and other environmental factors as needed. The TDS sensor will only be used to monitor the dissolved combined contents in the water. By maintaining optimal pH and TDS levels, the greenhouse can provide ideal conditions for the plants.

To achieve precise control over the entire system, an automated controller, such as Arduino Mega, is necessary. The Arduino utilizes a simplified C++ language for its syntax, and its libraries are also simplified for ease of use.

The electrical system would be sourced from a 12VDC that was supplied by the solar panel that were stored by the battery. All components were operated thru DC voltage as per requirement of most of the electrical parts. The overall electrical system would be operated off-grid as it is a low power system.

The project will adhere to standards set by the Philippine Electrical Code (PEC)

and the National Electrical Manufacturers Association (NEMA) for all electrical installations and components. Additionally, the agricultural construction will follow best practices in greenhouse design, considering local climate conditions and agricultural standards required by the PEC to minimize the risk of accidents. A smart greenhouse system will be developed and tested in collaboration with a private individual who owns the greenhouse. Despite the fixed size of the greenhouse, it will serve as a practical testbed, providing valuable insights and feedback for refining the smart greenhouse system and exploring potential future applications in agriculture.

However, certain limitations are essential to the project. Budget constraints dictate the scale and complexity of the automation system, and technological limitations may affect the feasibility of advanced features. Time constraints also play a role, influencing the depth and span of research, experimentation, and analysis.

Therefore, all the other types of lettuce other than batavia lettuce would be disregarded to be used or simply not optimally designed to be raised in this specific kind of greenhouse. This automation is only the production and does not include the planting process of lettuce which is classified as the germination. Geographical considerations acknowledge that the applicability of the system may vary based on different climatic and geographical conditions.

## 1.6 IMPORTANCE OF THE STUDY

The research aims to establish a solar powered greenhouse that helps in automating the whole process of production of lettuce within the greenhouse. This study can create great impacts to the following people in particular:

**To Greenhouse Owners.** The study's findings will provide greenhouse owners

with insights into how to optimize their plant growth conditions, particularly regarding sunlight exposure. By incorporating the smart greenhouse system, they can expect improved plant health and productivity, ultimately leading to increased yields and profits.

**To the Local Community and Agricultural Sector.** The implementation of the smart greenhouse system has the potential to contribute to the local agricultural sector's sustainability and growth. By enhancing the efficiency and productivity of greenhouse operations, the study aims to create a positive ripple effect, benefiting not only individual greenhouse owners but also the broader agricultural community.

**To the Electrical Engineering Department of Batangas State University.** The study serves as a platform for the Electrical Engineering Department to showcase its expertise in developing innovative solutions for real-world problems. By collaborating with a private individual and focusing on the practical application of electrical engineering principles, the department can demonstrate its commitment to addressing societal needs through research and development.

**To the Researchers.** The study presents an opportunity for researchers to contribute to the advancement of knowledge in the field of smart greenhouse systems. By conducting thorough investigations, designing and implementing the system, and analyzing its performance, researchers can deepen their understanding of the complex interactions between technology and agriculture, paving the way for future research endeavors.

**To Future Researchers:** The study's findings and methodologies can serve as a valuable resource for future researchers interested in smart greenhouse systems or related fields. By documenting the challenges, solutions, and lessons learned, the study can

provide a foundation for further exploration and innovation in agricultural technology.

# CHAPTER II

# LITERATURE REVIEW

This chapter discusses the review of literature used in the study. The discussion of literature is divided into two parts: conceptual literature and related literature. A synthesis regarding how the following studies would be used as well as the discussions regarding the similarities and differences of the study to those existing publications is also presented.

## 2.1 CONCEPTUAL LITERATURE

This section is concerned with various concepts that will be useful for this study. The information provided in this chapter is derived from books, publications, and websites.

### Principles and Theories of Automation

Automation is a fundamental idea and principle in the engineering fields, as well as in industrial civilization (manufacturing, processes, industries, etc.). Automatic machines are used to increase a plant's output per worker in order to lower growing wages and the production expenses that go along with it. High productivity can be achieved using automatic systems without sacrificing accuracy and precision. Therefore, automation is the process of reducing human intervention in machine operation and directly replacing it with technologically advanced systems like computers, robotics, etc.[17]

Automated systems generally outperform manual systems in terms of productivity, speed of operation, accuracy, and precision. Automation is applicable to a wide range of systems, from simple household appliances to complex industrial activities.

The control systems might be as simple as ON/OFF buttons or as complex as multivariable high-level algorithms. Industrial automation employs control systems and information technology to manage a variety of machinery and processes. Automation has made manufacturing lines much more flexible, resulting in higher output quality and quantity.

**Principles and Theories of Greenhouse**

A greenhouse is an external structure for growing plants, primarily made of a transparent material like glass or polycarbonate panels. In order for a greenhouse to function, as much light as possible must be let in and then stored as heat energy. All of the daylight is able to enter the greenhouse due to its transparent roof and walls. The greenhouse's soil and plants both become warmer as a result of this light. However, because glass is an insulator as well, the heat is trapped inside the structure, maintaining a comfortable temperature throughout the day. Maintaining a steady temperature is a big advantage of greenhouses. Even after the sun sets, the greenhouse remains warm because materials like water and soil within it absorb thermal energy from sunlight and release it gradually. The greenhouse is enclosed, so there isn't a breeze to release the heated air. Your plants remain comfortable as a result of the consistent temperature, which is typically quite warmer than the sudden cold temperatures we experience outside. In addition to being protected from inclement weather, they receive all the sunshine required for wholesome growth. [18]

According to the Philippine Agricultural Engineering Standard (PAES), gable roof greenhouses are required to adhere to specific height guidelines. The standard stipulates that the eave height, which is the distance from the ground to the point where

the roof begins, should be a minimum of 1.70 meters. Additionally, the gable height, which is the vertical distance from the eave to the highest point of the roof, must not be less than 2.4 meters. These specifications ensure that gable roof greenhouses comply with established standards to meet structural and functional requirements in agricultural engineering.[19]

**History of Greenhouses Development**

Historically, people have been using greenhouses for protecting plants from harsh weather conditions since ancient times. Here, the history of greenhouse development has been discussed. The first notes about greenhouses can be traced to the reign of Tiberius, Roman emperor from 14 to 37 CE. The Roman emperor Tiberius ate a cucumber-like vegetable daily, requiring Roman gardeners to discover artificial methods, similar to a greenhouse system, to grow it year-round. The gardeners first tried to install cucumber plants on carts so they could drag them into sheds when it became too cold. But if the cold lasted more than a few days, the cucumbers would start to die from lack of light. But someone came up with the idea of covering the structures not with slate, but sheets of selenite, a transparent rock, to let the sun in.[20]

There are nine greenhouse farming in the Philippines: Albay, Bulacan, Cavite, Laguna, Leyte, Negros Occidental, Nueva Ecija and Pangasinan. The five major greenhouse in the country are located in Albay (1,000 hectares), Cavite (500 hectares), Laguna (1,000 hectares), Leyte (2,000 hectares), and Negros Occidental (1,000 hectares). With ample sunlight and fertile soil, the Philippines is perfect for greenhouse farming. Philippines is estimated to have a production capacity of 6-7 million plants per year. The main challenges facing the Philippines greenhouse industry is logistics, it’s difficult to get

produce from rural areas into urban centers where it can be sold and distributed to customers.[21]

**Types of Greenhouses Based on Covering Materials & Construction**

**Glass Type Greenhouse**

**Figure 2.1** Glass Greenhouses (Source: Gothic Arch Greenhouses)

Glass is used as covering material in glass greenhouses. As a covering material it has the advantage of greater interior light intensity, has a higher air infiltration rate, and leads to lower interior humidity and excellent disease prevention quality. Ridge and furrow, lean-to type, even span type of designs are used for construction of glass greenhouse.[22]

**Plastic Film Type Greenhouse**

**Figure 2.2** Polyethylene Plastic for Greenhouses

The covering materials of flexible plastic including polyvinyl chloride, polyethylene and polyester are used in this type of greenhouses. As a covering material for greenhouses, plastics are more popular, cheap and the heating cost as compared to glass greenhouses. Plastic lms have a short lifespan which is the main disadvantage of this covering material. For example, the best quality ultraviolet (UV) stabilized can last for four years only. Quonset design as well as gutter-connected design is suitable for using this covering material.[22]

**Shade Cloth Type Greenhouse**

**Figure 2.3** Perfect Shade Cloth for Your Greenhouse

Shading is a way of keeping the greenhouse cool during the hotter months. It reduces the temperature inside by minimizing the amount of light passing to the greenhouse. Shade clothes typically reduce the light level by 75% and turn it into heat. The temperature of the cloth rises as it acts as a solar collector. The temp of the cloth is higher than the temp of the air, so the heat energy goes up. As it goes up, the cool air draws from below in the process known as evaporative cooling. The most common materials for the cloth are polyethylene and polypropylene. You can find a variety of shade cloths of different densities and degrees of shade ranging from 5 to 95 per cent.[22]

**Principles and Theories of Greenhouse Management**

Greenhouse management is crucial for maximizing efficiency and productivity in commercial greenhouse plant production. It encompasses a comprehensive approach, addressing various aspects such as the design and structure of greenhouses, environmental control systems, heating and cooling mechanisms, selection and maintenance of growing media, effective fertilization strategies, optimal carbon dioxide supplementation, precise irrigation techniques, and diligent pest management.

Moreover, it also includes the production of container-grown crops, ensuring that all components work in harmony to create ideal growing conditions. This holistic approach not only enhances plant growth but also promotes sustainable agricultural practices, making it an essential element in the success of commercial greenhouse operations.[23]

**Application Automated Greenhouse Management**

The application of automation in greenhouse management has developed the agricultural industry by combining modern technology with traditional farming. This

ensures optimal growth conditions for plants, reduces labor costs, minimizes errors, and guarantees consistent production. With the challenges posed by environmental changes and global warming, these smart and automated systems offer sustainable solutions for future agriculture.[24]

**Figure 2.4** Automated Greenhouse System by the University of Arizona

At different growth stages, plants need varying light types and intensities. Utilizing plant-specific light modulators guarantees that they receive the appropriate light when needed.[24]

**Figure 2.5** Retractable Shade Net

Figure 2.5 shows the retractable shade net that protract and retract with the use of pulley and rope. The Filipino farmers call it “automatic” because the manual work for them is when the workers will pull the end of the shade net to the other side to stretch it.[25]

The irrigation approach varies based on the plant type and farming conditions. Although drip and flood irrigation are common, modern farming practices are increasingly favoring tidal irrigation. Essential tools for effective irrigation management include water flow sensors, flow meters, electromagnetic valve controllers, water temperature sensors, and liquid level sensors. By utilizing these devices, one can more accurately regulate and supervise the irrigation process to ensure plants receive adequate water.[24]

**Figure 2. 6** Commercial Greenhouse Irrigation

**Principles and Theories of Hydroponics**

The word hydroponics comes from Latin, where "hydro" means water, and "ponos" means work. In hydroponics, plants grow in water instead of soil. When plants grow, they use light and chlorophyll to turn carbon dioxide and water into sugar and

oxygen through a process called photosynthesis. The interesting thing is that you don't see the word "soil" in there. That's because plants can grow without it. What they really need is water and nutrients, usually found in the soil. But if they can get those things somewhere else, like standing in a solution full of nutrients, they can do without soil altogether. This fundamental idea forms the basis of hydroponics. While the literal interpretation of "hydroponics" implies growing plants in water (derived from Greek words meaning "water" and "toil"), the commonly accepted definition involves cultivating plants without the use of soil.[26]

**Hydroponics System**

Growing plants hydroponically involves utilizing a water-based nutrition solution in place of soil, together with an aggregate substrate or growing media like perlite, vermiculite, or coconut coir. Commercial enterprises, hobbyists, and small farmers all use hydroponic production systems.

**Types of Hydroponics System**

5. **Nutrient Film Technique (NFT)**

The NFT (nutrient film technique) is a widely used hydroponic method where plants' roots are suspended in the air above a growing medium like gravel or perlite. A nutrient solution is pumped through this medium, flowing over the roots, before returning to the reservoir. Coined by Allen Cooper in 1965, the technique involves a shallow stream of water, hence the name "nutrient film technique." It's favored by commercial growers due to its simplicity in maintenance and fewer potential complications.[27]

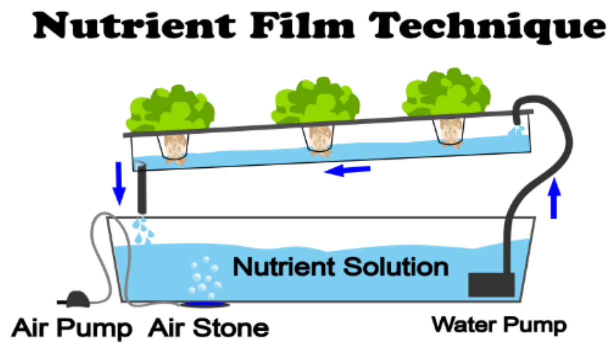


**Figure 2.7** Nutrient Film Technique

The fertilizer solution flows into channels that may support a variety of plant sizes in NFT hydroponics systems. Because the tubes are somewhat inclined, the nutritional solution runs through them, over the dangling roots of the plants, and then back into the hydroponic reservoir.[27]

6. **Deep Water Culture (DWC)**

Deep water culture (DWC) systems involve continuously immersing plant roots in a nutrient solution within a single basin, with an air stone at the bottom to aerate and oxygenate the water. Because it is simpler and easier to set up than more complex systems like aquaponics or aeroponics, this method is popular among new hydroponic gardeners. DWC is considered a passive system because it does not continuously recirculate water and nutrients. An air stone is required to improve oxygen circulation, which contributes to the system's success in maintaining suitable conditions for plant growth.[28]

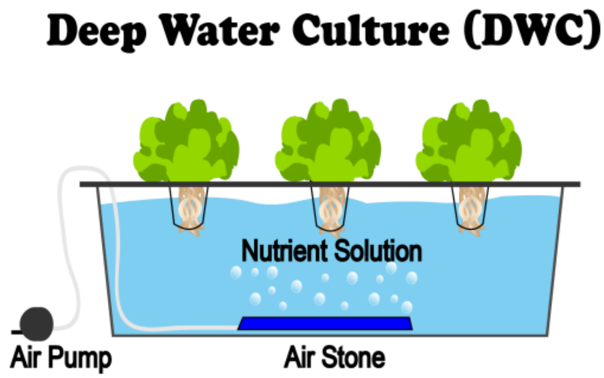


**Figure 2.8** Deep Water Culture

The roots of the plants in DWC hydroponic systems are suspended in the nutrient solution, and an air stone or diffuser delivers air straight to the roots. To help keep them secure, plants are placed in net pots filled with grow material.[28]

7. **Drip System**

Drip system hydroponics is a popular method in which nutrient solution is dripped onto plant roots and then recirculated back to the reservoir. It is an active hydroponic system that uses a pump to deliver nutrients and water to plants. Because of its drip mechanism, this system provides improved ecosystem control, allowing for precise management of the growing environment.[29]

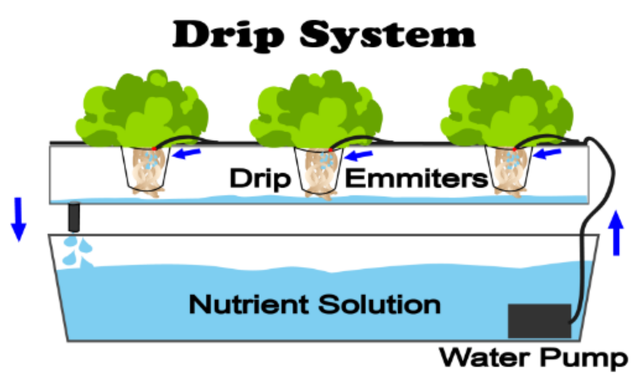


**Figure 2.9** Drip System

Drip hydroponic systems are perfect for people who frequently make adjustments because they are simple to use, set up, and adaptable in many ways. In these systems, the plant's base receives a direct supply of nutrients via tubes.[29]

**8. Aeroponics**

An improved form of hydroponics known as aeroponics involves suspending plants in the air and misting them with water on a regular basis using a timed sprinkler system that is linked to a primary nutrient reservoir. Because aeroponic roots aren't hindered by dense soil or thick growing media, this soilless growing technique is ideal for plants that require more oxygenation. Growing media is usually used sparingly or not at all by the grower, depending on the plant and type of aeroponics system.[30]

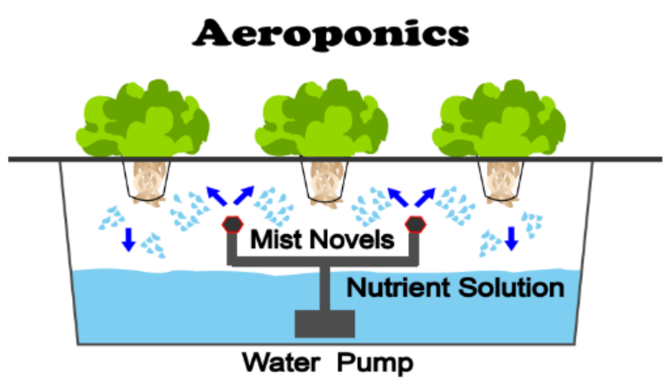


**Figure 2.10** Aeroponics

The piping that has mist nozzles installed is pumped with the nutrient solution. The solution returns to the reservoir as the pressure increases and the misters spray the plant's roots.[30]

**Significance of Light Intensity in Lettuce Cultivation**

Light intensity, or light quantity, refers to the total amount of light plants receive. This intensity drives photosynthesis, producing the carbohydrates that serve as the building blocks for plant growth. Unlike light quality, light intensity does not consider wavelength or color.[31]

Lux is a unit of measurement for illuminance, representing the amount of light that hits a surface. In the context of direct sunlight, understanding lux levels is essential for various applications, including agriculture, solar energy, and architectural design. On a clear day, direct sunlight typically ranges from 32,000 to 100,000 lux. Understanding sunlight lux helps optimize crop growth, ensuring plants receive adequate light for photosynthesis.[32]

**Conversion of Light Intensity to Lux**

Photosynthetic Photon Flux Density (PPFD) is a crucial unit used to measure the light that reaches a plant's canopy in the Photosynthetically Active Radiation (PAR) zone. This metric tells us the number of photosynthetically active photons falling on a given surface each second, expressed in µmol/s.m².[33]

$$Lux = PPFD \; x \; 54 \qquad \textbf{(Eq. 2.1)}$$

Where:

Lux = measurement of illuminance (lx)

PPFD = Photosynthetic Photon Flux Density

There are a few requirements that must be met while cultivating crops, tomatoes, lettuce, or cannabis in a big growing facility, our own backyard, or a grow tent. Enough air, water, and fertilizer are necessary for crops to grow well. Another thing to remember

is that everything grows in response to sunlight, and adequate light increases crop yields. When you have all of the above, your plants will grow healthily right away.

For most plants, the cold season is a difficult test of growth. Crops' metabolism will be significantly inhibited by low temperatures, which will postpone growth. We are all aware that sunshine is essential to plant growth and that sunlight influences plant growth in turn. As a result, plants cannot receive the optimal natural light during the day if they are placed in an interior dark space, and they will not grow normally and healthily. Nowadays, indoor planting is a highly popular option because it allows you to quickly adjust the growth environment to the crop's stage of development. This approach can be just as effective as the process of spontaneous growth if the right steps are done. Additionally, since grow light is a great alternative to sunshine for providing light supplementation to plants, you don't need to worry about the lack of light in the indoor setting.[34]

**Shade Net**

Shade net is a type of lightweight agricultural covering material that is primarily used for air permeability, wind proofing, heat and moisture preservation, and shading. An agricultural shade net may efficiently prevent excessive sunshine and high temperatures, lessen crop water evaporation, increase air humidity, and retain soil moisture all of which are favorable to crop growth. Furthermore, shade nets can operate as a windbreaker, lessening the effect of wind speed on crops while maintaining indoor air circulation, allowing for breathability, encouraging crop growth, and enhancing crop quality and yield.[35]

**Figure 2.11** Shade Net

The shade net regulates the amount of sunlight that enters, preventing overheating while maintaining optimal conditions for plant growth. Greenhouse shade nets work by blocking some sunlight, reducing intensity and minimizing temperature spikes within the enclosed space.[36]

**Pulley**


**Figure 2.12** Pulley

A pulley is a simple machine made up of a string (or rope) looped around a wheel (often with a groove), with one end connected to an object and the other to a human or a motor. Pulleys may appear basic, but they can provide a significant mechanical

advantage, making lifting duties much easier.[37]

**Shaft**

**Figure 2.13** Shaft

Shaft is basically the rotating component of any machine, which is round in the cross-section and is used for passing the power from one part to another or from the power producing machine to the power absorbing machine. A shaft is a rotating machine element, usually circular in cross section, which is used to transmit power from one part to another, or from a machine which produces power to a machine which absorbs power.[38]

**Determining the Allowable Stress of a Shaft**

The maximum allowable stress of a shaft depends on various factors, including material properties, loading conditions, and safety considerations.[39]

$$S_s = 30\%\ of\ S_y \qquad \textbf{(Eq. 2.2)}$$

Where:

$S_s = allowable\ stress\ for\ the\ shaft$ (MPa)

$S_y = yield\ strength\ for\ the\ material\ used\ for\ shaft$ (MPa)

**Determining Shaft Diameter**

Determining the correct diameter of a shaft is crucial for ensuring its strength, minimizing deflection, resisting fatigue, and maintaining safety and efficiency, all while balancing performance with cost and compatibility considerations. Proper sizing prevents mechanical failures, reduces vibration and noise, and ensure pps compliance with industry standards.[39]

$$D = \sqrt{\frac{8F}{\pi S_s}} \qquad \textbf{(Eq. 2.3)}$$

Where:

$D =$ diameter of the shaft (m)

$F =$ tension force from the shade net and the weight of the shaft itself. (N)

**Determining Shaft Torque**

Shaft torque is the amount of rotational force needed to drive a machine or carry out another planned function for a shaft. The force is influenced by factors such as the applied load and the required rotational speed of the shaft.[39]

$$T = \frac{\pi D^3 S_s}{16} \qquad \textbf{(Eq. 2.4)}$$

Where:

$T = torque\ (Nm)$

**Power Requirement**

The power requirement of a shaft involves calculating the power needed to perform a specific function, such as operating a machine or mechanical system. The calculation depends on the torque applied to the shaft and its rotational speed.[39]

$$P = 2\pi TN \qquad \textbf{(Eq. 2.5)}$$

Where:

$P$ = power (W)

$N = rotational\ speed\ (RPM)$

**TSL 2561 Sensor**

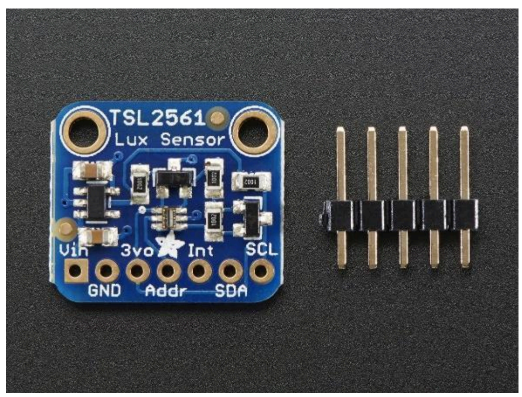


**Figure 2.14** TSL 2561 Sensor

The TSL2561 luminosity sensor is a digital light sensor that may be used in a variety of lighting conditions. Compared to low-cost CdS cells, this sensor is more precise, allowing for correct Lux metering, and it can be set for multiple gain/timing ranges to detect light levels ranging from 0.1 to 40,000+ Lux on its own. The best thing about this sensor is that it includes both infrared and full spectrum diodes! This means that you can measure infrared, full-spectrum, and visible light separately. Most sensors

can only detect one or the other, which does not exactly represent what human eyes see (since most photodiodes detect infrared light).[40]

**Importance of Misting System to maintain humidity and temperature**

The implementation of a misting system into farming practices brings about a significant improvement in managing plant growth. One of its main roles is to carefully regulate humidity, maintaining an optimal moisture level for plants. By releasing fine water droplets, the system strikes a balance, preventing issues caused by both too much and too little moisture. The precise control over humidity is crucial for ensuring the health and vitality of plants.

Misting system acts as a reliable protector against temperature fluctuations and excessive evaporation. When temperatures rise, the controlled mist cools the surroundings, shielding plants from the harmful effects of overheating. At the same time, it acts as a shield, reducing evaporation and preserving the necessary moisture levels. This dual function not only helps control temperature but also safeguards plants from the negative impacts of dehydration. [41]

**Determining Relative Humidity**

The amount of water vapor in the air is known as the "vapor pressure," wherein air can only hold a certain amount of water vapor at a given temperature before it starts condensing back to liquid in the form of rain. [42]

$$Relative\ Humidity\ =\ \frac{AVP}{SVP}\ X\ 100\% \qquad \textbf{(Eq. 2.6)}$$

Where:

$AVP\ =\ actual\ vapor\ pressure$

$SVP\ =\ saturation\ vapor\ pressure$

**Determining Flow Rate**

Flow rate refers to the quantity of fluid passing through a particular point in a system per unit of time. It is a key parameter for understanding and analyzing fluid behavior, as well as for designing and optimizing various systems and processes that involve the movement of fluids, such as pipelines, pumps, and ventilation systems. [43]

$$Q = \frac{V}{t} \quad \textbf{(Eq. 2.7)}$$

Where:

$Q = flowrate\ (\frac{m^3}{s})$

$V = volume\ (m^3)$

$t = time\ (s)$

**Mist Maker**

Misting nozzles are used to cool outdoor spaces in all sorts of industries and for all kinds of purposes, from public venues and commercial establishments to industrial plants and agricultural environments. It is useful because they create drops of water that are around 15 millionths of a meter, or microns, in width. The size of the droplets is crucial because they are small enough that they evaporate quickly, rather than collecting on everything around them.[44]

**Figure 2.15** Misting Nozzles

Misting nozzles consist of a series of nozzles placed in a line. When attached to high-pressure pumps, water is forced through nozzles, forming droplets which evaporate into mist when they reach the outdoor air. This can reduce the temperatures by 35 to 40 degrees Fahrenheit. If the misting system is in a confined indoor area, it will provide a cool mist but will also increase humidity.[44]

**Humidity and Temperature Sensor**

A sensor is typically defined as an input device that generates an output signal in response to a physical quantity detected. The term "input device" in this case implies that the sensor is part of a larger system, giving data to a central control unit such as a processor or microcontroller. A sensor can also be defined as a device that converts signals from various forms of energy into electrical signals.[45]

Humidity sensors, also called hygrometer, are devices that detect and measure the amount of water vapor or moisture that is contained in the air, which can not only influence the level of comfort that is experienced by people and animals but also plays an important role in the production of products and other manufacturing processes. Being able to sense and measure the level of humidity is necessary in order to exercise control over it, such as by turning on the air conditioner in the summertime or a humidifier in the winter.[46]

Temperature sensor is an instrument that is constructed to sense the condition of coolness or hotness in the target. The fundamental working of this sensor is based on the voltage in its diode. The temperature variation is directly related to the resistance of this diode. The resistance of the diode is detected and transformed into simple and readable values of temperature such as Fahrenheit, Kelvin, or Centigrade and demonstrated in

meaningful formats instead of readout values. These temperature sensors are employed to sense the internal temperature of various structures like power plants.[47]

The DHT11 sensor is a widely employed temperature and humidity sensor, known for its reliability and ease of use in various applications. This sensor is equipped with a dedicated Negative Temperature Coefficient (NTC) element to accurately measure temperature and an 8-bit microcontroller responsible for transmitting temperature and humidity data as serial data. Additionally, the DHT11 sensor is pre-calibrated at the factory, simplifying its integration with other microcontrollers.

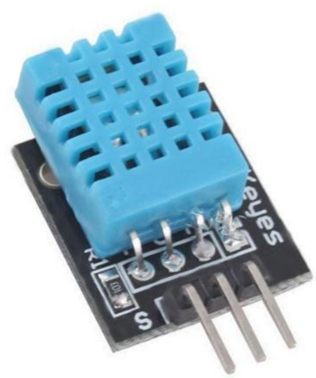


**Figure 2.16** DHT11-Temperature and Humidity Sensor

This versatile sensor is capable of measuring temperature within the range of 0°C to 50°C and humidity levels ranging from 20% to 90%. It boasts an impressive level of accuracy, with temperature readings accurate to within ±1°C and humidity readings accurate to within ±1%. If your research requires measurements within this temperature and humidity range, the DHT11 sensor stands as a suitable and dependable choice for your application.[48]

### Water Flow Rate & Volume Measurement

**Figure 2.17** Water Flow Rate & Volume Measurement

A water flow sensor is made of a plastic valve through which water can pass. A water rotor and a hall effect sensor are present to sense water flow rate and monitor water volume. Water passes through the valve, causing the rotor to rotate. This allows the change in the motor's speed to be seen. The hall effect sensor calculates the change and outputs it as a pulse signal. Thus, the rate of flow of water may be determined.[49]

### Solenoid Valve

**Figure 2.18** Solenoid Valves

Solenoid valves are control units which, when electrically energized or de-energized, either shut off or allow fluid flow. The actuator takes the form of an electromagnet. When energized, a magnetic field builds up which pulls a plunger or

pivoted armature against the action of a spring. When de-energized, the plunger or pivoted armature is returned to its original position by the spring action.[50]

**Solar Water Pump**

A solar water pump operates by harnessing energy from the sun, which is converted into electricity by solar panels. These panels consist of photovoltaic cells that capture sunlight and transform it into direct current (DC) electricity.

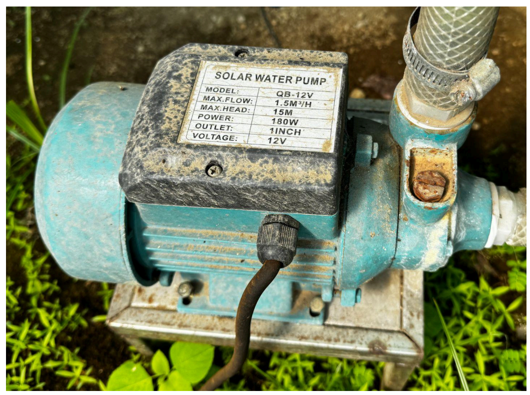


**Figure 2.19** Solar Water Pump

Solar water pump is used in a hydroponic system to circulate the nutrient and water to plants grown without soil. Solar panels convert sunlight into electricity, which then powers a surface pump to distribute the nutrient solution through the hydroponic setup.[51]

**Nutrient Solution**

The nutrient solution is composed of key elements such as nitrogen, phosphorus, potassium, calcium, magnesium, and trace elements like iron, manganese, and zinc, all provided in precise concentrations to promote optimal plant growth. For example, the concentration of nitrogen might vary, presented in forms that plants can easily absorb,

such as nitrate and ammonium. The water quality used in preparing the nutrient solution is critical; it must be free from contaminants, and its pH and electrical conductivity (EC) must be maintained within specific ranges to ensure nutrient availability and uptake.

Moreover, the nutrient solution in hydroponics can be recycled in a closed system, reducing water and nutrient waste and minimizing environmental impact. The system continuously supplies nutrients to the plant roots, recirculates the runoff, and adjusts the composition based on the uptake and transpiration rates observed in the plants, which can be monitored through changes in EC levels. This recycling process not only conserves resources but also controls the growth conditions more precisely, enhancing overall plant health and yield.[52]

**Nutrient Flow Control**

Maintaining proper nutrition is one of the most important parts of growing greenhouse crops. There are two components of crop nutrition that growers must address. One component of nutrition is the total amount of nutrients accessible to the plant. The absolute amount of nutrients required by a plant increases as its size and fruit load rise. A key principle to understand about fertilization is that plant development is regulated by the mineral nutrient in the shortest supply, even when other nutrients are abundant. The second part of nutrition is the appropriate ratio or balance of nutrients accessible to the plant. Maintaining the right balance between vegetative growth and fruit load is critical to the crop's long-term output. When nutrients are not balanced, serious shortages or toxicities can emerge.

To control nutrition, growers must have a quick and dependable technique of monitoring the nutrient status of the cropping medium. A conductivity meter and a pH

meter are necessary tools. The pH of the medium influences the availability of individual nutrients. As a result, as the pH changes, so does the crop's nutrient balance. Understanding the nutrients needed to grow plants is simply one part of successful crop production. Optimum yield also necessitates understanding the rate to apply, the technique and timing of application, the source of nutrients to employ, and how the components are affected by substrate and greenhouse environmental conditions. [53]

**Hydroponic Solution**


**Figure 2.20** Solution A and B

Hydro A and Hydro B. This system divides essential nutrients into two separate solutions, allowing for optimized nutrient uptake and reduced interaction conflicts. Hydro A is enriched with calcium, crucial for enhancing plant structural strength and heat tolerance, while Hydro B provides magnesium, essential for chlorophyll production and energy transfer within the plant. This method facilitates precise control over the nutrient environment, crucial for maximizing plant health and productivity.[54]

**pH Down**

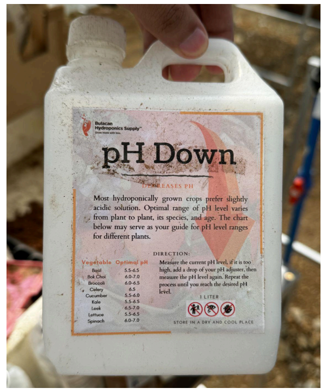


**Figure 2.21** pH Down Solution

pH Down is a phosphorus-based pH control additive that effectively reduces water pH levels, which is essential for hydroponics, aeroponics, sprinklers, and irrigation systems. Maintaining the proper pH is essential for efficient nutrient absorption, resulting in healthier and more vigorous plant development.[55]

**Importance of pH Level in Hydroponics**

The pH value in hydroponics refers to the acidity or alkalinity of the nutrient solution, with readings ranging from 0 to 14 (0-6 being acidic, 7 neutral, and 8-14 alkaline). For general hydroponic solutions, the recommended pH level falls between 6 and 6.5 (Nicholls, 63). Various factors can influence pH levels, including temperature, light intensity, evaporation, the quality of tap water, and the quantity of nutrients.

Given the numerous variables affecting pH, regular monitoring is important to maintain an optimal environment for plant growth. Adjusting the pH level can be achieved simply: to reduce acidity, add one tablespoon of baking soda to three gallons of solution, while to decrease alkalinity, add one tablespoon of white vinegar per four

gallons of solution. These adjustments help ensure a balanced pH level, which is vital for healthy plant development in hydroponic systems.[56]

**Water pH Level Sensor**

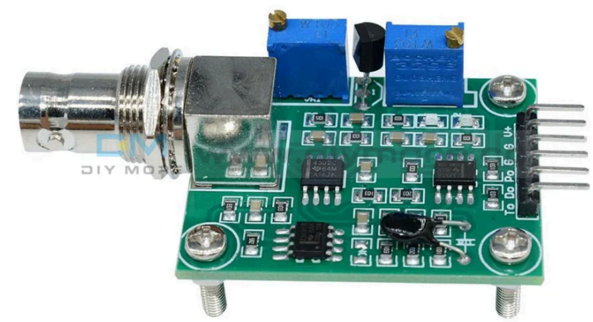

**Figure 2.22** PH4502C module

The PH4502C module features a working voltage of 5±0.2V (AC/DC) and a working current of 5-10mA, with a detection concentration range of pH 0-14 and a temperature detection range of 0-60 degrees Celsius. It has a quick response time of ≤ 5 seconds and stability time of ≤ 60 seconds, consuming ≤ 0.5W of power. Designed to operate in temperatures ranging from -10 to 50 degrees Celsius (with a nominal temperature of 20 degrees Celsius) and 95% relative humidity (with a nominal humidity of 65% RH), this sensor has a service life of 3 years. Its compact size measures 42mm x 32mm x 20mm, weighing 25g, and it provides an analog voltage signal output.[57]

**Figure 2.23** Analytical Surver Electrode pH Probe

The Analytical Surver Electrode pH Probe with a BNC (Bayonet Neill-Concelman) Plug Connector is designed for use with aquarium pH meters, controllers, and sensors. This pH electrode features a single cylinder for direct connection to BNC input terminals, ensuring accurate and reliable pH readings. With a pH range of 0-14, temperature range of 0-60°C, and zero-point of 7 ± 0.5 pH, this electrode minimizes alkali errors to 0.2 pH. Theoretical percentage slope exceeds 98.5%, ensuring precise measurements. With an internal resistance of less than or equal to 250MΩ and a response time of less than or equal to 1 minute, this electrode operates effectively in temperatures ranging from 0-60°C. The BNC plug connector is compatible with most pH meters and controllers, making it suitable for a wide range of applications, including aquariums, hydroponics, and laboratory settings.[58]

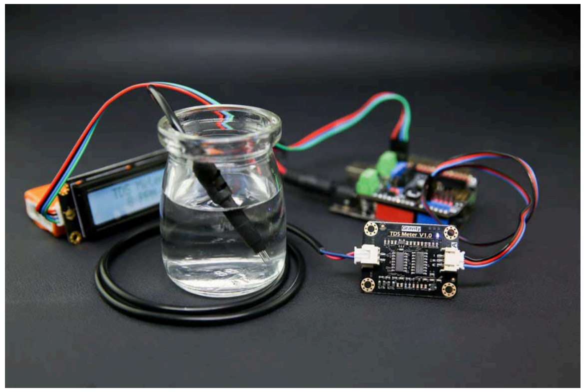

**Figure 2.24** DFRobot Gravity: Analog TDS Sensor/Meter

The DFRobot Gravity: Analog TDS Sensor/Meter for Arduino is a device that allows you to measure the total dissolved solids (TDS) in water using an Arduino microcontroller. This sensor can be used to monitor the water quality by detecting the TDS level, which is an important parameter for applications such as water filtration, aquaculture, and hydroponics. The sensor can be easily interfaced with an Arduino board and the TDS value can be displayed on a 16x2 LCD screen. The sensor comes with a calibration mode that allows you to calibrate it using a known TDS solution, ensuring accurate measurements. Overall, this TDS sensor provides a simple and cost-effective way to monitor water quality using an Arduino-based system. [59]

**ARDUINO BOARD**

Arduino serves as an accessible platform for electronics and programming enthusiasts. It features an open-source board used to create various electronics projects. The Arduino board, comprising an integrated development environment (IDE) and a microcontroller, enables users to write and upload code to the board via a simple USB cable, requiring no additional hardware. Its user-friendly interface, employing a simplified version of C++, makes it popular among beginners in electronics. The board's

conventional design encapsulates the microcontroller's functionalities in an easily manageable package, further enhancing its usability.[60]

**Types of Arduino board**

**Arduino Uno**

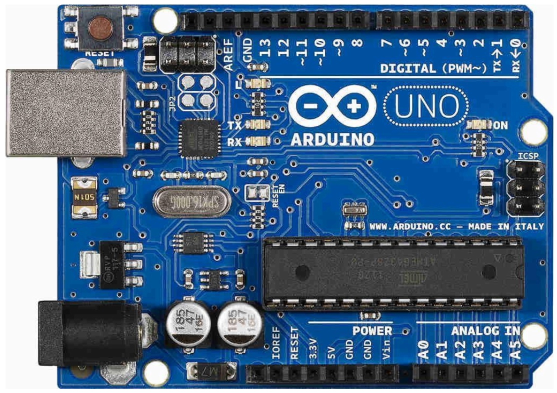


**Figure 2.25** Arduino Uno

Arduino Uno is a popular microcontroller development board based on the 8-bit ATmega328P microcontroller. Along with ATmega328P MCU IC, it consists other components such as crystal oscillator, serial communication, voltage regulator, etc. to support the microcontroller.[60]

**Arduino Due**


**Figure 2.26** Arduino Due

The Arduino Due is a microcontroller board that relies on the ARM Cortex-M3 architecture, marking the inaugural Arduino board of its kind. This board boasts an array of features, including 54 digital I/O pins, with 12 of them serving as PWM output pins, along with 12 analog pins, 4 UARTs, a clock speed of 84 MHz, USB OTG connectivity, 2 DACs, a power jack, 2 TWI (Two-Wire Interface) ports, a JTAG header, an SPI header, and two buttons for reset and erase functions.

Operable at 3.3V, the Arduino Due's input/output pins can tolerate a maximum voltage of 3.3V. Exceeding this voltage threshold can potentially damage the board. The board can be conveniently connected to a computer using a standard USB cable or powered through an AC to DC adapter. Moreover, the Arduino Due is compatible with all Arduino shields designed for 3.3V operation, further enhancing its versatility for various project applications.[60]

**Arduino Mega**

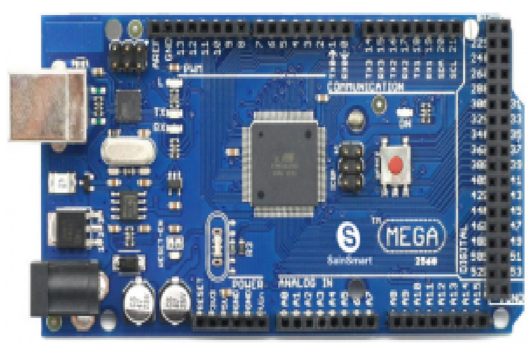


**Figure 2.27** Arduino Mega

The Arduino Mega (R3) Board can be likened to the bigger sibling of the UNO. It boasts numerous digital I/O pins, with 14 of them capable of functioning as PWM outputs. Additionally, it offers 6 analog input pins, a reset button, a power jack, and a

USB connection. This board provides all the essential components for supporting the microcontroller. Simply connect it to a computer via a USB cable and provide power through an AC-to-DC adapter or battery to kickstart your projects. The abundance of pins on the Arduino Mega board makes it exceptionally valuable for projects that require a multitude of digital inputs or outputs, such as applications involving numerous buttons.[60]

**Arduino Leonardo**

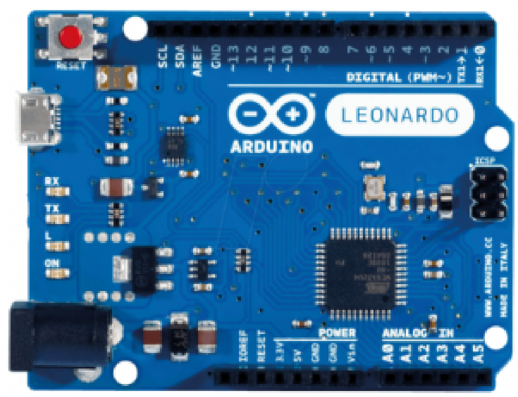


**Figure 2.28** Arduino Leonardo

The Arduino Leonardo board represents the initial iteration of Arduino development boards. It leverages a single microcontroller in conjunction with USB functionality, making it an economical and straightforward option. Due to its direct USB handling capabilities, various program libraries are accessible, enabling the Arduino board to emulate computer peripherals like keyboards and mice, thus enhancing its versatility.[60]

**Choosing the Right Arduino Board**

There is a wide variety of Arduino boards available in today's market, including options like Free Duino and NetDuino. The ideal approach for selecting the most suitable

Arduino board is to carefully examine and differentiate the brand names on the original boards. Finding affordable Arduino boards is easily achievable through online retailers and electronic stores. These boards come in various versions and specifications.

All these boards can be programmed using the Arduino IDE software, which enables anyone to write and upload code. However, each board differs in terms of inputs, outputs, speed, physical dimensions, voltage requirements, and more. The operational voltage for these boards typically ranges from 3.7V to 5V.[60]

**Raspberry Pi**

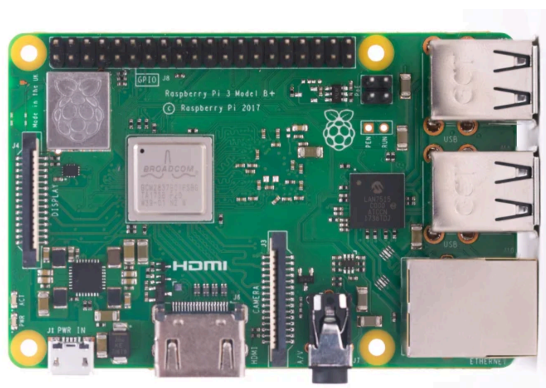


**Figure 2.29** Raspberry Pi

The Raspberry Pi is a single-board computer developed by the Raspberry Pi Foundation. Launched in 2012, the Raspberry Pi has seen several iterations with increasing processing power and memory, while maintaining an affordable price. These compact computers run Linux and provide GPIO (general-purpose input/output) pins, allowing users to control electronic components, explore the Internet of Things, and engage in physical computing projects. The Raspberry Pi is widely used for learning

programming, building hardware projects, home automation, and even industrial applications.[61]

**Power Supply**

**Figure 2.30** Power Supply

A power supply is a hardware component that supplies power to an electrical device. It receives power from an electrical outlet and converts the current from AC (alternating current) to DC (direct current), which is what the computer requires. It also regulates the voltage to an adequate amount, which allows the computer to run smoothly without overheating. The power supply an integral part of any computer and must function correctly for the rest of the components to work.[62]

### Circuit Breaker

**Figure 2.31** Circuit Breaker

Circuit breaker is a type of switching mechanism used to regulate and protect an electrical power supply. It can be controlled manually or automatically. A fixed contact and a moving contact are its two primary contacts. Normally, the connections are closed, allowing current to pass through the system. A mechanism that releases accumulated potential energy separates the contacts in the event of a failure, such as an overload or short circuit. Circuit breakers protect electrical circuits from damage caused by overcurrent, short circuits, or overload. They interrupt the flow of current when a fault occurs and restore it when the fault is cleared.[63]

### ESP32

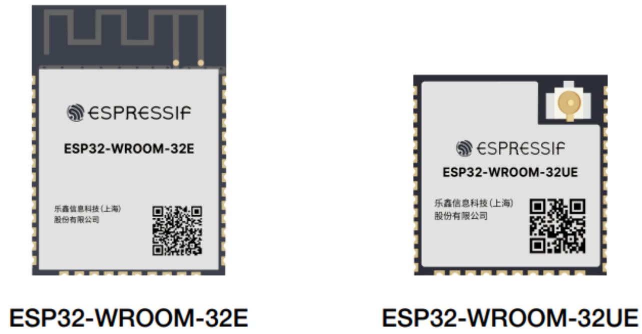


**Figure 2.32** ESP32

An ESP32 device in Arduino refers to a development board that uses the ESP32 chip, which is a powerful microcontroller with built-in Wi-Fi and Bluetooth capabilities. The ESP32 is often used in IoT (Internet of Things) projects due to its ability to connect to the internet and communicate wirelessly. When used with the Arduino IDE (Integrated Development Environment), the ESP32 can be programmed to perform various tasks, such as reading sensor data, controlling actuators, and sending/receiving data over the internet.[64]

### Relay Module

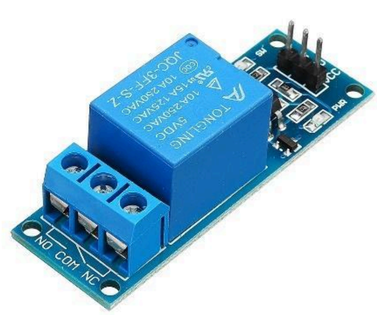


**Figure 2.31** Relay

Relay is an electromechanical device that uses an electric current to open or close the contacts of a switch. The single-channel relay module is much more than just a plain relay, it is composed of components that make switching and connection easier and act as indicators to show if the module is powered and if the relay is active or not.[65]

**Jumping Wire**

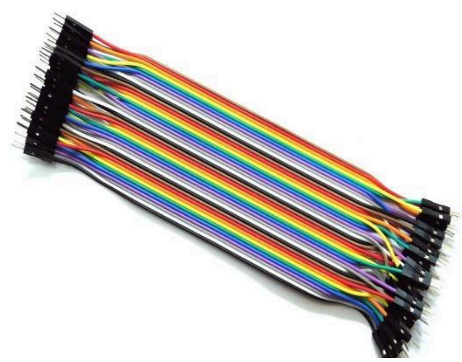

**Figure 2.34** Jumping Wire

Generally, jumpers are tiny metal connectors used to close or open a circuit part. They have two or more connection points, which regulate an electrical circuit board. Their function is to configure the settings for computer peripherals, like the motherboard. Suppose your motherboard supported intrusion detection. A jumper can be set to enable or disable it. Jumping wires are electrical wires with connector pins at each end. They are used to connect two points in a circuit without soldering.[66]

**Relay Board**

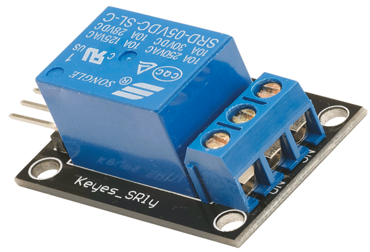


**Figure 2.35** Relay Board

A Relay is a simple electromechanical switch. While we use normal switches to close or open a circuit manually, a relay is also a switch that connects or disconnects two circuits. But instead of a manual operation, a relay uses an electrical signal to control an electromagnet, which in turn connects or disconnects another circuit.[67]

**Contactor**


**Figure: 2.36** Contactor

A contactor is an electrical device which is used for switching an electrical circuit on or off. It is considered to be a special type of relay. However, the basic difference between the relay and contactor is that the contactor is used in applications with higher current carrying capacity, whereas the relay is used for lower current applications. Contactors can be field mounted easily and are compact in size. Generally, these electrical devices feature multiple contacts. These contacts are in most cases normally open and provide operating power to the load when the contactor coil is energized. Contactors are most commonly used for controlling electric motors. [68]

**Stepper Motor**

**Figure 2.37** Stepper Motor

A stepper motor is an electric motor whose main feature is that its shaft rotates by performing steps, that is, by moving by a fixed amount of degrees. This feature is obtained thanks to the internal structure of the motor, and allows to know the exact angular position of the shaft by simply counting how many steps have been performed, with no need for a sensor. This feature also makes it fit for a wide range of applications.[69]

## 2.2 RELATED LITERATURE

The proponents to several studies related to the design of the present project. Different theories and principles related to the design of the greenhouse, ventilation, and hydroponic. In order to provide justification for the feasibility of the studies, the following research and studies related to the project design are presented and reviewed.

**FOREIGN STUDIES**

The study of Miao, C. et al. (2023) was conducted to comprehensively understand the impact of light intensity on the growth and quality of different crops and to develop precise lighting schemes for specific cultivars. Lettuce and Spinach were used in this experiment, using a light-emitting diode (LED) under intensities of 300, 240, 180, and 120 $\mu mol\ m^{-2}\ s^{-1}$ to gather information on growth and quality of the plants. The light intensity received by the plant changes as the plant grows taller; therefore, the computer-based LED plant supplementary lighting control system was adjusted to match the desired experimental light intensity after the measurement of growth parameters.

Crunchy (exhibiting the non-heading trait) developed tipburn when exposed to the light intensity of 300 $\mu mol\ m^{-2}\ s^{-1}$, whereas tipburn and leaf shrinkage were observed in Deangelia (semi-heading lettuce cultivar) under both 240 µmol m−2 s−SS1 and 300 $\mu mol\ m^{-2}\ s^{-1}$. The spinach cultivar, Shawen, exhibited leaf curling under all LED light intensities, impeding normal growth. These results indicated that although higher light intensity is beneficial for increasing yield and quality, the light intensity should be regulated as per the specific variety. Light intensity is an important factor and should be

optimized for specific crop species and cultivars to achieve healthy growth in plant factories.[70]

In the study of J. Zhou (2022), the interaction between light and temperature is crucial for the growth and development of lettuce. The optimal light range for photosynthesis and yield varies with temperature. At low temperatures (15 °C), a light intensity of 350–500 $\mu mol \cdot m^{2} \cdot s^{-1}$ is recommended. For medium temperatures (23 °C), a light intensity of 350–600 $\mu mol \cdot m^{2} \cdot s^{-1}$ is suggested. At high temperatures (30 °C), a light intensity of 500–600 $\mu mol \cdot m^{2} \cdot s^{-1}$ is advisable. Additionally, light intensity should be reduced during the late growth stage for lettuce grown at medium and high temperatures. This study suggests that a balanced combination of light intensity and temperature can optimize lettuce photosynthesis and yield in greenhouses and plant factories.[9]

Based on the study of the Government of Newfoundland and Labrador (2020) that a lettuce plant is truly a crop that grows in a cold environment. The climate limitations for lettuce are focused on ensuring a suitable water supply throughout its growth stages and preventing exposure to temperatures exceeding 30°C. It is strongly recommended to maintain an environmental temperature below 30°C to prevent the occurrence of flowering or bolting, which imparts a bitter taste to the lettuce plant.[71]

The study of Sanders, C. (2018) stated that the cultivation of lettuce in greenhouses is negatively impacted by high temperatures, especially in hot climates. Therefore, developing an efficient method to regulate the internal temperature of greenhouses is crucial to maintaining crop productivity throughout the year. The optimal air temperature for lettuce plants, classified as cool-season vegetables, in a plant factory

or temperate zone is between 22 and 26 °C. However, it has been suggested that the ideal temperature for growing lettuce in tropical environments is between 22 and 30 °C, or even 33 °C for other leafy vegetables like mustard greens.[72]

Furthermore, it's crucial to note that the optimal temperature range for lettuce cultivation falls between 60 and 65°F according to the study of Kumsong, N. et al. in 2023, as this leafy green is inherently adapted to thrive in cool growing conditions. Despite its preference for cooler climates, lettuce exhibits a degree of resilience, demonstrating the ability to endure occasional temperature spikes of 80 to 85°F for short durations, provided that the nights maintain a refreshing coolness. This resilience underscores the adaptable nature of lettuce, allowing it to withstand temporary deviations from its ideal growing conditions while maintaining its overall health and vitality.[73]

The study of B. Frestya et al. 2021 entitled “The effect of hydroponics systems on the growth of lettuce”, used different kinds of experimental methods consisting of 5 treatments. A = Hydroponic Installation of the Nutrient Film Technique (NFT), B = Hydroponic Installation of Deep Film Technique (DFT), C = Hydroponic Installation of EBB and FLOW or Tidal Systems, D = Installation of Aeroponic Hydroponic Systems, and E = Installation of Floating Assembling Hydroponic System. They used these methods to measure the effectiveness of each system in increasing the growth of plant height, and leaf number. Different hydroponic systems affect the growth of lettuce, namely plant height and number of leaves. The NFT hydroponic system is 6% -10% more efficient in increasing the yield of lettuce. The NFT and RFS systems are recommended for use in hydroponic lettuce production.[74]

The study of G. M. Barbade, et al. (2021), entitled “Automatic Water Tank Filling System with Water Level Indicator” primary goal is to conserve water by using an automatic water level controller and indicator. The water level controller works by using the fact that water can conduct electricity due to minerals in it. This allows it to control circuits, turning them on or off as the water level changes. The carbon sensor also plays a role, sensing water without direct contact to trigger the LED light and turn off the pump once the tank is full. There have been several approaches to constructing an automatic water level control with a switching device, but all of them require human intervention. This project uses electrical control to build an automatic water level control system with a switching device for both overhead and underground tanks to replace the water without human intervention. When the water tank falls below a certain level, the system turns off the electric pump and shuts down the water pump. When the tank is full, the system turns off the electric pump and shuts down the water pump.[75]

The study of Demi, et. al, 2019, proposed a system that utilizes sensors to measure pH and TDS levels in the nutrient film technique (NFT) to maintain the quality of hydroponic plants. This system monitors the nutrient solution's pH (acidity or basicity) and total dissolved solids (TDS) using pH and TDS sensors. A control system is employed to manage nutrition controllers such as pH down, pH up, and AB nutrition by turning them on or off. Depending on the specific conditions, various pumps (for pH up/down, TDS up/down, and nutrition A/B) and a chiller are activated or deactivated to maintain optimal conditions. This approach aims to ensure plants grow in the best possible environment, resulting in healthier and more robust crops..[76]

The study of Danita, et.al, 2018, used Internet of Things (IoT) for monitoring the temperature and humidity to ensure the good yield of plants. The sensors used here are YL69 moisture sensor and DHT11 (Temperature & Humidity sensor). From the data received, Raspberry PI3 automatically controls Moisture, Temperature, Humidity efficiently inside the greenhouse by actuating an irrigating pipe, cooling fan, and sliding windows respectively according to the required conditions of the crops to achieve maximum growth and yield. The recorded temperature and humidity are stored in a cloud database (Thing Speak), and the results are displayed in a webpage, from where the user can view them directly.[77]

The study of Ardiansah et al, 2020. conducted research in the field of agriculture. They used IoT for crop management as a media for monitoring and controlling, especially in greenhouses and is called Precision Farming. In the Internet of Things, the data that has been acquired by the hardware will then be transmitted wirelessly. The wireless connections used are Bluetooth, ZigBee Protocol, and Wi-Fi, where Bluetooth and Zigbee connections have a short distance between 10 - 100 meters, while Wi-Fi has a longer distance especially when connected to the Internet.[78]

**LOCAL STUDIES**

The article of Semilla et al. (2018) entitled “Indoor production of loose-leaf lettuce (Lactuca sativa L.) using artificial lights and cooling system in tropical lowland” used controlled environment agriculture (CEA) for farming set-up in the Philippines. It is a controlled environment developed using locally available materials, light emitting diodes (LED) as sole-source of light and cooling system for temperature manipulation.

This study was conducted to determine the optimal temperature and light intensity requirements for growing loose-leaf lettuce in lowland tropics.[79]

In addition, the study constructed three chambers with an area of 2.5m 2.5m x 6.0m and ceiling height of 2.5m. Each chamber was equipped with two 1hp window-type air-conditioning units (AC) operated alternately for 12 hours, two 70-watt circulating fans, and two sprinkler foggers. They employed ECOLUM LED T8 tube lights with a daylight color temperature of 6500K were used to produce PPF. Light intensities of 50, 100 and 150 μmol m-2 s-1 were tested under temperature settings of 25 °C and 18 °C. Carbon dioxide and relative humidity were maintained at recommended levels. No significant difference in productivity was observed under 25 °C and 18 °C. Also, no significant difference in productivity was observed between plants in two temperature settings and plants outside.[79]

The study of D. Jose (2020) stated that lettuce plant lettuce plants demonstrate a remarkable ability to adapt in areas with relative humidity that ranges from 65% to 85%. The study suggests lettuce varieties can be carefully selected based on their tolerance to specific environmental conditions.[80]

The study of Albius, J et. al, 2018. "Solar-Powered Multi-Network Greenhouse: Automated Mushroom Monitoring and Management System Using Microcontrollers and IoT-Based Applications". utilized microcontrollers and Internet of Things applications to power the Solar Powered Multi-Network Greenhouse and create an automated system for managing and monitoring mushrooms. Due to the fact that mushrooms are more susceptible to temperature changes, particularly in tropical nations like the Philippines, this study creates an automated system whose composition is managed by a greenhouse

monitoring device utilizes an Arduino IDE microcontroller several extremely powerful sensors that provide precise metrics for monitoring systems and improved agricultural control management. There was discussion of the many approaches that could be used to regulate variables and preserve stability values appropriate for mushroom farming. To guarantee the device's accuracy and operation, a number of experiments and testing were conducted on the prototype. Similarly, performance tests were carried out to regulate and track the requirements of the mushroom with regard to temperature, relative humidity, and light. The equipment is accurate, functional, and capable, according to the results. According to the study, installing a CCTV system to continuously monitor the greenhouse's exterior and interior would improve it. In addition to being in a more isolated location, the greenhouse might also enhance some application functions.[81]

The study of Mastul, A et, al, 2023, “The Use of IoT on Smart Agriculture in the Philippines”. The study examines the advantages of using Internet of Things (IoT) technologies with modern agriculture, with a particular focus on the Philippines to evaluate the effects of IoT on precision steering, automated irrigation, field mapping, weather monitoring, livestock tracking, greenhouse automation, and crop monitoring. They used IoT-based livestock tracking to guarantee the welfare of the animals and effective breeding methods. Making educated decisions for crop protection and risk management is made easier with the help of IoT-based weather monitoring. IoT-enabled automated irrigation lowers water waste while enhancing crop health. During planting and harvesting, resource management is improved by precision steering systems. Automation in greenhouses minimizes manual labor while optimizing growing conditions for plants. IoT-based field mapping enables site-specific management, increasing

sustainability and yield. Comprehensive plans for IoT integration in Philippine agriculture are necessary regardless of the benefits because problems like internet connectivity and early investment are still present.[82]

The study of J. Anthony (2018) entitled “Auto GMS: An Automated Greenhouse Monitoring System of Abiotic Factors for Leafy Vegetables Production” conducted at Oriental Mindoro, shows that they were able to automate greenhouse processes by using multiple highly sensitive sensors to monitor the current working condition of their greenhouse. Additionally, they added SMS functionality to their system to provide real time updates to the end user about their system. These integrations were powered by the wifi module installed and the LCD screen display to provide information to the user. Internet of things (Iot) was greatly showcased as the integration of a user's GSM phone to the system for monitoring. Arduino uno were used to monitor and automate processes together with solenoid valves controlled by the relays to switch on or off for water intake to the irrigation system.[83]

The study of R. Amy (2020) entitled “Automated pH Monitoring and Controlling System for Hydroponics under Greenhouse Condition” conducted at Tarlac, Philippines, demonstrate a system for automatic monitoring and controlling was created in order to regulate the pH level of the water in the system by adding acid and base solution. A minimum pH of 6.0 and a maximum pH of 6.54 were observed. The pH level of the nutrient solution was maintained at a range of 6.0-6.8 level which is the recommended range for hydroponic lettuce production. It was determined that the automated pH monitoring and controlling system was effective after a performance evaluation and

validation finished. By lowering labor costs and enabling real-time pH monitoring, this device helps farmers produce more crops and make more revenue.[84]

## 2.3 SYNTHESIS

The comprehensive review of the literature presented in Chapter 2 underscores the transformative potential of automation and advanced technologies in the field of agriculture, with a particular focus on greenhouse management systems. This synthesis brings together key findings from the studies reviewed, demonstrating both the current state and future possibilities of technology-enhanced agriculture.

The development of automated control systems in greenhouse management is supported by many studies that look at how automation, hydroponics, and IoT technologies can work together to improve farming efficiency. A key part of this research is the use of automation in agriculture, which cuts down on the need for manual labor while boosting productivity.

### Foreign Studies

The experiment of C. Miao et al, aimed to study how light intensity affects the growth and quality of lettuce and spinach in a plant factory. They used LED lights at different intensities and controlled the light using a computer-based system. Results showed that high light intensity can be good for yield and quality, but it needs to be managed carefully. They used crunchy lettuce and it had tipburn at 300 μmol $m^{-2}$ $s^{-1}$, while Deangelia lettuce had tipburn and leaf shrinkage at 240 and 300 μmol $m^{-2}$ $s^{-1}$. Shawen spinach had leaf curling at all intensities, which affected its growth. This study

highlights the importance of optimizing light intensity for different crops and varieties. By doing so, planting facility can ensure healthy growth and better-quality produce.

The study of J. Zhou et al, highlights the critical role of temperature over light intensity in influencing lettuce photosynthesis and growth. Optimal lettuce cultivation requires prioritizing temperature management, with specific light intensity recommendations tailored to varying temperatures. At lower temperatures (15 °C), a light intensity of 350–500 μmol·m−2·s−1 is beneficial, while medium temperatures (23 °C) require 350–600 μmol·m−2·s−1, and higher temperatures (30 °C) are best supported by 500–600 μmol·m−2·s−1. Additionally, reducing light intensity during the late growth stage for medium and high-temperature conditions is advantageous. The study emphasizes that a strategic balance of light and temperature can enhance lettuce photosynthesis and yield in controlled environments.

The study by the Government of Newfoundland and Labrador (2020) emphasizes that lettuce thrives in cold environments. The primary climate considerations for cultivating lettuce involve maintaining a consistent water supply and avoiding temperatures above 30°C. Keeping the environmental temperature below 30°C is crucial to prevent flowering or bolting, which can cause the lettuce to develop a bitter taste. Ensuring these conditions supports optimal growth and quality of lettuce crops.

The study of Sanders, C. discussed the efficient methods to regulate greenhouse temperature are crucial for maintaining crop productivity year-round. Lettuce is classified as a cool-season vegetable, with the optimal air temperature for growth in a plant factory or temperate zone being between 22 and 26 °C. However, in tropical environments, the

ideal temperature for lettuce cultivation is suggested to be between 22 and 30 °C. The findings provide insights to the researchers on optimizing temperature according to the type of lettuce being grown in the greenhouse.

The study by Kumsong, N. et al., stated that lettuce is adapted to thrive in cool growing conditions, with an optimal temperature range for cultivation between 16°C and 19°C. Despite this preference, lettuce can withstand occasional temperature spikes of 27°C to 30°C for short durations, as long as the nights remain cool. This resilience allows lettuce to adapt to temporary deviations from its ideal growing conditions while maintaining its health and vitality.

The study of Frestya et al. compared five hydroponic systems (NFT, DFT, EBB and FLOW, Aeroponic, Floating Assembling) to see which is best for lettuce growth. They measured plant height and leaf number to determine effectiveness. Plant height is mainly influenced by water and light availability. This study shows ways to reduce water usage and enhance nutrient delivery, highlighting their potential to improve greenhouse practices by creating optimal growth conditions with minimal resource waste. Water shortage can slow growth and reduce yields. By using these advanced methods, greenhouse management can become more efficient and sustainable, demonstrating the significant benefits of automated control systems and hydroponic techniques. This study becomes a reason for the proposed study to choose the NFT system in hydroponics.

The study of G. M. Barbade et al, entitled "Automatic Water Tank Filling System with Water Level Indicator," focuses on conserving water by implementing an automatic water level controller and indicator. Utilizing water's conductivity due to minerals, the

system controls circuits to turn them on or off as the water level fluctuates. A carbon sensor detects water levels without direct contact, activating an LED light and stopping the pump when the tank is full. However, the study above uses carbon sensor to measure the water level, while the proposed study will be using water flow sensor and float switch.

The study of Demi, et. al, proposed a system for measuring pH and TDS in the nutrient film technique (NFT) using sensors to maintain the quality of hydroponic plants. They used a control system to turn on or off the nutrition controllers, such as pH down, pH up and AB nutrition. Depending on the specific condition, various pumps (pH up/down, TDS up/down, nutrition A/B) and the chiller are activated or deactivated to maintain the desired conditions. The study helps the researchers in using pH and TDS sensors and adapting the process of turning valves on or off.

The research by Ardiansah et al. (2020) explores the application of IoT in agriculture, particularly in greenhouse settings, under the concept of Precision Farming. This approach leverages IoT for real-time monitoring and control of crop management. The study highlights the use of various wireless technologies for data transmission, including Bluetooth, ZigBee, and Wi-Fi. Bluetooth and ZigBee are effective for short-range communication (10-100 meters), whereas Wi-Fi enables longer-range connectivity, especially with Internet access. This integration of IoT in agriculture facilitates enhanced precision and efficiency in crop management practices.

The study of M. Danita et al., implemented IoT sensors, specifically the YL69 moisture sensor and DHT11 temperature & humidity sensor, to monitor and ensure

optimal conditions for plant growth. A Raspberry Pi3 was used to control irrigation, cooling, and ventilation systems based on the sensor data. The system recorded temperature and humidity data, which were stored in a cloud database (ThingSpeak) and displayed on a webpage for user access. The study becomes a guide for the proposed study to use DHT11 to measure temperature and humidity.

**Local Studies**

The study of M.G. Semilla et al, in the Philippines utilized Controlled Environment Agriculture (CEA) for indoor lettuce production, focusing on identifying optimal temperature and light intensity conditions for cultivating loose-leaf lettuce in tropical lowlands. The CEA setup used locally available materials, LED lights as the main light source, and a cooling system for temperature control. They constructed three chambers, each equipped with air conditioning units, circulating fans, and sprinkler foggers. The findings suggests that the temperature setting is play a significant role in cultivation of lettuce, highlighting the potential of CEA for year-round lettuce production in tropical climates.

D. Jose's 2020 study emphasized the adaptability of lettuce plants to areas with relative humidity ranging from 65% to 85%. The research suggests that lettuce varieties can be chosen based on their tolerance to specific environmental conditions. This indicates that farmers can select lettuce types suited to their region's humidity levels, potentially enhancing crop productivity and resilience.

The study by Albius et al. focuses on creating a Solar-Powered Multi-Network Greenhouse with an automated system for managing and monitoring mushrooms, which are particularly sensitive to temperature changes, especially in tropical regions like the

Philippines. The system utilizes microcontrollers and Internet of Things (IoT) applications to regulate variables and maintain stable conditions ideal for mushroom farming. The greenhouse monitoring device, managed by an Arduino IDE microcontroller, integrates several powerful sensors to provide precise metrics for monitoring and improving agricultural control management. Performance tests were also carried out to regulate and monitor temperature, relative humidity, and light requirements for mushrooms Additionally, the study suggests installing a CCTV system to continuously monitor the greenhouse's exterior and interior, which could further enhance its functionality, especially in isolated locations. The study helps the researchers to adapt only the utilization of IoT application and Arduino as microcontroller to the system.

The study by Mastul et al. focuses on the use of Internet of Things (IoT) in smart agriculture in the Philippines, aiming to evaluate its effects on various aspects such as precision steering, automated irrigation, field tracking, and weather monitoring, greenhouse automation, and crop monitoring. The study found that IoT technologies can significantly enhance agricultural practices in the Philippines. The study emphasizes the need for comprehensive plans for IoT integration in Philippine agriculture to overcome these challenges and fully realize the benefits of IoT technologies. This study helps the researchers to produce an IoT application in managing hydroponics that can adapt to the generation and to keep the quality of the product.

The study by JE. Anthony in 2018, titled "Auto GMS: An Automated Greenhouse Monitoring System of Abiotic Factors for Leafy Vegetables Production," conducted at Oriental Mindoro, focused on automating greenhouse processes using highly sensitive sensors to monitor the greenhouse's working conditions. The system included SMS

functionality to provide real-time updates to users and was powered by a wifi module and an LCD screen display for user information. The study focuses on the application of integration of Internet of Things (IoT) technology, specifically a user's GSM phone, for monitoring. Arduino Uno microcontrollers were used to monitor and automate processes, including controlling solenoid valves via relays for water intake to the irrigation system. The researchers considered the utilization of Arduino Uno and IoT for monitoring the whole process of the system.

The study of R. Amy (2020) entitled "Automated pH Monitoring and Controlling System for Hydroponics under Greenhouse Condition" demonstrates a system for automatic monitoring and controlling of hydroponics to regulate the pH level of the water in the system by adding acid and base solution. A minimum pH of 6.0 and a maximum pH of 6.54 were observed. The pH level of the nutrient solution was maintained at a range of 6.0-6.8 level which is the recommended range for hydroponic lettuce production. This study provides researchers with valuable insights into the optimal pH levels needed to ensure high-quality lettuce cultivation in the Philippines.

# CHAPTER III

# DESIGN AND METHODS

This chapter discusses the design and methods that have been improved for this project study. It includes the conceptual framework along with the technical design and procedure. Further discussed are the equipment, facilities, and programs used, the data collection and treatment, as well as the required budget to conduct the project study. Also presented are the expected output and a tabulated Gantt chart for the duration of this project study.

## 3.1 CONCEPTUAL FRAMEWORK

This project study focuses on the design and construction of a Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, pH level and TDS monitoring. This framework will guide the research to understand and show how the greenhouse management system can help make farming more sustainable and efficient. Moreover, it was constructed and improved the greenhouse considering the environment of the greenhouse that will affect the crops, such as the temperature, relative humidity and monitoring system. The position, size of the land, temperature, and pH level at the location of the control system installation were also taken into consideration due to its impact to the automated systems performance in the greenhouse.

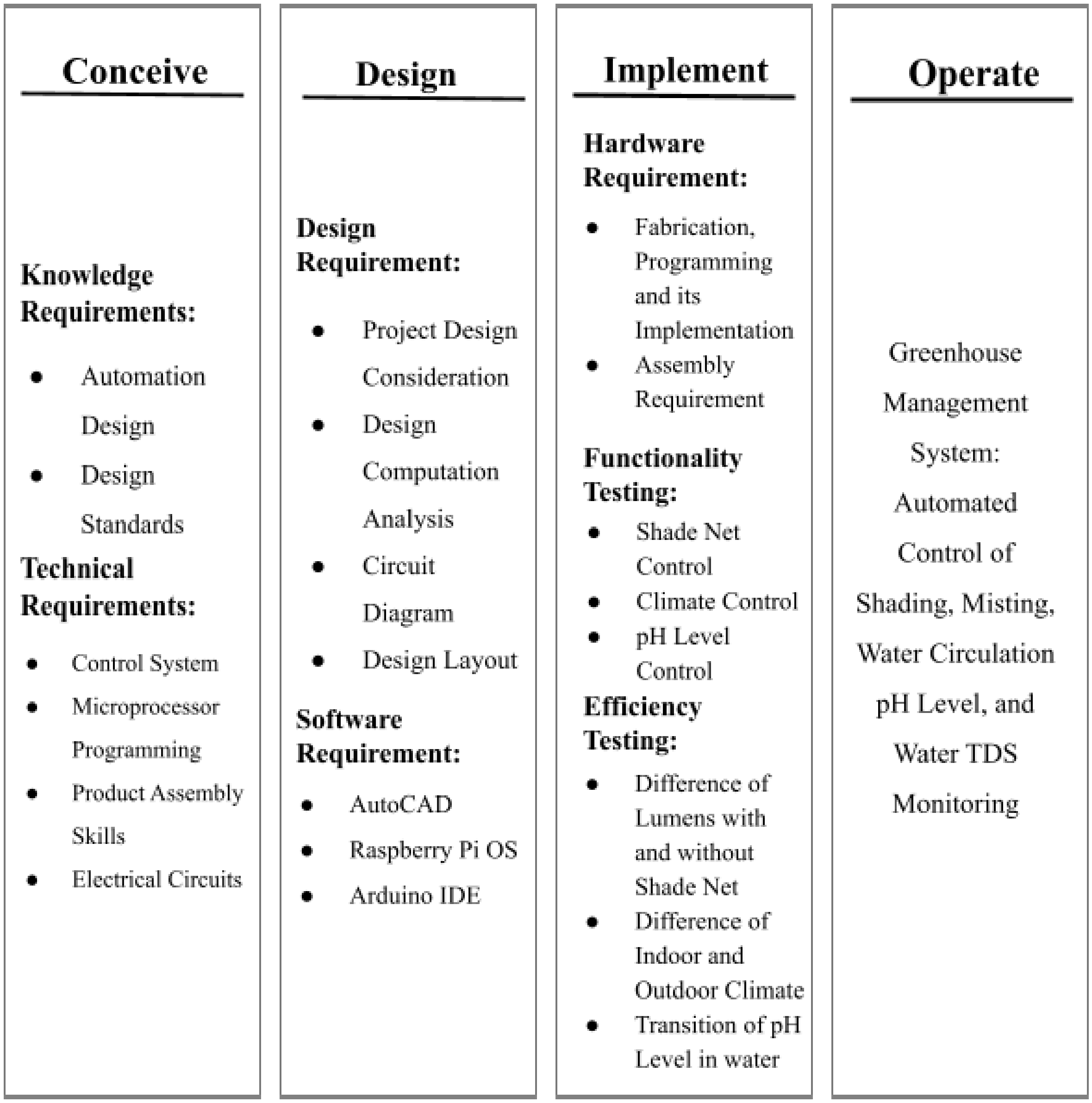


**Figure 3.1** Conceptual Paradigm of the Study

The Conceive Stage's purpose is to acquire essential knowledge for an automated greenhouse management system involving a thorough evaluation of the collaboration between software and hardware. This includes establishing a comprehensive monitoring and control system. Proficiency in programming is crucial for connecting the various elements of the automated system. Expertise in understanding the ideal environmental conditions within the greenhouse, including temperature, humidity, nutrient solution level

and light intensity. Recognizing that any changes in these parameters can have a direct impact on crops indicates the need of taking a comprehensive approach in implementing and managing an efficient automated greenhouse management system.

During the Design Stage, the design and software requirements are determined. The project study contains different design requirements, material specifications and system components, the general description of the project, design standard, design computation and Analysis, design layout, circuit diagram, materials and components, programs and complementation, bills of materials and specification of the study. The monitoring and control system automatic function hinges upon considering the factors mentioned. These factors have been taken to ensure the effective operation of the system.

The implementation of the project construction and programming as well as the fabrication of the output. Functionality testing was also included, which was divided into Climate control test, Nutrient solution monitoring control test, Shade net control test of greenhouse management and the efficiency testing which contains: Difference of outdoor and indoor climate, Flowrate of water outflow & inflow, and Difference of lumens with & without shade net is considered. Lastly, the operation stage was presented as the output of the project study. This project study entitled Greenhouse Management System: Automated Control of Shading, Misting, and Nutrient Monitoring for Sustainable Agriculture.

Furthermore, the materials and equipment used are considered to achieve the effectivity and purpose also the expected output of the project study. To enhance comprehension of the study core principles, the research team crafted a conceptual model encompassing the necessary expertise, as well as the design criteria and prerequisites.

Additionally, the scope covers the construction and programing, along with the architectural planning and physical build of the Greenhouse Management System for sustainable agriculture.

## 3.2 TECHNICAL DESIGN AND PROCEDURE

### IV. Designing Stage

In order to collect the existing information and foundation parts of the prototype, its focus is on the comprehensive development of an automated control system for shading, misting, water circulation, pH level, and TDS monitoring. The design process begins with determining the specific components required for each subsystem, ensuring the system meets the environmental needs of the greenhouse. The computation phase involves calculating necessary parameters such as light intensity, water flow rates, nutrient concentrations, and the power requirements of the solar-powered system. Additionally, material identification is critical to select durable and efficient components like sensors, pumps, microcontrollers, and shading mechanisms that ensure system reliability. A thorough cost analysis is performed to estimate the total expenses for materials, labor, and installation, ensuring that the project remains within budget while achieving the desired functionality. This holistic approach to design not only aligns with automation and greenhouse principles but also addresses the project's efficiency, practicality, and sustainability objectives.

### V. Fabrication Stage

In this phase, the development and specifications of the machine are built in accordance with the goals of the research. When choosing materials that satisfy the requirements, a number of variables will be taken into account, such as cost, accessibility

locally, and material specifications. The nearby machine shop will be the location of real manufacture, with materials sourced locally employed in the fabrication process. The many parts of the Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, Water TDS and pH level monitoring control equipment will then be assembled and integrated over time. The final inspection will assess how well the machine operates and how well it follows the standards.

**VI. Preliminary Testing Stage**

The tests will focus on evaluating the core components of the system, such as the shading mechanism, misting system, water circulation, pH level control, and TDS monitoring. These tests aim to confirm that each subsystem functions as expected under real-world conditions. Specifically, the tests will measure the responsiveness of the shading system, the efficiency of the misting and water circulation systems, and the accuracy of the pH and TDS sensors. Preliminary testing is an essential phase after the manufacture of the system, designed to assess its overall operational capabilities and identify any issues. Key parameters, including system response time, resource efficiency, and accuracy, will be evaluated during this stage. Any detected problems will be corrected before proceeding with further testing and integration.

## 3.3 EQUIPMENT / FACILITIES / PROGRAMS

The content outlines the key elements involved in project planning and implementation, with a focus on the necessary equipment and infrastructure. It emphasizes the importance of choosing appropriate software for both programming and designing the system, which is critical in defining aspects such as layout, size, block diagrams, and control mechanisms. The passage also mentions the use of various

software tools for demonstrating the capabilities of the software and displaying the project's results. This indicates a systemic approach to project management, combining both physical and digital resources to achieve project objectives.

## EQUIPMENT

A complete set of equipment is required for the assembly of the automated system within the greenhouse. This includes:

### 1. Fabrication Tools for Mechanical Components

- Welding Machine: For assembling metal parts of the greenhouse structure and mechanical supports for components like the shade net and misting system.
- Cutting Tools: For cutting metal sheets, pipes, and other structural components.

### 2. Electrical and Wiring Tools

- Soldering Station: Essential for connecting electronic components, such as control boards, sensors, and wiring for the automation system.
- Multimeter: For checking voltage, current, and continuity in the electrical system to ensure proper connections.
- Crimping Tools: For connecting wires securely with terminals when installing the greenhouse's electrical and control systems.

### 3. Hydraulic and Plumbing Equipment

- PVC Pipe Cutters and Joiners: For the installation of water circulation and misting systems.

- Nozzle Installers: To install misting nozzles that regulate humidity and cooling within the greenhouse.

**4. Control and Automation Tools**

- Arduino Kit (with compatible sensors and actuators): For the control system of shading, misting, water circulation, and environmental monitoring.
- Relay Modules and Stepper Motors: For automating functions like opening/closing the shade net or adjusting water circulation based on environmental data.

**5. Precision Measuring Instruments**

- Digital Calipers: For precise measurement of fabricated parts and ensuring proper fits, especially in components like shafts or mounting brackets.
- Temperature and Humidity Sensors: To monitor the environment and calibrate the automated control systems for maintaining optimal greenhouse conditions.
- pH and TDS Meters: To measure and regulate the water quality in the hydroponic system, ensuring the proper nutrient balance.

**6. Programming and Debugging Tools**

- Computer with Arduino IDE (or Raspberry Pi setup): For coding and testing the software that will automate the shading, misting, and circulation systems.

## FACILITY

SIMCO, located in San Isidro Batangas City, serves as the primary facility for the research, equipped with two previous advanced hydroponic greenhouse systems. These greenhouses, built with study materials suitable for the local climate, feature automated controls for temperature, humidity, and watering to create optimal growth conditions for lettuce crops. They also have an efficient irrigation system for water and nutrient management in hydroponics. The researchers chose this location to allow convenient access. Another reason for selecting it is because of the support from the beneficiary who will provide a fabricator to help the researcher complete the prototype.

## PROGRAM

Different software and programs were used to achieve the study's results. The layout of the study was presented using AutoCAD software, while data was organized using spreadsheet programs such as Google Sheets during system testing. The Arduino IDE was the programming software that was used to program the Arduino board. It consists of a text editor for writing code, a message area, a text console, a toolbar with buttons for common functions, and a series of menus. To connect the Arduino to the computer, a cable converter and Ethernet cable were used as communicators. As a result, a laptop computer was required, as well as a greenhouse where the automated system was installed.


**Figure 3.1** AutoCad Software

AutoCAD (Computer-Aided Design) is a computer application that is very useful for project layout, design, and taking complex measurements of various lengths and angles in modeling 2D and 3D. The application is extremely useful for idea visualization and dimensioning, especially during the project's planning and design stages. The design was most likely done in 3D in order to view the output in isometry as well as observe the actual construction while using some of the parameters mentioned.

**Figure 3.2** Google Sheet

Spreadsheet programs, such as Google Sheets and Microsoft Excel, are powerful computer applications that can be used for data organization, computation, analysis, and

storage. Users can create, edit, and format spreadsheets in Google Sheets, as well as import and export data from other sources.

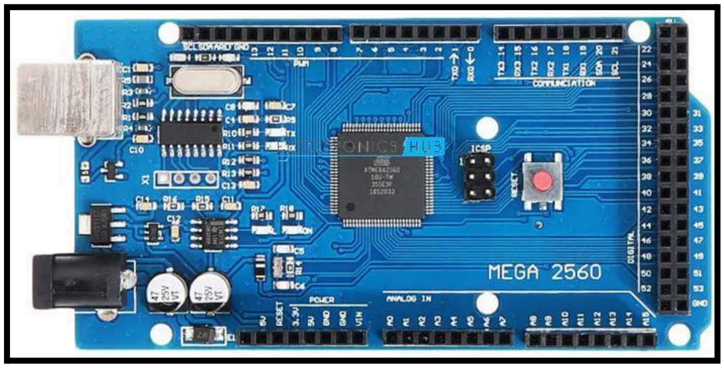


**Figure 3.3** Arduino Mega

The Arduino Mega is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It's a powerful board that's great for projects requiring a lot of I/O pins or complex functionality.


**Figure 3.4** Arduino IDE (Integrated Development Environment)

The Arduino IDE (Integrated Development Environment) is free and open-source software that simplifies code compilation, particularly for those with no prior technical knowledge. It was created by Arduino.cc and is compatible with a variety of operating systems, including MAC, Windows, and Linux. It is based on the Java platform and includes built-in functions and commands for debugging, editing, and compiling code. The Arduino modules available include the Arduino Uno, Arduino Mega, Arduino Leonardo, and Arduino Micro, each of which has a microcontroller on the board that is programmed in the form of code. The editor for writing the code and the IDE are the two main components of the IDE. Code and the compiler are required for compiling and uploading the code.

### 3.4 DATA COLLECTION AND TREATMENT

The proponents employed design and development research which entails the implementation of procedures and methodologies to create a functional prototype. In obtaining necessary information, the researchers gathered data through various methods. The researchers conducted a comprehensive review of related literature and previous studies as the foundation for the project design. Methods such as Internet and E-library research, interviews, and consultation were used to complete this project study.

**Functionality Test**

**d) Shade Net Control**

**Table 3.1** Shade Net Control Functionality Testing

| Shade Net Control Testing | | | | |
|---|---|---|---|---|
| Trial | Temperature (°C) | Luminous Flux (lm) | Shading Motor Status (On/Off) | Remarks (Passed/Failure) |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

This test assesses the effectiveness of the automated shade net control system in the greenhouse. The system is designed to adjust the deployment of the shade net based on real-time monitoring of light intensity and temperature to optimize plant growth conditions. The test involves monitoring the response of the shade net system to changes in external light and temperature conditions. Given its location within a resort, nearby artificial light may trigger the luminous sensor. Therefore, considering temperature is crucial when activating the shading system. The shade net control system operates by deploying and retracting the net with precision based on predefined light and temperature thresholds. A "PASSED" remark is noted if the shading motor starts to take action when temperature is on 30°C and luminous intensity reaches beyond 600 $\mu mol \cdot m^2 \cdot s^{-1}$ or 32,400 lux [9], ensuring that plants receive the optimal temperature and luminous flux for the lettuce plant. Otherwise, the test result is marked as "FAILURE".

**Table 3.2** Shade Net Control Efficiency Test

| Difference of Lumens with and without Shade Net | | | | |
|---|---|---|---|---|
| Trial | Lumens with Shade Net | Lumens without Shade Net | Required Luminous Flux | Remarks (Passed/ Failure) |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

This test is designed to determine the effectiveness of the shade net in managing light exposure within the greenhouse. It involves recording the lumens, a measure of light intensity, inside the greenhouse with the shade net installed and without it. Measurements are taken using a luminosity sensor during multiple trials to ensure reliability of the data. Each trial will note the lumens with the shade net and compare it to the lumens recorded without the shade net. The system is deemed efficient if the light intensity with the shade net falls within the optimal range for plant growth, avoiding both underexposure and harmful overexposure. A "PASSED" remark is noted if the desired luminous flux is achieved, ensuring that plants receive the correct amount of light for healthy photosynthesis without excess stress from over-illumination. Otherwise, the test result is marked as "FAILURE".

**e) Climate Control Testing**

**Table 3.3** Humidity and Temperature Functionality Testing

| Humidity and Temperature Functionality Testing | | | | |
|---|---|---|---|---|
| Trial | Humidity (%) | Temperature (°C) | Misting Element Status (On/Off) | Remarks (Passed/ Failure) |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

The method of determining the functionality of the humidity and temperature sensor will be evaluated. These evaluations are intended to provide crucial information to advocates, allowing them to make adjustments and improvements. This assessment comprises three trials under humidity and temperature conditions, where the misting element will activate when the sensors reach any of the set values for humidity and temperature. A "PASSED" remark will be assigned if the misting element activates when the temperature rises beyond 30°C [71] and the humidity drops to 65%[73]. Also testing if the mister shuts down when the 27°C[71] temperature and 85%[73] of humidity were met. However, if not, it will be considered "FAILURE".

**Table 3.4** Humidity and Temperature Efficiency Test

| Difference of Indoor and Outdoor Climate | | | | |
|---|---|---|---|---|
| Trial | Indoor (Temperature & Humidity) | Outdoor (Temperature & Humidity) | Required Humidity & Temperature | Remarks (Passed/ Failure) |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

This test assesses the efficiency of the greenhouse management system in stabilizing indoor climate conditions compared to the fluctuating outdoor environment. The evaluation involves measuring and comparing the temperature and humidity levels inside and outside the greenhouse across multiple trials. Each trial will record the temperature and humidity data from sensors located inside the greenhouse and in the external environment. The result is marked as "PASSED" if the indoor climate remains within the desired data, otherwise, it is noted as "FAILURE".

### f) pH Level Control Test

**Table 3.5** pH Level Control Functionality Testing

| pH Level Control Testing | | | |
|---|---|---|---|
| Trial | pH Level | pH Downer Pump (On/Off) | Remarks (Passed/Failure) |
| 1 | | | |
| 2 | | | |
| 3 | | | |

This test evaluates the functionality of pH Level Control in the greenhouse management system. The test specifically assesses the control mechanism's ability to maintain the pH condition at predetermined levels. During the test, the pH levels are closely monitored to ensure that the concentrations stay within the required value. For each trial, the pH sensor detects the nutrient level, triggering the pH downer pump to attain the optimal ph level. A "PASSED" remark is assigned if the system successfully activates the pH downer pump when pH level rises to 7 and stops when the pH level is 6. However, if the system fails to activate the valves despite meeting the requirement, a "FAILURE" is noted.

**Table 3.6** Transition of pH Level Efficiency Test

| Transition of pH Level in water | | | | |
|---|---|---|---|---|
| Trial | Initial pH Level | New pH Level | Required pH Level | Remarks (Passed/Failure) |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

The evaluation method of pH level control will involve a series of tests to assess the stability and accuracy of the system's ability to maintain optimal pH level concentration. This examination will focus on the system's response under various conditions to ensure consistent pH level. The test consists of three trials. In each trial, we will record the initial pH level and new pH level reading to control whether the valve will activate or deactivate based on the current reading. The pH downer valve will activate once the minimum required pHlevel has been met, and it will deactivate once the maximum required pH level has been attained. A "PASSED" remark will be assigned if the new pH level met the required pH level; otherwise, it will be marked as "FAILURE".

**Performance Test**

**Table 3.7** Weekly Growth Stage of Lettuce

| | Weekly Growth Stage | | | |
|---|---|---|---|---|
| | Week 1 | Week 2 | Week 3 | Week 4 |
| Greenhouse 1 | | | | |
| Greenhouse 2 | | | | |

Table 3.7 presents the growth characteristics of lettuce at different growth stages under two greenhouse systems: Greenhouse 1, which operates with a manual system, and Greenhouse 2, which uses an automatic system. The performance testing is designed to compare these two approaches in managing the growth conditions. The growth conditions will be monitored on a weekly basis from week 1 to week 4 to collect a detailed progression of the lettuce's growth over time. The results will provide valuable insights into the advantages of automation in maintaining optimal conditions for lettuce cultivation compared to manual control.

### 3.5 BUDGET REQUIREMENTS

The researchers make sure that the resources are widely accessible and available in order to properly carry out this study and construct the Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, Water TDS and pH level monitoring control. The financial requirements are also based on the theoretical framework and findings of the researchers. The table below shows the estimated costs for the components, materials and production output.

**Table 3.8** Bill of Materials

| Description | Specification | Quantity | Unit | Unit/Price | Total |
|---|---|---|---|---|---|
| Arduino Mega | ATmega2560/ 6-20V | 1 | pc | ₱ 1,145.00 | ₱ 1,145.00 |
| Contactor | 9-32 A AC | 1 | pc | ₱ 395.00 | ₱ 395.00 |
| DFRobot Gravity | 3.3-5.5 V | 1 | pc | ₱ 2,499.00 | ₱ 2,499.00 |
| DHT11 sensor | 5.5 V/0.2 mA | 2 | pc | ₱ 125.00 | ₱ 1125.00 |
| ESP32 | 78.32 mW | 1 | pc | ₱ 631.00 | ₱ 631.00 |
| Float Switch | 10W | 2 | pcs | ₱ 199.50 | ₱ 399.00 |
| Jumping Wire | Male 20cm | 3 | pcs | ₱ 35.00 | ₱ 105.00 |
| Pulley | 36kN high grade alloy | 1 | pc | ₱ 298.00 | ₱ 298.00 |
| PH4502C module | 5±0.2 V | 1 | pc | ₱ 999.00 | ₱ 999.00 |
| Raspberry Pi | 3.7-5 V | 1 | pc | ₱ 4,720.00 | ₱ 4,720.00 |
| Relay Module | 5V Single | 3 | pcs | ₱ 42.00 | ₱ 126.00 |
| Relay Board | 12V Single Channel | 3 | pcs | ₱ 50.00 | ₱ 150.00 |
| Shaft | 12mm | 2 | pcs | ₱ 353.00 | ₱ 706.00 |
| Shade Net | Anti UV | 1 | pcs | ₱ 499.00 | ₱ 499.00 |
| Solenoid Valve | 2 way/NC | 3 | pcs | ₱ 330.00 | ₱ 990.00 |
| Stepper Motor | 12 V/ 1.7 A | 1 | pcs | ₱ 699.00 | ₱ 699.00 |
| Water Pump | 12 V | 1 | pc | ₱ 1,499.00 | ₱ 1,499.00 |
| TSL2561 Sensor | 3.3V – 5V | 2 | pcs | ₱ 499.00 | ₱ 998.00 |
| Misting Nozzle | 3-12 kg | 1 | set | ₱ 541.00 | ₱ 541.00 |
| Water Flow Sensor | 1-25L/min | 1 | pcs | ₱ 184.00 | ₱ 552.00 |
| | | | | **Total Amount** | ₱ 25,993.00 |

**Table 3.7** shows the list of the expenses of the automated greenhouse management system, which includes the necessary equipment for the automated greenhouse management system and other electronic components. The total required budget for the said prototype amounted to ₱ 25,993.00.

**Table 3.9** Bill of Labor Costs

| Description | Costs (Php) |
|---|---|
| Construction Labor | ₱ 15,000.00 |
| Fabrication Labor | ₱ 30,000.00 |
| Programming Labor | ₱ 15,000.00 |
| Total Amount | ₱ 60,000.00 |

**Table 3.8** shows the list of the expenses of the development and installation of the Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, Water TDS and pH level monitoring control, which includes the programming, construction and fabrication of the prototype. The total required budget for the laborer and fabricator amounted to ₱ 60,000.00.

## 3.6 EXPECTED OUTPUT

The expected output is a fully functional greenhouse that can automatically water and harvest lettuce. It is also expected that it can regulate the temperature within the building to maintain the optimal growing condition for lettuce.

**Perspective View**

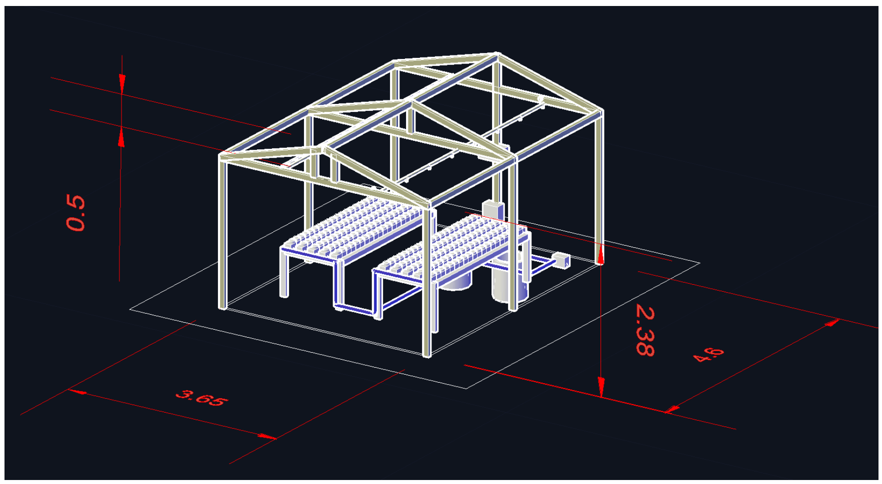


**Figure 3.5** Expected Output with Overall Dimension

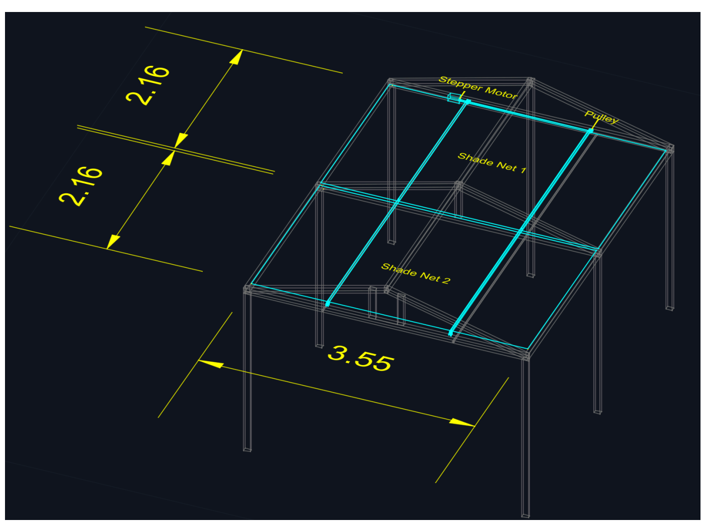


**Figure 3.6** Shading System

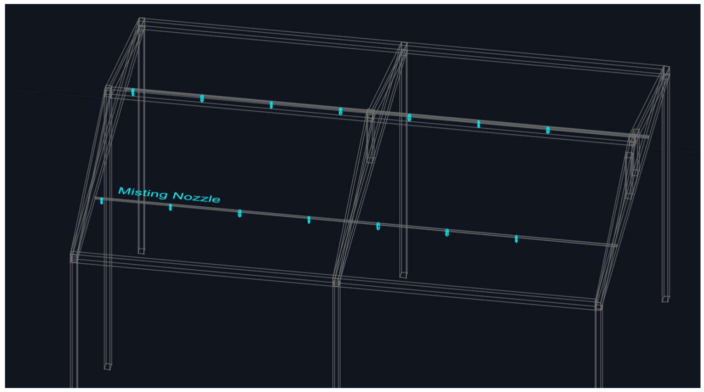


**Figure 3.7** Misting System

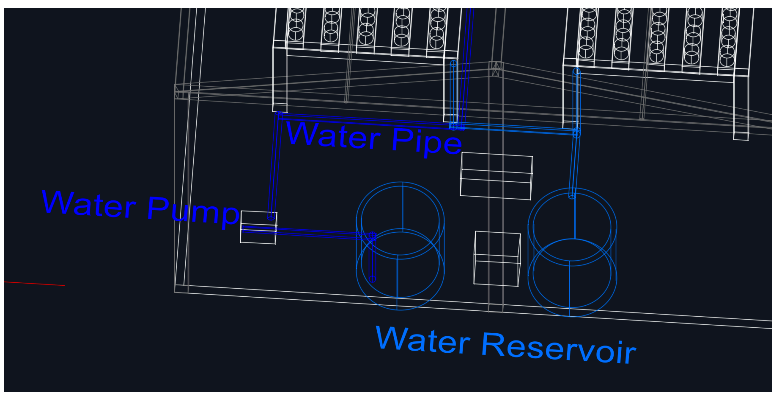


**Figure 3.8** Watering System

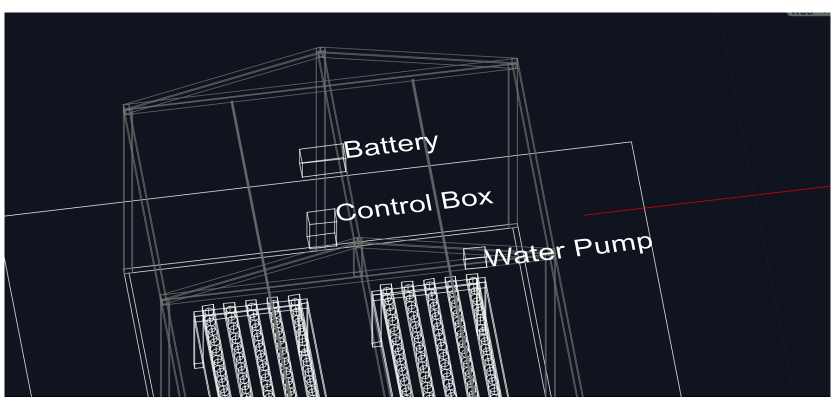


**Figure 3.9** Electronics System

The research aims to design an automated greenhouse management system for sustainable agriculture, specifically focusing on shading, misting, watering, and nutrient monitoring. This project aligns with the objectives of the DOST 6Ps Project by contributing to several key outputs. The innovative aspects of the automated control system could lead to potential patents, indicating an innovation. This would be evaluated based on the progress of the patent application process.

Overall, the research aligns with the goals of the DOST 6Ps Project by not only contributing to the advancement of knowledge in sustainable agriculture but also by potentially leading to practical innovations and solutions that benefit society and the environment.

Creating a greenhouse system positively impacts the economy by increasing crop yields, improving crop quality, creating jobs, and enabling year-round production, which expands market opportunities and can lead to higher profits. Efficient resource use and potential energy savings further enhance economic benefits.

### 3.7 GANTT CHART

The Gantt chart illustrates the work sequence of activities and corresponding duration in designing of the project “Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, Water TDS and pH level monitoring control”. It begins with groupings, conceptualization and title proposal in January and February, followed by construction of Chapter I in February to March, and then Chapter II in the month of March. After that if we have a revision of Chapter I and II we will do it in March, Canvassing and Chapter III through the month of April, and the month of May is allotted for manuscript revisions and proposal defense.

**Table 3.10** Gantt Chart

| | January | February | March | April | May |
|---|---|---|---|---|---|
| **Groupings** | | | | | |
| **Conceptualizing** | | | | | |
| **Title Proposal** | | | | | |
| **Chapter I** | | | | | |
| **Chapter II** | | | | | |
| **Revision of Chapter I and II** | | | | | |
| **Canvassing** | | | | | |
| **Chapter III** | | | | | |
| **Revisions** | | | | | |
| **Proposal Defense** | | | | | |

The Table Gantt chart shows the progress of the researchers in every month and what month we started and finished each part of the chapter within the 1st week up to 18th week of Second Semester Academic year 2023-2024.

# CHAPTER 4

# PRODUCT DEVELOPMENT

This chapter encompasses the technicalibes in the construction of the product prototype. This Includes the Product Specification, Product Development, and Simulation and Testing. Design bases are specified in the Product Specification. Methods undertaken in the creation of the prototype are inscribed in the Product Development section, The testing procedures and summary of testing carried out is presented by simulation and testing.



## 4.1 PRODUCT SPECIFICATIONS

**Wire Sizing**

25 – 50 Feet Extension Cords

16 Gauge(1-13 Amps)

14 Gauge (14-15 Amps)

12-10 Gauge (16-20 Amps)

100 Feet Extension Cords

16 Gauge (1-10 Amps)

14 Gauge (11-13 Amps)

12 Gauge (14-15 Amps)

10 Gauge (16-20 Amps)

150 Feet Extension Cords

14 Gauge (1-7 Amps)

12 Gauge (8-10 Amps)

10 Gauge (11-15 Amps)

**[85]**

**SHADING**

**L298N motor driver**

The L298N motor driver is an affordable and straightforward option for controlling stepper motors, particularly suited for small to medium-sized bipolar stepper motors like the NEMA 17. It enables control over both the speed and direction of the motor. The L298N provides the necessary power and control to handle the NEMA 17's requirements, supporting up to 2A per channel and operating between 5V and 35V. [86]

**NEMA 17 stepper motor**

NEMA 17 stepper motors, which are characterized by 1.7 x 1.7-inch faceplate. These motors are distinguished by high torque, which is designed to maximize efficiency while minimizing vibration and noise, making it ideal for precise applications. The availability of customized windings allows these motors to be perfectly designed to specific voltage, current, and torque requirements.

Additionally, the NEMA standard, set by the National Electrical Manufacturers Association, ensures compatibility and safety across a wide range of electrical products, promoting consistency and reliability in power generation and transmission applications.[87]

**TSL2561 [40]**

**MISTING AND WATER CIRCULATION**

Misting Nozzle

Water Pump

**WATER TDS**

DFRobot Gravity: Analog TDS Sensor/Meter

**PH LEVEL MONITORING**

PH4502C module

Analytical Surver Electrode pH Probe

4.2 PRODUCT DEVELOPMENT

I2C is critical for enabling devices like sensors and displays to communicate over a two-wire interface (SDA and SCL). This protocol is essential for the development of products that require efficient, low-cost, and minimal wiring communication between

multiple devices. I2C is particularly valuable in complex systems where numerous sensors and components need to interact seamlessly.

### 4.3 SIMULATION AND TESTING

# CHAPTER 5

# RESULTS AND DISCUSSION

### 5.1 DISCUSSION OF RESULTS

### 5.2 SUMMARY OF FINDINGS

### 5.3 CONCLUSIONS

### 5.4 RECOMMENDATION

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# APPENDIX

## APPENDIX A

## LETTER FROM THE BENEFICIARY

BatStateU @120

**BATANGAS STATE UNIVERSITY**
The National Engineering University

*Propelling Transformations and Accelerating Reforms for National Development*

**College of Engineering – Department of Electrical Engineering**

**San Isidro Multi-Purpose Cooperative (SIMCO)**
Brgy. San Isidro, Batangas City
October 02, 2024

To Whom It May Concern,

Greetings!

We, the researchers, are submitting a proposal for the implementation of a Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, Ph Level and TDS Monitoring at San Isidro Multi-Purpose Cooperative (SIMCO) located in Barangay San Isidro, Batangas city. As providers of agricultural resources, we hold a strong conviction that the incorporation of hydroponics techniques into cultivation practices will significantly improve the well-being of our farmers and enhance the overall quality of their crops.

The implementation of this automated system, which controls essential greenhouse functions like shading, misting, and nutrient and water monitoring, will improve the overall efficiency of crop cultivation. By addressing key challenges such as maintaining optimal environmental conditions, monitoring pH and TDS levels, and automating watering schedules, the system aims to ensure a sustainable and high-yield operation, benefiting your crops, particularly in hydroponic lettuce farming.

Our approach aligns with sustainable agricultural practices and is designed to contribute to the achievement of your long-term productivity goals while minimizing environmental impact. We are confident that this innovative system will not only restore the functionality of your greenhouse but also contribute to the prosperity of your community's agricultural sector.

We sincerely seek your partnership and approval for this initiative and are grateful for your consideration.

Thank you.

Sincerely,

________________________________
Signature and Name of Representative

**APPENDIX B**

**CIRCUIT DIAGRAMS**

- DETAILED CIRCUIT DIAGRAMS SHOWING THE ELECTRICAL WIRING, SENSORS, MICROCONTROLLER CONNECTIONS, AND AUTOMATION CONTROL SYSTEMS FOR SHADING, MISTING, WATER CIRCULATION, AND PH/TDS MONITORING.

**APPENDIX C**

**TECHNICAL SPECIFICATIONS**

- SPECIFICATION SHEETS OF THE EQUIPMENT AND COMPONENTS USED (E.G., SENSORS, PUMPS, ARDUINO BOARDS, MOTORS). THIS INCLUDES POWER REQUIREMENTS, DIMENSIONS, AND PERFORMANCE RATINGS.

Computation:

Pumps

Electrical Loads

**APPENDIX D**

**PROGRAMMING CODE**

- FULL SOURCE CODE FOR THE CONTROL SYSTEM, TYPICALLY WRITTEN FOR ARDUINO OR OTHER MICROCONTROLLERS USED TO MANAGE SHADING, MISTING, AND WATER CIRCULATION.

**APPENDIX E**

**FABRICATION DRAWINGS**

- MECHANICAL DRAWINGS OR CAD DESIGNS THAT SHOW THE DIMENSIONS AND ASSEMBLY STEPS OF FABRICATED PARTS, SUCH AS

THE GREENHOUSE FRAME, SHADE NET MECHANISM, OR MISTING SYSTEM.

**APPENDIX F**

**TEST DATA**

- RAW DATA COLLECTED FROM FUNCTIONALITY AND EFFICIENCY TESTS, SUCH AS TEMPERATURE, HUMIDITY, LIGHT INTENSITY READINGS, OR PH AND TDS LEVELS DURING THE TRIAL RUNS.

**APPENDIX G**

**GANTT CHART**

- A DETAILED PROJECT TIMELINE OR GANTT CHART OUTLINING THE STAGES OF DESIGN, FABRICATION, AND TESTING OF THE GREENHOUSE MANAGEMENT SYSTEM.

**APPENDIX H**

**USER MANUAL/INSTRUCTIONS**

- INSTRUCTIONS OR A USER MANUAL FOR OPERATING THE AUTOMATED SYSTEM, INCLUDING HOW TO CALIBRATE SENSORS, ADJUST SETTINGS, AND MAINTAIN THE EQUIPMENT.

**APPENDIX I**

**SAFETY GUIDELINES**

- SAFETY PROTOCOLS FOLLOWED DURING THE FABRICATION AND INSTALLATION OF ELECTRICAL, PLUMBING, AND MECHANICAL SYSTEMS IN THE GREENHOUSE, PARTICULARLY RELATING TO HIGH-VOLTAGE COMPONENTS AND HANDLING CHEMICALS.

# Documentation for Sensor and Actuator Control System

## Overview

**This Arduino-based program implements a monitoring and control system for various environmental and operational parameters. It uses multiple sensors to collect data, processes the data, and sends it to a server for further analysis or action. The system also includes actuator controls to respond to environmental changes based on predefined thresholds.**

---

## Components and Libraries

### Libraries Used

1. **DFRobot_SHT20: For reading temperature and humidity.**
2. **Adafruit_TSL2561_U: For light sensor readings.**
3. **Adafruit_INA3221: For power consumption monitoring.**
4. **RTClib: For real-time clock (RTC) functionality.**
5. **WiFiS3: For Wi-Fi connectivity.**
6. **ArduinoHttpClient: For HTTP communication.**
7. **ArduinoJson: For creating and parsing JSON data.**

---

# Pin Definitions

### Sensors

- **TDS Sensor:** `A3`
- **pH Sensor:** `A2`

### Actuators

- **Water Pump Relay:** `8`
- **Misting Relay:** `12`
- **pH Downer Relay:** `A1`
- **Fan Relay:** `A0`

### Stepper Motor

- **Step Pin: `9`**
- **Direction Pin: `10`**
- **Enable Pin: `11`**

---

# Functional Blocks

### Wi-Fi Initialization

**The `setupWifi` function connects to a specified Wi-Fi network. It retries 20 times before halting the program if the connection fails.**

### Sensor Initialization

**The `setupSensors` function initializes all connected sensors and displays their status. It checks for the following:**

- **SHT20 for temperature and humidity**
- **TSL2561 for light**
- **INA3221 for power consumption**
- **RTC for real-time clock**

### Actuator Initialization

**The `setupActuators` function sets the initial states of all actuators to ensure a safe startup state.**

# Core Features

## Data Acquisition

1. **Sensors:**
    - **Light (lux): TSL2561**
    - **Temperature (°C) and Humidity (%): SHT20**
    - **pH: Analog sensor**
    - **TDS (ppm): Analog sensor**
2. **Power Consumption:**
    - **Solar panel, battery, and load: INA3221 (Channel 1)**
    - **Actuator consumption: INA3221 (Channel 2)**

## Data Processing

- **Filters out abnormal readings based on acceptable thresholds.**
- **Detects significant changes and sends data only when a threshold is crossed.**

## Data Reporting

**The `reportData` function sends all sensor readings and system status to the server. It uses the `sendSensorData`, `sendComponentStatus`, and `sendMetricData` functions for HTTP POST requests with JSON payloads.**

### Actuator Control

1. **Misting System:**
   - **Activates when temperature exceeds or humidity drops below acceptable limits.**
2. **pH Downer:**
   - **Activates when pH value exceeds the maximum limit.**
3. **Shade Net:**
   - **Stepper motor rotates forward or backward to control the shade based on light intensity.**

---

## Thresholds and Limits

### Sensors

| Parameter | Minimum | Maximum |
|---|---|---|
| Temperature (°C) | 10.0 | 50.0 |
| Humidity (%) | 0.0 | 100.0 |
| pH | 5.0 | 8.0 |

| | | |
|---|---|---|
| **TDS (ppm)** | **0.0** | **2000.0** |
| **Light (lux)** | **0.0** | **100,000.0** |

**Significant Change Detection**

| **Parameter** | **Threshold Change** |
|---|---|
| **Light (lux)** | **200** |
| **Temperature (°C)** | **0.5** |
| **Humidity (%)** | **1.0** |
| **pH** | **0.1** |
| **TDS (ppm)** | **50** |

---

# Periodic Tasks

1. **Sensor Readings:**
    - **Processed every 2 seconds (`sensorReadInterval`).**
2. **Data Reporting:**
    - **Sends periodic reports to the server every 10 minutes (`REPORT_INTERVAL`).**

# Server Communication

## Endpoints

| Purpose | Endpoint |
| --- | --- |
| Sensor Data | `/api/sensor-data` |
| Component Status | `/api/component-status` |
| Power Consumption Metrics | `/api/save-metric` |

## JSON Payload Structure

**Sensor Data:**

json

Copy code


```json
{
"sensor": "temp",
"output": "Temperature Sensor Output",
"parameter": "celsius",
```

```
"value": 25.0,
"timestamp": "2023-11-18T10:30:00Z"
}
```

**Component Status:**

**json**

**Copy code**

```json
{
"component": "misting_process",
"status": "ON",
"timestamp": "2023-11-18T10:30:00Z"
}
```

**Power Metrics:**

**json**

**Copy code**

```json
{
"metric_type": "battery_percentage",
"metric_value": "75",
"timestamp": "2023-11-18T10:30:00Z"
}
```

---

# Control Logic

### Light Sensor

- **Rotates stepper motor to adjust shade when light exceeds `32,400 lux` or drops below `22,400 lux` for 5 seconds.**

### Temperature and Humidity

- **Activates misting system if:**
  - **Temperature exceeds `30°C`.**
  - **Humidity drops below `65%`.**

### pH Sensor

- **Activates pH downer relay for 3 seconds if pH exceeds `7.0`.**

---

# Key Functions

### Initialization

- **`setupWifi`: Connects to Wi-Fi.**

- `setupSensors`: **Initializes all sensors.**
- `setupActuators`: **Initializes actuators.**

### Sensor Processing

- `processLightSensor`: **Adjusts shade based on light intensity.**
- `processTempAndHumidity`: **Controls misting system.**
- `processPHSensor`: **Adjusts pH level.**
- `processTDSSensor`: **Monitors TDS levels.**

### Data Reporting

- `sendSensorData`: **Sends sensor data.**
- `sendComponentStatus`: **Sends actuator status.**
- `sendMetricData`: **Sends power consumption metrics.**

---

## Usage Example

### Setup

1. **Configure Wi-Fi credentials (`ssid`, `password`).**
2. **Set the server's IP and port (`serverAddress`, `serverPort`).**

### Execution

- **The system continuously monitors sensors, processes data, and adjusts actuators as needed.**
- **Reports data periodically to the server.**

---

# Troubleshooting

## Common Issues

1. **Wi-Fi Connection Fails:**
   - **Ensure the correct `ssid` and `password`.**
   - **Check if the server is reachable.**
2. **Sensor Initialization Errors:**
   - **Verify sensor connections.**
   - **Check I2C addresses and configurations.**
3. **Abnormal Readings:**
   - **Check sensor calibration and placement.**

College of Engineering

Batangas State University

The National Engineering University

Alangilan, Batangas City

Proponents:

**20-06252 | BAUTISTA, NIÑO LUIS BERNABE M.**

**20-06612 | CANTOS, WYNN ELDON P.**

**20-04390 | FACTOR, JOHN KENNEDY C.**

**20-08175 | SANDOVAL, JEREMY L.**

Group No. 4~ BSEE 4209

Submitted To:

**ENGR. MARJORIE M. SALVA**

EE 411 INSTRUCTOR

**AY - 2024**

# DECLARATION

This project study, entitled **"GREENHOUSE MANAGEMENT SYSTEM: AUTOMATED CONTROL OF SHADING, MISTING, WATER CIRCULATION, PH LEVEL, AND WATER TDS MONITORING,"** is a presentation of the proponents' original work. Wherever contributions from others are involved, every effort is made to indicate this clearly, with due reference to the literature and acknowledgement of collaborative research and discussions. This project study was done under the guidance of the project study adviser, **ENGR. MARA JESSA B. MACARAIG.**

Bautista, Nino Luis Bernabe M.

Cantos, Wynn Eldon P.

Factor, John Kennedy C.

Sandoval, Jeremy L.

## APPROVAL SHEET

The project study entitled **"GREENHOUSE MANAGEMENT SYSTEM: AUTOMATED CONTROL OF SHADING, MISTING, WATER CIRCULATION, PH LEVEL, AND WATER TDS MONITORING,"** was prepared and submitted by **Bautista, Nino Luis Bernabe M., Cantos, Wynn Eldon P., Factor, John Kennedy C., and Sandoval, Jeremy L.,** in partial fulfillment of the requirement for the degree of BSEE is hereby recommended for an oral examination.

______________________________

**ENGR. MARA JESSA B. MACARAIG**

Approved by the Committee on Oral Presentation with a grade of ___________.

**PANEL OF EXAMINERS**

______________________________

**ENGR. ELENOR M. REYES**
CHAIRMAN

______________________________

**ENGR. DINDO T. ANI**
MEMBER

______________________________

**ENGR. RICHARD DEAN M. BRIONES**
MEMBER

Accepted and approved in partial fulfillment of the requirements for the degree of **BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING.**

______________________________

**DATE**

______________________________

**DR. CRISTINA AMOR M. ROSALES**
DEAN, CoE

## CAPSULE PROPOSAL

Automation has a huge impact on society since it increases productivity and efficiency. This creates new opportunities for technology focused businesses as well as the displacement of jobs. Automation transforms industries by maximizing operations, guaranteeing precision, and fostering consistency while minimizing human interaction. A future where technology and human skills work together to create efficient operations begins to take shape as it spreads. Furthermore, agriculture is essential to international trade, the production of jobs, and economic growth since it combines innovation, expertise, and technological technology. To meet the increasing demand for food while automating difficult duties and reducing the impact on the environment, creative solutions are crucial.

The Greenhouse System creates ideal conditions for maximum plant growth and productivity, modernizing contemporary agriculture. It is perfect for typhoon-prone regions like the Philippines because it shields crops from bad weather and pests. When combined with hydroponics, which cultivates plants in nutrient solutions without soil, high-quality produce and decorative plants can be grown all year round. A important hydroponic crop, lettuce, grows well with greenhouse automation that regulates temperature, humidity, and ventilation precisely. Compared to conventional farming methods, this approach offers a significant gain in production and sustainability.

The purpose is to create an innovative greenhouse management system that supports a few Sustainable Development Goals and adheres with industry requirements. The practical significance of this research on expanding agricultural technology is

highlighted by the implementation of this advanced system at San Isidro, Batangas City. This research could lead to increased food efficiency, less human involvement, the development of sustainable communities, and a greater integration of technology in the agriculture sector.

**KEYWORDS:** Automation, Greenhouse System, Hydroponics, San Isidro, SIMCO

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First and foremost, to the Almighty God, who always gives guidance and undying love, for never-ending support, courage, strength and knowledge to provide which made possible the completion of this research;

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To their friends and fellow students, who were always there to motivate them and give them moral support;

To Engr. Mara Jessa Macaraig, our Project Design I, Thesis Adviser, for the supervision, insightful criticism and suggestions about the research paper and for her valuable directives;

To all the authors of the book and unpublished materials used by the researchers to gather more useful information for their study.

We are sending our warmest gratitude to all of you.

## DEDICATION

The study is dedicated, first and foremost, to Batangas State University - The National Engineering University, our beloved University, for supplying us with the information that we have employed for this research.

We also dedicate this work to our project beneficiary, SIMCO, in the hope that this project will significantly benefit them.

Wholeheartedly, we dedicate the completion of this research to all of the people behind our success.

To our Almighty God, to our beloved families, to our skilled professor, Engr. Marjorie M. Salva, to the Chairman and panel members, to the evaluator, and to our friends and loved ones.

The research will never be possible without all of you.

**N.L.B.M.B**

**W.E.P.C**

**J.K.C.F**

**J.L.S**

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# CHAPTER I

# INTRODUCTION

This chapter presents the introduction, background to the study, statement of the problem, research objectives, research questions, significance of the study, scope and delimitation and definition of terms.

## 1.1 BACKGROUND OF THE STUDY

Automation impacts our society by increasing efficiency and production, resulting in job displacement while also creating new opportunities for technology-focused companies. It involves using technology to perform activities with minimal human intervention, resulting in a major change in the industries. The adoption of automation technologies, incorporating different methods and processes, improves the efficiency, reliability, and speed of tasks that were previously conducted by human workers. This shift not only optimizes operational workflows but also promotes precision and consistency across various sectors. As automation becomes more widespread, it emphasizes the potential of a future characterized by efficient and reliable operations, where human and technological expertise work together to improve productivity and overall performance. [1]

Agriculture is the practice of cultivating natural resources to sustain human life and provide economic gain. It combines the creativity, imagination, and skill involved in planting and raising animals with modern production methods and new technologies. Agriculture impacts global trade because it’s tied to other sectors of the economy, supporting job creation and encouraging economic development. Countries with strong

agricultural sectors experience employment growth in other sectors, according to the United State Agency for International Development (USAID). Countries with agricultural productivity growth and robust agriculture infrastructure also have higher per capita incomes, since producers in these countries innovate through technology and farm management practices to boost agricultural productivity and profitability. Innovative solutions are required to meet the world's growing food demand while reducing farming's environmental impact and automating manual processes.[2]

The Greenhouse System optimizes environmental conditions to increase plant growth with maximum yield possible time, which is one of the primary goals of the modern agricultural system. Greenhouses have long been recognized as a means of improving crop productivity and quality. They provide a controlled environment, protecting crops from adverse weather conditions, pests, and diseases. However, even within the protected confines of a greenhouse, maintaining optimal weather conditions remains a significant challenge due to the dynamic and unpredictable nature of external factors. [3]

Internet of Things (IoT) enables real-time monitoring and control of environmental factors such as temperature, humidity, water circulation, and nutrient levels, allowing farmers to optimize crop growth while minimizing resource waste. [4] IoT ensures that ideal growing conditions are consistently maintained by automating adjustments based on sensor data, resulting in improved crop yields and quality while significantly reducing the need for manual intervention.

Hydroponics is the cultivation of plants in a liquid nutrient solution with or without the use of artificial medium. Hydroponics has been recognized as a viable way

of producing vegetables (tomatoes, lettuce, cucumbers, pechay, and kangkong) as well as ornamental crops such as herbs, roses, freesia, and foliage plants. Because of the ban on methyl bromide in soil culture, the demand for hydroponically grown produce has risen significantly in recent years.[5]

Lettuce (Lactuca sativa) is the fourth most important vegetable crop grown hydroponically in greenhouses preceded by tomatoes, cucumbers and peppers. Although greenhouse production of lettuce is very small in comparison to field grown, it has a specific market niche as a gourmet, high-quality item. Hydroponic farming revolutionizes conventional farming practices and contributes to a greener future by providing a sustainable and effective technique for growing lettuce.[6]

Greenhouse automation, the focal point of the study, confronts the challenges in lettuce production head-on by effectively incorporating technology and automation into the hydroponic cultivation process within the greenhouse. This approach provides a complex method to regulate vital factors like: temperature, humidity, and ventilation, resulting in an environment that is perfectly suited to the particular requirements of lettuce throughout its entire growth cycle. In lettuce production, the significance of this technology becomes apparent when compared with traditional manual processes.

The Sustainable Development Goals (SDGs) represent a global commitment to addressing some of the most issues confronting humanity. Adopted by all United Nations Member States in 2015, these 17 goals serve as a universal call to action to end poverty, protect the planet, and ensure prosperity for all by the year 2030. By optimizing irrigation practices through automated hydroponic systems, the project contributes to SDG 6 (Clean Water and Sanitation), addressing the goal of ensuring sustainable water management.

Additionally, the adoption of sustainable farming practices and the reduction of carbon footprints align with SDG 13 (Climate Action). Furthermore, the research contributes to the preservation of terrestrial ecosystems, supporting SDG 15 (Life on Land) by promoting efficient and sustainable agricultural practices that minimize environmental impact on land and biodiversity. In addressing these SDGs collectively, the research aims to make a positive and comprehensive contribution to global sustainability efforts, tackling issues related to water, energy, climate change, and ecosystems.[7]

In the community of Brgy. San Isidro, Batangas City, the project beneficiaries are local farmers who have embraced innovative agricultural practices to enhance their productivity. Being the main implementation to their efforts is a greenhouse, which is an important asset that was intended to optimize crop growth and ensure year-round agricultural output.

This greenhouse is already powered by solar panels, representing a significant step towards farming by renewable energy to reduce operational costs and environmental impact. However, despite its potential, the greenhouse has been non-functional, making its advanced infrastructure for not being used. Revitalizing this facility not only promises to enhance the local economy but also aligns with the broader goals of sustainable development and energy efficiency within the community. The restoration and optimization of this greenhouse is to transform agricultural practices in Brgy. San Isidro, advocating both economic growth and environmental care.

The greenhouse measures 3.65 meters wide by 4.6 meters long, at a height of 2.3 meters. Its rectangular shape maximized the available growing space, allowing for efficient use of the 16.79 square meters of floor area. The structure's height provided

enough room for taller plants and allowed for proper air circulation, creating an ideal climate for nurturing lettuce. The greenhouse's dimensions were chosen to accommodate the specific needs of the plants being cultivated, ensuring optimal growing conditions and maximizing the potential for a successful harvest.

In this study, the implications of the technology extend well beyond the agricultural sector. Greenhouse automation not only ensures food security by allowing for consistent crop production, but it also has the potential to reduce agriculture's environmental impact. It aligns with the broader goals of environmental sustainability and resilience by minimizing resource use and waste. The design and development of the greenhouse management system represents agricultural innovation in this context. This research will provide insight into the various components of these systems, from their design principles to the incorporation of modern technologies, as well as their potential for altering agriculture's future. This study adds to a growing body of knowledge by addressing the pressing need for automated lettuce production.

## 1.2 STATEMENT OF THE PROBLEM

Greenhouses play an important role in modern agriculture by creating controlled environments optimal to the growth and yield of lettuce crops. However, the effectiveness of greenhouse operations relies heavily on maintaining precise weather conditions for optimal lettuce production. External factors such as temperature, humidity, TDS Level, pH level and changing light intensities pose significant challenges to greenhouse operators.

The primary issue facing the beneficiary in Brgy. San Isidro, Batangas City, is the non-functionality of their existing greenhouse, which is powered by solar panels. Despite

the significant investment in this advanced agricultural infrastructure, the greenhouse remains underutilized, preventing the farmers from producing crops with its potential benefits. The restoration and optimization of the greenhouse facility are essential steps toward achieving these goals.

Implementation of Internet of Things (IoT) can effectively address challenges in greenhouse management by enabling real-time monitoring and automated control of key environmental factors such as temperature, humidity, and nutrient levels. Sensors continuously gather data, providing farmers with immediate insights and allowing for automatic adjustments when conditions exceed set thresholds.[8]

Light serves as a fundamental catalyst for photosynthesis, the process crucial for the synthesis of essential nutrients and plant growth. Adequate light exposure is essential for healthy development, photosynthesis, and nutrient uptake all of which have an impact on overall plant health and nutritional status. Some studies have found that simultaneous increases of light intensity and temperature within a practical range could significantly facilitate lettuce's growth and nutritional value. Regular monitoring of light levels and adjustments based on plant response is key to achieving the best results in lettuce cultivation. [9]

Temperature and humidity play an important role in the successful cultivation of hydroponic lettuce. Lettuce is a cool-season crop that thrives in specific temperature ranges, with the optimal temperature for growth being between 20 to 24°C (68 to 75°F.[10] Maintaining the proper temperature is essential, as lettuce can bolt (rapidly shoot up to go to seed) when exposed to temperatures exceeding 80 to 85°F (26 to 29°C), making the lettuce unmarketable.[11]

Relative humidity (RH) is another factor in hydroponic lettuce production. The ideal RH range for lettuce is between 50 to 70 percent. High humidity, exceeding 70%, can lead to issues such as tip burn, a physiological disorder caused by a calcium deficiency. The higher the RH, the less transpiration occurs in the plant, resulting in inadequate calcium uptake. Conversely, RH lower than 50% can cause outer leaf edge burn, another physiological disorder.[12]

Water is the medium in which plants absorb nutrients, plants are grown in a nutrient-rich solution instead of soil. It is possible to attain great yields and high quality in hydroponics. When water and nutrients are supplied in the required quantities, characteristics emerge. The nutrients and water needed by the plants are calculable. However, the water quality given is as crucial, but the quality (the salt and nutrient content) is generally fixed. As a result, it is critical to understand the water quality being used and, as a result, what fertilization modifications are required. [13]

The Nutrient Film Technique (NFT) hydroponic system relies on a continuous flow of nutrient-enriched water to provide plants with the necessary moisture and nutrients. In a typical NFT setup, a submersible pump circulates the water from the reservoir, through the channels where the plants are situated, and back to the reservoir in a constant loop.

However, it indicates that some NFT growers have found it beneficial to put the pumps on cycles, effectively flooding and draining the system, rather than running the pump continuously. This is done to address a key drawback of the NFT system, the constant submersion of the roots in the water film, which can limit aeration and lead to

issues like root rot and bacterial diseases.By cycling the water flow, the growers are able to provide the plants with intermittent periods of water and air exposure, which can improve oxygenation and overall plant health.[14]

Total Dissolved Solids (TDS) refers to the cumulative measurement of inorganic salts, minerals, and other dissolved substances present in the water and nutrient solution used in hydroponics. These substances include essential nutrients such as nitrogen, phosphorus, potassium, and micronutrients like calcium, magnesium, and iron. By measuring TDS, growers gain an overall understanding of the nutrient concentration in their hydroponic systems. The plant species, development stage, and nutrient solution formulation all affect the optimal TDS range. Most hydroponic crops do best with a TDS range of 800 to 1500 parts per million (ppm). [15]

In hydroponics, maintaining the right pH level is important for plant health and nutrient absorption. The pH scale ranges from 0 to 14, with 7 being neutral. Most plants survive in a slightly acidic to neutral range, between 5.5 and 6.5. Different plants have specific pH preferences, and maintaining the correct pH ensures they can access important nutrients. pH levels can change due to various factors, such as nutrient concentration, growing media, and organic matter like algae and bacteria. Regular testing and adjustments are necessary to keep pH levels stable.

There are several methods for testing and adjusting pH levels, including test strips, liquid kits, and digital pH meters. For consistent pH control, automatic pH controllers are recommended, especially in recirculating systems. Maintaining the right pH level in hydroponics ensures plants can absorb nutrients properly, leading to healthier

and more productive growth.[16]

These automation systems are specifically crafted to intelligently control and manage the overall lettuce production in real-time, ensuring a more efficient and consistent cultivation process. Despite the potential benefits they offer, greenhouse automation systems particular for hydroponic lettuce production face several critical problems and challenges that require careful investigation and resolution during the design and development phases.

## 1.3 RESEARCH QUESTIONS

7. What are the design standards, requirements, and considerations for automated control of shading, misting, water circulation, pH level, and TDS monitoring?
8. What are the methods and procedures needed for the fabrication, construction, and assembly of an automated control of shading, misting, water circulation, pH level, and TDS monitoring?
9. What tests are necessary to determine the machine's reliability and efficiency?

## 1.4 RESEARCH OBJECTIVES

The main objective of the study is to design and develop the automated control system of shading, misting, water circulation, pH Level, and TDS monitoring. Specifically, this aims to achieve the following:

7. To design the system in terms of:
   - 1.1 General Description of the Project
   - 1.2 Design Standards
   - 1.3 Design Computation and Analysis
   - 1.4 Design Layout

1.5 Circuit Diagram
1.6 Materials and Components
1.7 Programs and Its implementation
1.8 Bill of materials and specifications

8. To develop the System in terms of its methods of fabrication and assembly.
9. To evaluate the overall system performance in terms of:

3.1 Functionality Test
  3.1.1 Shade Net Control Test
  3.1.2 Climate Control & Misting Control Test
  3.1.3 pH Level Control Test
3.2 Performance Testing
  3.2.1 Growth Stage of Lettuce

**1.5 SCOPE AND DELIMITATION OF THE STUDY**

The research will be carried out at Brgy. San Isidro, Batangas City, Philippines. This venue is ideally suited due to its established infrastructure for hydroponic farming, providing a relevant setting for testing the proposed automated control system. The hydroponic greenhouse measures 3.65 by 4.6 meters with a height of 2.9 meters.

The study focuses on developing a smart greenhouse system that will control the environment inside the greenhouse. Innovating the greenhouse through the use of a retracting shading net that will automatically adjust the environment condition especially when excess sunlight is detected. According to the design, the proposed shade net will be string-pulled by a stepper motor that is automatically operated by a microcontroller. By implementing this shading net, the internal environment of the greenhouse can be optimized, ensuring that plants receive the right amount of sunlight without being exposed to excessive heat or light levels, ultimately enhancing their growth and

productivity.

Moreover, the study aims to develop a misting system for the greenhouse. The mister is mounted underneath the roof within the greenhouse railings. The water supply for the misting is directly connected to the water distribution utility and is automatically controlled by a microcontroller such as the Arduino Mega.

The study also involves designing the watering system. The goal is to implement automated controls of watering schedules based on real-time data related to crop needs and environmental conditions. The proposed watering system will operate every 15 minutes within an hour.

pH sensors will be installed in the greenhouse to continuously monitor the acidity and alkalinity of the water. These sensors will provide real-time data that can be used to adjust irrigation, fertilization, and other environmental factors as needed. The TDS sensor will only be used to monitor the dissolved combined contents in the water. By maintaining optimal pH and TDS levels, the greenhouse can provide ideal conditions for the plants.

To achieve precise control over the entire system, an automated controller, such as Arduino Mega, is necessary. The Arduino utilizes a simplified C++ language for its syntax, and its libraries are also simplified for ease of use.

The electrical system would be sourced from a 12VDC that was supplied by the solar panel that were stored by the battery. All components were operated thru DC voltage as per requirement of most of the electrical parts. The overall electrical system would be operated off-grid as it is a low power system.

The project will adhere to standards set by the Philippine Electrical Code (PEC)

and the National Electrical Manufacturers Association (NEMA) for all electrical installations and components. Additionally, the agricultural construction will follow best practices in greenhouse design, considering local climate conditions and agricultural standards required by the PEC to minimize the risk of accidents. A smart greenhouse system will be developed and tested in collaboration with a private individual who owns the greenhouse. Despite the fixed size of the greenhouse, it will serve as a practical testbed, providing valuable insights and feedback for refining the smart greenhouse system and exploring potential future applications in agriculture.

However, certain limitations are essential to the project. Budget constraints dictate the scale and complexity of the automation system, and technological limitations may affect the feasibility of advanced features. Time constraints also play a role, influencing the depth and span of research, experimentation, and analysis.

Therefore, all the other types of lettuce other than batavia lettuce would be disregarded to be used or simply not optimally designed to be raised in this specific kind of greenhouse. This automation is only the production and does not include the planting process of lettuce which is classified as the germination. Geographical considerations acknowledge that the applicability of the system may vary based on different climatic and geographical conditions.

## 1.6 IMPORTANCE OF THE STUDY

The research aims to establish a solar powered greenhouse that helps in automating the whole process of production of lettuce within the greenhouse. This study can create great impacts to the following people in particular:

**To Greenhouse Owners.** The study's findings will provide greenhouse owners

with insights into how to optimize their plant growth conditions, particularly regarding sunlight exposure. By incorporating the smart greenhouse system, they can expect improved plant health and productivity, ultimately leading to increased yields and profits.

**To the Local Community and Agricultural Sector.** The implementation of the smart greenhouse system has the potential to contribute to the local agricultural sector's sustainability and growth. By enhancing the efficiency and productivity of greenhouse operations, the study aims to create a positive ripple effect, benefiting not only individual greenhouse owners but also the broader agricultural community.

**To the Electrical Engineering Department of Batangas State University.** The study serves as a platform for the Electrical Engineering Department to showcase its expertise in developing innovative solutions for real-world problems. By collaborating with a private individual and focusing on the practical application of electrical engineering principles, the department can demonstrate its commitment to addressing societal needs through research and development.

**To the Researchers.** The study presents an opportunity for researchers to contribute to the advancement of knowledge in the field of smart greenhouse systems. By conducting thorough investigations, designing and implementing the system, and analyzing its performance, researchers can deepen their understanding of the complex interactions between technology and agriculture, paving the way for future research endeavors.

**To Future Researchers:** The study's findings and methodologies can serve as a valuable resource for future researchers interested in smart greenhouse systems or related fields. By documenting the challenges, solutions, and lessons learned, the study can

provide a foundation for further exploration and innovation in agricultural technology.

# CHAPTER II

# LITERATURE REVIEW

This chapter discusses the review of literature used in the study. The discussion of literature is divided into two parts: conceptual literature and related literature. A synthesis regarding how the following studies would be used as well as the discussions regarding the similarities and differences of the study to those existing publications is also presented.

## 2.1 CONCEPTUAL LITERATURE

This section is concerned with various concepts that will be useful for this study. The information provided in this chapter is derived from books, publications, and websites.

### Principles and Theories of Automation

Automation is a fundamental idea and principle in the engineering fields, as well as in industrial civilization (manufacturing, processes, industries, etc.). Automatic machines are used to increase a plant's output per worker in order to lower growing wages and the production expenses that go along with it. High productivity can be achieved using automatic systems without sacrificing accuracy and precision. Therefore, automation is the process of reducing human intervention in machine operation and directly replacing it with technologically advanced systems like computers, robotics, etc.[17]

Automated systems generally outperform manual systems in terms of productivity, speed of operation, accuracy, and precision. Automation is applicable to a wide range of systems, from simple household appliances to complex industrial activities.

The control systems might be as simple as ON/OFF buttons or as complex as multivariable high-level algorithms. Industrial automation employs control systems and information technology to manage a variety of machinery and processes. Automation has made manufacturing lines much more flexible, resulting in higher output quality and quantity.

**Principles and Theories of Greenhouse**

A greenhouse is an external structure for growing plants, primarily made of a transparent material like glass or polycarbonate panels. In order for a greenhouse to function, as much light as possible must be let in and then stored as heat energy. All of the daylight is able to enter the greenhouse due to its transparent roof and walls. The greenhouse's soil and plants both become warmer as a result of this light. However, because glass is an insulator as well, the heat is trapped inside the structure, maintaining a comfortable temperature throughout the day. Maintaining a steady temperature is a big advantage of greenhouses. Even after the sun sets, the greenhouse remains warm because materials like water and soil within it absorb thermal energy from sunlight and release it gradually. The greenhouse is enclosed, so there isn't a breeze to release the heated air. Your plants remain comfortable as a result of the consistent temperature, which is typically quite warmer than the sudden cold temperatures we experience outside. In addition to being protected from inclement weather, they receive all the sunshine required for wholesome growth. [18]

According to the Philippine Agricultural Engineering Standard (PAES), gable roof greenhouses are required to adhere to specific height guidelines. The standard stipulates that the eave height, which is the distance from the ground to the point where

the roof begins, should be a minimum of 1.70 meters. Additionally, the gable height, which is the vertical distance from the eave to the highest point of the roof, must not be less than 2.4 meters. These specifications ensure that gable roof greenhouses comply with established standards to meet structural and functional requirements in agricultural engineering.[19]

**History of Greenhouses Development**

Historically, people have been using greenhouses for protecting plants from harsh weather conditions since ancient times. Here, the history of greenhouse development has been discussed. The first notes about greenhouses can be traced to the reign of Tiberius, Roman emperor from 14 to 37 CE. The Roman emperor Tiberius ate a cucumber-like vegetable daily, requiring Roman gardeners to discover artificial methods, similar to a greenhouse system, to grow it year-round. The gardeners first tried to install cucumber plants on carts so they could drag them into sheds when it became too cold. But if the cold lasted more than a few days, the cucumbers would start to die from lack of light. But someone came up with the idea of covering the structures not with slate, but sheets of selenite, a transparent rock, to let the sun in.[20]

There are nine greenhouse farming in the Philippines: Albay, Bulacan, Cavite, Laguna, Leyte, Negros Occidental, Nueva Ecija and Pangasinan. The five major greenhouse in the country are located in Albay (1,000 hectares), Cavite (500 hectares), Laguna (1,000 hectares), Leyte (2,000 hectares), and Negros Occidental (1,000 hectares). With ample sunlight and fertile soil, the Philippines is perfect for greenhouse farming. Philippines is estimated to have a production capacity of 6-7 million plants per year. The main challenges facing the Philippines greenhouse industry is logistics, it's difficult to get

produce from rural areas into urban centers where it can be sold and distributed to customers.[21]

### Types of Greenhouses Based on Covering Materials & Construction

### Glass Type Greenhouse

**Figure 2.1** Glass Greenhouses (Source: Gothic Arch Greenhouses)

Glass is used as covering material in glass greenhouses. As a covering material it has the advantage of greater interior light intensity, has a higher air infiltration rate, and leads to lower interior humidity and excellent disease prevention quality. Ridge and furrow, lean-to type, even span type of designs are used for construction of glass greenhouse.[22]

**Plastic Film Type Greenhouse**

**Figure 2.2** Polyethylene Plastic for Greenhouses

The covering materials of flexible plastic including polyvinyl chloride, polyethylene and polyester are used in this type of greenhouses. As a covering material for greenhouses, plastics are more popular, cheap and the heating cost as compared to glass greenhouses. Plastic lms have a short lifespan which is the main disadvantage of this covering material. For example, the best quality ultraviolet (UV) stabilized can last for four years only. Quonset design as well as gutter-connected design is suitable for using this covering material.[22]

**Shade Cloth Type Greenhouse**

**Figure 2.3** Perfect Shade Cloth for Your Greenhouse

Shading is a way of keeping the greenhouse cool during the hotter months. It reduces the temperature inside by minimizing the amount of light passing to the greenhouse. Shade clothes typically reduce the light level by 75% and turn it into heat. The temperature of the cloth rises as it acts as a solar collector. The temp of the cloth is higher than the temp of the air, so the heat energy goes up. As it goes up, the cool air draws from below in the process known as evaporative cooling. The most common materials for the cloth are polyethylene and polypropylene. You can find a variety of shade cloths of different densities and degrees of shade ranging from 5 to 95 per cent.[22]

**Principles and Theories of Greenhouse Management**

Greenhouse management is crucial for maximizing efficiency and productivity in commercial greenhouse plant production. It encompasses a comprehensive approach, addressing various aspects such as the design and structure of greenhouses, environmental control systems, heating and cooling mechanisms, selection and maintenance of growing media, effective fertilization strategies, optimal carbon dioxide supplementation, precise irrigation techniques, and diligent pest management.

Moreover, it also includes the production of container-grown crops, ensuring that all components work in harmony to create ideal growing conditions. This holistic approach not only enhances plant growth but also promotes sustainable agricultural practices, making it an essential element in the success of commercial greenhouse operations.[23]

**Application Automated Greenhouse Management**

The application of automation in greenhouse management has developed the agricultural industry by combining modern technology with traditional farming. This

ensures optimal growth conditions for plants, reduces labor costs, minimizes errors, and guarantees consistent production. With the challenges posed by environmental changes and global warming, these smart and automated systems offer sustainable solutions for future agriculture.[24]

**Figure 2.4** Automated Greenhouse System by the University of Arizona

At different growth stages, plants need varying light types and intensities. Utilizing plant-specific light modulators guarantees that they receive the appropriate light when needed.[24]

**Figure 2.5** Retractable Shade Net

Figure 2.5 shows the retractable shade net that protract and retract with the use of pulley and rope. The Filipino farmers call it “automatic” because the manual work for them is when the workers will pull the end of the shade net to the other side to stretch it.[25]

The irrigation approach varies based on the plant type and farming conditions. Although drip and flood irrigation are common, modern farming practices are increasingly favoring tidal irrigation. Essential tools for effective irrigation management include water flow sensors, flow meters, electromagnetic valve controllers, water temperature sensors, and liquid level sensors. By utilizing these devices, one can more accurately regulate and supervise the irrigation process to ensure plants receive adequate water.[24]

**Figure 2. 6** Commercial Greenhouse Irrigation

**Principles and Theories of Hydroponics**

The word hydroponics comes from Latin, where "hydro" means water, and "ponos" means work. In hydroponics, plants grow in water instead of soil. When plants grow, they use light and chlorophyll to turn carbon dioxide and water into sugar and

oxygen through a process called photosynthesis. The interesting thing is that you don't see the word "soil" in there. That's because plants can grow without it. What they really need is water and nutrients, usually found in the soil. But if they can get those things somewhere else, like standing in a solution full of nutrients, they can do without soil altogether. This fundamental idea forms the basis of hydroponics. While the literal interpretation of "hydroponics" implies growing plants in water (derived from Greek words meaning "water" and "toil"), the commonly accepted definition involves cultivating plants without the use of soil.[26]

**Hydroponics System**

Growing plants hydroponically involves utilizing a water-based nutrition solution in place of soil, together with an aggregate substrate or growing media like perlite, vermiculite, or coconut coir. Commercial enterprises, hobbyists, and small farmers all use hydroponic production systems.

**Types of Hydroponics System**

9. **Nutrient Film Technique (NFT)**

The NFT (nutrient film technique) is a widely used hydroponic method where plants' roots are suspended in the air above a growing medium like gravel or perlite. A nutrient solution is pumped through this medium, flowing over the roots, before returning to the reservoir. Coined by Allen Cooper in 1965, the technique involves a shallow stream of water, hence the name "nutrient film technique." It's favored by commercial growers due to its simplicity in maintenance and fewer potential complications.[27]

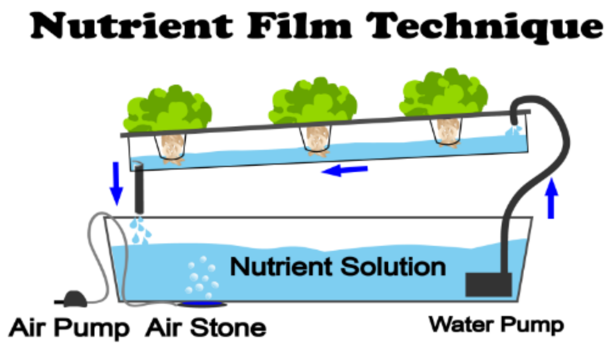


**Figure 2.7** Nutrient Film Technique

The fertilizer solution flows into channels that may support a variety of plant sizes in NFT hydroponics systems. Because the tubes are somewhat inclined, the nutritional solution runs through them, over the dangling roots of the plants, and then back into the hydroponic reservoir.[27]

**10. Deep Water Culture (DWC)**

Deep water culture (DWC) systems involve continuously immersing plant roots in a nutrient solution within a single basin, with an air stone at the bottom to aerate and oxygenate the water. Because it is simpler and easier to set up than more complex systems like aquaponics or aeroponics, this method is popular among new hydroponic gardeners. DWC is considered a passive system because it does not continuously recirculate water and nutrients. An air stone is required to improve oxygen circulation, which contributes to the system's success in maintaining suitable conditions for plant growth.[28]

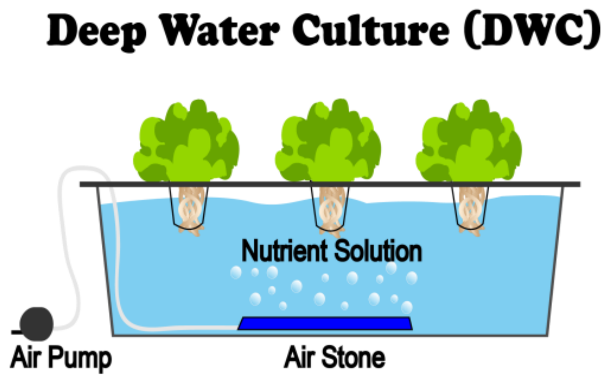


**Figure 2.8** Deep Water Culture

The roots of the plants in DWC hydroponic systems are suspended in the nutrient solution, and an air stone or diffuser delivers air straight to the roots. To help keep them secure, plants are placed in net pots filled with grow material.[28]

**11. Drip System**

Drip system hydroponics is a popular method in which nutrient solution is dripped onto plant roots and then recirculated back to the reservoir. It is an active hydroponic system that uses a pump to deliver nutrients and water to plants. Because of its drip mechanism, this system provides improved ecosystem control, allowing for precise management of the growing environment.[29]

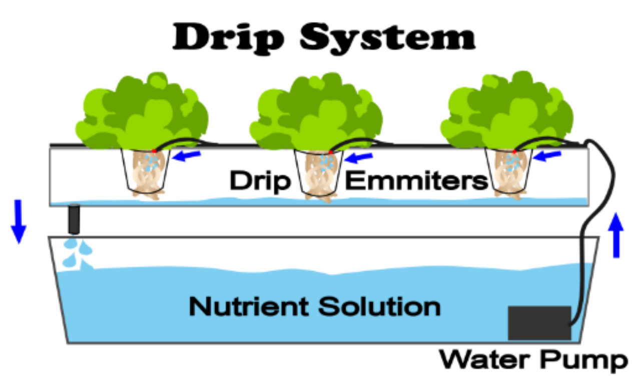


**Figure 2.9** Drip System

Drip hydroponic systems are perfect for people who frequently make adjustments because they are simple to use, set up, and adaptable in many ways. In these systems, the plant's base receives a direct supply of nutrients via tubes.[29]

**12. Aeroponics**

An improved form of hydroponics known as aeroponics involves suspending plants in the air and misting them with water on a regular basis using a timed sprinkler system that is linked to a primary nutrient reservoir. Because aeroponic roots aren't hindered by dense soil or thick growing media, this soilless growing technique is ideal for plants that require more oxygenation. Growing media is usually used sparingly or not at all by the grower, depending on the plant and type of aeroponics system.[30]

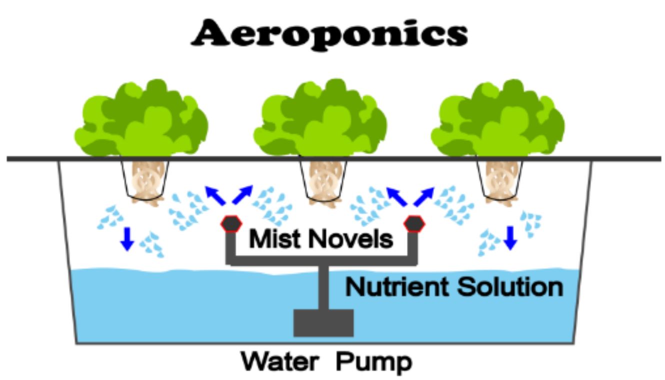


**Figure 2.10** Aeroponics

The piping that has mist nozzles installed is pumped with the nutrient solution. The solution returns to the reservoir as the pressure increases and the misters spray the plant's roots.[30]

**Significance of Light Intensity in Lettuce Cultivation**

Light intensity, or light quantity, refers to the total amount of light plants receive. This intensity drives photosynthesis, producing the carbohydrates that serve as the building blocks for plant growth. Unlike light quality, light intensity does not consider wavelength or color.[31]

Lux is a unit of measurement for illuminance, representing the amount of light that hits a surface. In the context of direct sunlight, understanding lux levels is essential for various applications, including agriculture, solar energy, and architectural design. On a clear day, direct sunlight typically ranges from 32,000 to 100,000 lux. Understanding sunlight lux helps optimize crop growth, ensuring plants receive adequate light for photosynthesis.[32]

**Conversion of Light Intensity to Lux**

Photosynthetic Photon Flux Density (PPFD) is a crucial unit used to measure the light that reaches a plant's canopy in the Photosynthetically Active Radiation (PAR) zone. This metric tells us the number of photosynthetically active photons falling on a given surface each second, expressed in $\mu mol/s.m^2$.[33]

$$Lux = PPFD \; x \; 54 \qquad \textbf{(Eq. 2.1)}$$

Where:

Lux = measurement of illuminance (lx)

PPFD = Photosynthetic Photon Flux Density

There are a few requirements that must be met while cultivating crops, tomatoes, lettuce, or cannabis in a big growing facility, our own backyard, or a grow tent. Enough air, water, and fertilizer are necessary for crops to grow well. Another thing to remember

is that everything grows in response to sunlight, and adequate light increases crop yields. When you have all of the above, your plants will grow healthily right away.

For most plants, the cold season is a difficult test of growth. Crops' metabolism will be significantly inhibited by low temperatures, which will postpone growth. We are all aware that sunshine is essential to plant growth and that sunlight influences plant growth in turn. As a result, plants cannot receive the optimal natural light during the day if they are placed in an interior dark space, and they will not grow normally and healthily. Nowadays, indoor planting is a highly popular option because it allows you to quickly adjust the growth environment to the crop's stage of development. This approach can be just as effective as the process of spontaneous growth if the right steps are done. Additionally, since grow light is a great alternative to sunshine for providing light supplementation to plants, you don't need to worry about the lack of light in the indoor setting.[34]

**Shade Net**

Shade net is a type of lightweight agricultural covering material that is primarily used for air permeability, wind proofing, heat and moisture preservation, and shading. An agricultural shade net may efficiently prevent excessive sunshine and high temperatures, lessen crop water evaporation, increase air humidity, and retain soil moisture all of which are favorable to crop growth. Furthermore, shade nets can operate as a windbreaker, lessening the effect of wind speed on crops while maintaining indoor air circulation, allowing for breathability, encouraging crop growth, and enhancing crop quality and yield.[35]

**Figure 2.11** Shade Net

The shade net regulates the amount of sunlight that enters, preventing overheating while maintaining optimal conditions for plant growth. Greenhouse shade nets work by blocking some sunlight, reducing intensity and minimizing temperature spikes within the enclosed space.[36]

**Pulley**


**Figure 2.12** Pulley

A pulley is a simple machine made up of a string (or rope) looped around a wheel (often with a groove), with one end connected to an object and the other to a human or a motor. Pulleys may appear basic, but they can provide a significant mechanical

advantage, making lifting duties much easier.[37]

**Shaft**

**Figure 2.13** Shaft

Shaft is basically the rotating component of any machine, which is round in the cross-section and is used for passing the power from one part to another or from the power producing machine to the power absorbing machine. A shaft is a rotating machine element, usually circular in cross section, which is used to transmit power from one part to another, or from a machine which produces power to a machine which absorbs power.[38]

**Determining the Allowable Stress of a Shaft**

The maximum allowable stress of a shaft depends on various factors, including material properties, loading conditions, and safety considerations.[39]

$$S_s = 30\%\ of\ S_y \qquad \textbf{(Eq. 2.2)}$$

Where:

$S_s = allowable\ stress\ for\ the\ shaft$ (MPa)

$S_y = yield\ strength\ for\ the\ material\ used\ for\ shaft$ (MPa)

**Determining Shaft Diameter**

Determining the correct diameter of a shaft is crucial for ensuring its strength, minimizing deflection, resisting fatigue, and maintaining safety and efficiency, all while balancing performance with cost and compatibility considerations. Proper sizing prevents mechanical failures, reduces vibration and noise, and ensure pps compliance with industry standards.[39]

$$D = \sqrt{\frac{8F}{\pi S_s}} \quad \textbf{(Eq. 2.3)}$$

Where:

$D =$ diameter of the shaft (m)

$F =$ tension force from the shade net and the weight of the shaft itself. (N)

**Determining Shaft Torque**

Shaft torque is the amount of rotational force needed to drive a machine or carry out another planned function for a shaft. The force is influenced by factors such as the applied load and the required rotational speed of the shaft.[39]

$$T = \frac{\pi D^3 S_s}{16} \quad \textbf{(Eq. 2.4)}$$

Where:

$T = torque\ (Nm)$

**Power Requirement**

The power requirement of a shaft involves calculating the power needed to perform a specific function, such as operating a machine or mechanical system. The calculation depends on the torque applied to the shaft and its rotational speed.[39]

$$P = 2\pi TN \qquad \textbf{(Eq. 2.5)}$$

Where:

$P$ = power (W)

$N = rotational\ speed\ (RPM)$

**TSL 2561 Sensor**

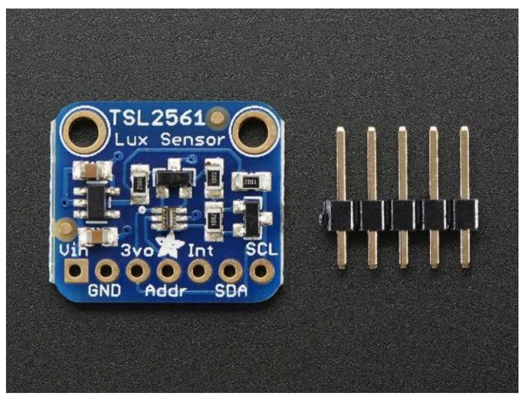


**Figure 2.14** TSL 2561 Sensor

The TSL2561 luminosity sensor is a digital light sensor that may be used in a variety of lighting conditions. Compared to low-cost CdS cells, this sensor is more precise, allowing for correct Lux metering, and it can be set for multiple gain/timing ranges to detect light levels ranging from 0.1 to 40,000+ Lux on its own. The best thing about this sensor is that it includes both infrared and full spectrum diodes! This means that you can measure infrared, full-spectrum, and visible light separately. Most sensors

can only detect one or the other, which does not exactly represent what human eyes see (since most photodiodes detect infrared light).[40]

**Importance of Misting System to maintain humidity and temperature**

The implementation of a misting system into farming practices brings about a significant improvement in managing plant growth. One of its main roles is to carefully regulate humidity, maintaining an optimal moisture level for plants. By releasing fine water droplets, the system strikes a balance, preventing issues caused by both too much and too little moisture. The precise control over humidity is crucial for ensuring the health and vitality of plants.

Misting system acts as a reliable protector against temperature fluctuations and excessive evaporation. When temperatures rise, the controlled mist cools the surroundings, shielding plants from the harmful effects of overheating. At the same time, it acts as a shield, reducing evaporation and preserving the necessary moisture levels. This dual function not only helps control temperature but also safeguards plants from the negative impacts of dehydration. [41]

**Determining Relative Humidity**

The amount of water vapor in the air is known as the "vapor pressure," wherein air can only hold a certain amount of water vapor at a given temperature before it starts condensing back to liquid in the form of rain. [42]

$$Relative\ Humidity = \frac{AVP}{SVP} X\ 100\% \qquad \textbf{(Eq. 2.6)}$$

Where:

$AVP = actual\ vapor\ pressure$

$SVP = saturation\ vapor\ pressure$

**Determining Flow Rate**

Flow rate refers to the quantity of fluid passing through a particular point in a system per unit of time. It is a key parameter for understanding and analyzing fluid behavior, as well as for designing and optimizing various systems and processes that involve the movement of fluids, such as pipelines, pumps, and ventilation systems. [43]

$$Q = \frac{V}{t} \quad \textbf{(Eq. 2.7)}$$

Where:

$Q = flowrate\ (\frac{m^3}{s})$

$V = volume\ (m^3)$

$t = time\ (s)$

**Mist Maker**

Misting nozzles are used to cool outdoor spaces in all sorts of industries and for all kinds of purposes, from public venues and commercial establishments to industrial plants and agricultural environments. It is useful because they create drops of water that are around 15 millionths of a meter, or microns, in width. The size of the droplets is crucial because they are small enough that they evaporate quickly, rather than collecting on everything around them.[44]

**Figure 2.15** Misting Nozzles

Misting nozzles  consist of a series of nozzles placed in a line. When attached to high-pressure pumps, water is forced through nozzles, forming droplets which evaporate into mist when they reach the outdoor air. This can reduce the temperatures by 35 to 40 degrees Fahrenheit. If the misting system is in a confined indoor area, it will provide a cool mist but will also increase humidity.[44]

**Humidity and Temperature Sensor**

A sensor is typically defined as an input device that generates an output signal in response to a physical quantity detected. The term "input device" in this case implies that the sensor is part of a larger system, giving data to a central control unit such as a processor or microcontroller. A sensor can also be defined as a device that converts signals from various forms of energy into electrical signals.[45]

Humidity sensors, also called hygrometer, are devices that detect and measure the amount of water vapor or moisture that is contained in the air, which can not only influence the level of comfort that is experienced by people and animals but also plays an important role in the production of products and other manufacturing processes. Being able to sense and measure the level of humidity is necessary in order to exercise control over it, such as by turning on the air conditioner in the summertime or a humidifier in the winter.[46]

Temperature sensor is an instrument that is constructed to sense the condition of coolness or hotness in the target. The fundamental working of this sensor is based on the voltage in its diode. The temperature variation is directly related to the resistance of this diode. The resistance of the diode is detected and transformed into simple and readable values of temperature such as Fahrenheit, Kelvin, or Centigrade and demonstrated in

meaningful formats instead of readout values. These temperature sensors are employed to sense the internal temperature of various structures like power plants.[47]

The DHT11 sensor is a widely employed temperature and humidity sensor, known for its reliability and ease of use in various applications. This sensor is equipped with a dedicated Negative Temperature Coefficient (NTC) element to accurately measure temperature and an 8-bit microcontroller responsible for transmitting temperature and humidity data as serial data. Additionally, the DHT11 sensor is pre-calibrated at the factory, simplifying its integration with other microcontrollers.

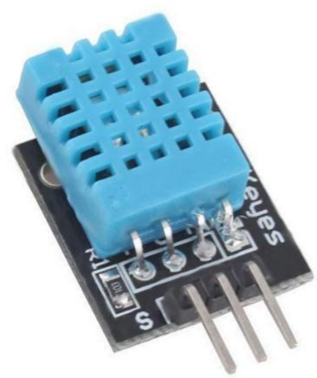

**Figure 2.16** DHT11-Temperature and Humidity Sensor

This versatile sensor is capable of measuring temperature within the range of 0°C to 50°C and humidity levels ranging from 20% to 90%. It boasts an impressive level of accuracy, with temperature readings accurate to within ±1°C and humidity readings accurate to within ±1%. If your research requires measurements within this temperature and humidity range, the DHT11 sensor stands as a suitable and dependable choice for your application.[48]

**Water Flow Rate & Volume Measurement**

**Figure 2.17** Water Flow Rate & Volume Measurement

A water flow sensor is made of a plastic valve through which water can pass. A water rotor and a hall effect sensor are present to sense water flow rate and monitor water volume. Water passes through the valve, causing the rotor to rotate. This allows the change in the motor's speed to be seen. The hall effect sensor calculates the change and outputs it as a pulse signal. Thus, the rate of flow of water may be determined.[49]

**Solenoid Valve**

**Figure 2.18** Solenoid Valves

Solenoid valves are control units which, when electrically energized or de-energized, either shut off or allow fluid flow. The actuator takes the form of an electromagnet. When energized, a magnetic field builds up which pulls a plunger or

pivoted armature against the action of a spring. When de-energized, the plunger or pivoted armature is returned to its original position by the spring action.[50]

### Solar Water Pump

A solar water pump operates by harnessing energy from the sun, which is converted into electricity by solar panels. These panels consist of photovoltaic cells that capture sunlight and transform it into direct current (DC) electricity.

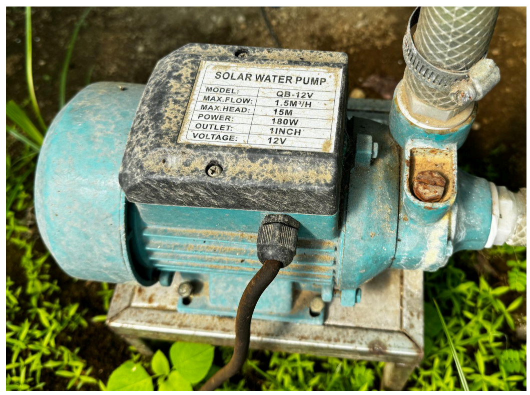


**Figure 2.19** Solar Water Pump

Solar water pump is used in a hydroponic system to circulate the nutrient and water to plants grown without soil. Solar panels convert sunlight into electricity, which then powers a surface pump to distribute the nutrient solution through the hydroponic setup.[51]

### Nutrient Solution

The nutrient solution is composed of key elements such as nitrogen, phosphorus, potassium, calcium, magnesium, and trace elements like iron, manganese, and zinc, all provided in precise concentrations to promote optimal plant growth. For example, the concentration of nitrogen might vary, presented in forms that plants can easily absorb,

such as nitrate and ammonium. The water quality used in preparing the nutrient solution is critical; it must be free from contaminants, and its pH and electrical conductivity (EC) must be maintained within specific ranges to ensure nutrient availability and uptake. Moreover, the nutrient solution in hydroponics can be recycled in a closed system, reducing water and nutrient waste and minimizing environmental impact. The system continuously supplies nutrients to the plant roots, recirculates the runoff, and adjusts the composition based on the uptake and transpiration rates observed in the plants, which can be monitored through changes in EC levels. This recycling process not only conserves resources but also controls the growth conditions more precisely, enhancing overall plant health and yield.[52]

**Nutrient Flow Control**

Maintaining proper nutrition is one of the most important parts of growing greenhouse crops. There are two components of crop nutrition that growers must address. One component of nutrition is the total amount of nutrients accessible to the plant. The absolute amount of nutrients required by a plant increases as its size and fruit load rise. A key principle to understand about fertilization is that plant development is regulated by the mineral nutrient in the shortest supply, even when other nutrients are abundant. The second part of nutrition is the appropriate ratio or balance of nutrients accessible to the plant. Maintaining the right balance between vegetative growth and fruit load is critical to the crop's long-term output. When nutrients are not balanced, serious shortages or toxicities can emerge.

To control nutrition, growers must have a quick and dependable technique of monitoring the nutrient status of the cropping medium. A conductivity meter and a pH

meter are necessary tools. The pH of the medium influences the availability of individual nutrients. As a result, as the pH changes, so does the crop's nutrient balance. Understanding the nutrients needed to grow plants is simply one part of successful crop production. Optimum yield also necessitates understanding the rate to apply, the technique and timing of application, the source of nutrients to employ, and how the components are affected by substrate and greenhouse environmental conditions. [53]

**Hydroponic Solution**


**Figure 2.20** Solution A and B

Hydro A and Hydro B. This system divides essential nutrients into two separate solutions, allowing for optimized nutrient uptake and reduced interaction conflicts. Hydro A is enriched with calcium, crucial for enhancing plant structural strength and heat tolerance, while Hydro B provides magnesium, essential for chlorophyll production and energy transfer within the plant. This method facilitates precise control over the nutrient environment, crucial for maximizing plant health and productivity.[54]

## pH Down

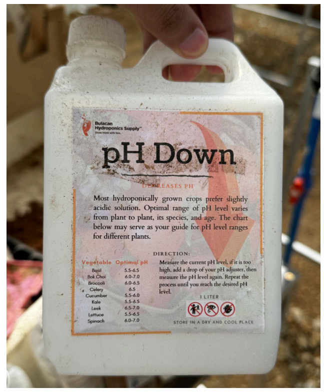


**Figure 2.21** pH Down Solution

pH Down is a phosphorus-based pH control additive that effectively reduces water pH levels, which is essential for hydroponics, aeroponics, sprinklers, and irrigation systems. Maintaining the proper pH is essential for efficient nutrient absorption, resulting in healthier and more vigorous plant development.[55]

## Importance of pH Level in Hydroponics

The pH value in hydroponics refers to the acidity or alkalinity of the nutrient solution, with readings ranging from 0 to 14 (0-6 being acidic, 7 neutral, and 8-14 alkaline). For general hydroponic solutions, the recommended pH level falls between 6 and 6.5 (Nicholls, 63). Various factors can influence pH levels, including temperature, light intensity, evaporation, the quality of tap water, and the quantity of nutrients.

Given the numerous variables affecting pH, regular monitoring is important to maintain an optimal environment for plant growth. Adjusting the pH level can be achieved simply: to reduce acidity, add one tablespoon of baking soda to three gallons of solution, while to decrease alkalinity, add one tablespoon of white vinegar per four

gallons of solution. These adjustments help ensure a balanced pH level, which is vital for healthy plant development in hydroponic systems.[56]

**Water pH Level Sensor**

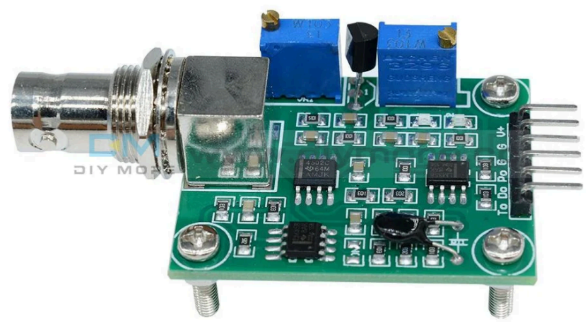

**Figure 2.22** PH4502C module

The PH4502C module features a working voltage of 5±0.2V (AC/DC) and a working current of 5-10mA, with a detection concentration range of pH 0-14 and a temperature detection range of 0-60 degrees Celsius. It has a quick response time of ≤ 5 seconds and stability time of ≤ 60 seconds, consuming ≤ 0.5W of power. Designed to operate in temperatures ranging from -10 to 50 degrees Celsius (with a nominal temperature of 20 degrees Celsius) and 95% relative humidity (with a nominal humidity of 65% RH), this sensor has a service life of 3 years. Its compact size measures 42mm x 32mm x 20mm, weighing 25g, and it provides an analog voltage signal output.[57]

**Figure 2.23** Analytical Surver Electrode pH Probe

The Analytical Surver Electrode pH Probe with a BNC (Bayonet Neill-Concelman) Plug Connector is designed for use with aquarium pH meters, controllers, and sensors. This pH electrode features a single cylinder for direct connection to BNC input terminals, ensuring accurate and reliable pH readings. With a pH range of 0-14, temperature range of 0-60°C, and zero-point of 7 ± 0.5 pH, this electrode minimizes alkali errors to 0.2 pH. Theoretical percentage slope exceeds 98.5%, ensuring precise measurements. With an internal resistance of less than or equal to 250MΩ and a response time of less than or equal to 1 minute, this electrode operates effectively in temperatures ranging from 0-60°C. The BNC plug connector is compatible with most pH meters and controllers, making it suitable for a wide range of applications, including aquariums, hydroponics, and laboratory settings.[58]

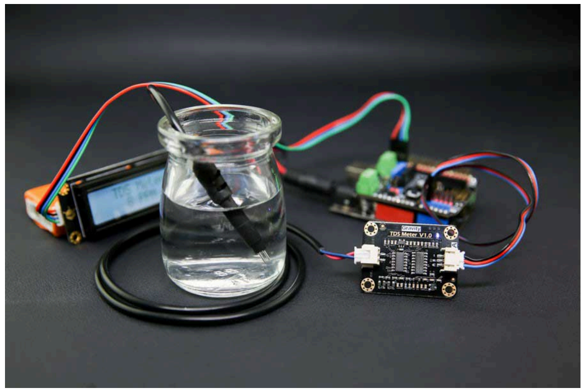

**Figure 2.24** DFRobot Gravity: Analog TDS Sensor/Meter

The DFRobot Gravity: Analog TDS Sensor/Meter for Arduino is a device that allows you to measure the total dissolved solids (TDS) in water using an Arduino microcontroller. This sensor can be used to monitor the water quality by detecting the TDS level, which is an important parameter for applications such as water filtration, aquaculture, and hydroponics. The sensor can be easily interfaced with an Arduino board and the TDS value can be displayed on a 16x2 LCD screen. The sensor comes with a calibration mode that allows you to calibrate it using a known TDS solution, ensuring accurate measurements. Overall, this TDS sensor provides a simple and cost-effective way to monitor water quality using an Arduino-based system. [59]

**ARDUINO BOARD**

Arduino serves as an accessible platform for electronics and programming enthusiasts. It features an open-source board used to create various electronics projects. The Arduino board, comprising an integrated development environment (IDE) and a microcontroller, enables users to write and upload code to the board via a simple USB cable, requiring no additional hardware. Its user-friendly interface, employing a simplified version of C++, makes it popular among beginners in electronics. The board's

conventional design encapsulates the microcontroller's functionalities in an easily manageable package, further enhancing its usability.[60]

**Types of Arduino board**

**Arduino Uno**

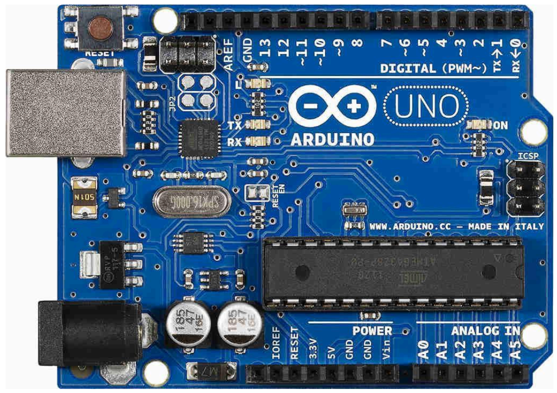


**Figure 2.25** Arduino Uno

Arduino Uno is a popular microcontroller development board based on the 8-bit ATmega328P microcontroller. Along with ATmega328P MCU IC, it consists other components such as crystal oscillator, serial communication, voltage regulator, etc. to support the microcontroller.[60]

**Arduino Due**

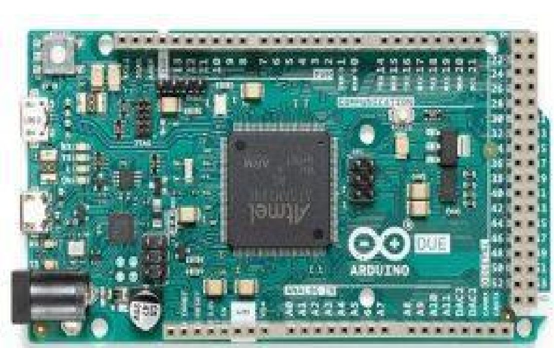


**Figure 2.26** Arduino Due

The Arduino Due is a microcontroller board that relies on the ARM Cortex-M3 architecture, marking the inaugural Arduino board of its kind. This board boasts an array of features, including 54 digital I/O pins, with 12 of them serving as PWM output pins, along with 12 analog pins, 4 UARTs, a clock speed of 84 MHz, USB OTG connectivity, 2 DACs, a power jack, 2 TWI (Two-Wire Interface) ports, a JTAG header, an SPI header, and two buttons for reset and erase functions.

Operable at 3.3V, the Arduino Due's input/output pins can tolerate a maximum voltage of 3.3V. Exceeding this voltage threshold can potentially damage the board. The board can be conveniently connected to a computer using a standard USB cable or powered through an AC to DC adapter. Moreover, the Arduino Due is compatible with all Arduino shields designed for 3.3V operation, further enhancing its versatility for various project applications.[60]

**Arduino Mega**

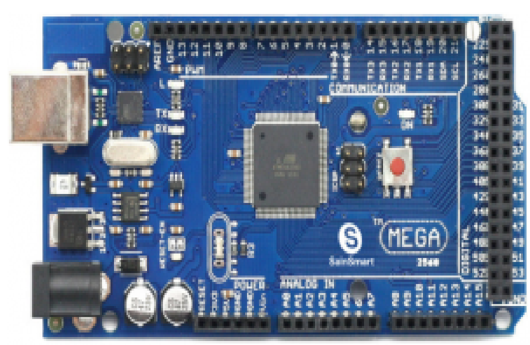

**Figure 2.27** Arduino Mega

The Arduino Mega (R3) Board can be likened to the bigger sibling of the UNO. It boasts numerous digital I/O pins, with 14 of them capable of functioning as PWM outputs. Additionally, it offers 6 analog input pins, a reset button, a power jack, and a

USB connection. This board provides all the essential components for supporting the microcontroller. Simply connect it to a computer via a USB cable and provide power through an AC-to-DC adapter or battery to kickstart your projects. The abundance of pins on the Arduino Mega board makes it exceptionally valuable for projects that require a multitude of digital inputs or outputs, such as applications involving numerous buttons.[60]

**Arduino Leonardo**

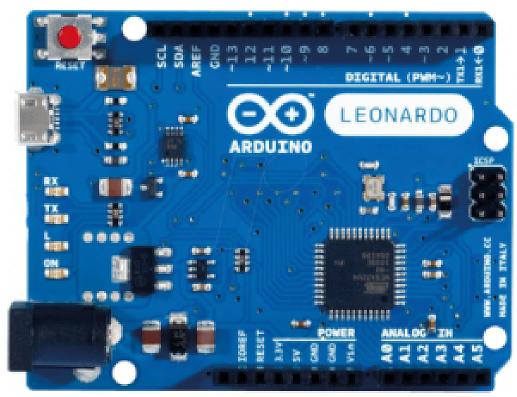


**Figure 2.28** Arduino Leonardo

The Arduino Leonardo board represents the initial iteration of Arduino development boards. It leverages a single microcontroller in conjunction with USB functionality, making it an economical and straightforward option. Due to its direct USB handling capabilities, various program libraries are accessible, enabling the Arduino board to emulate computer peripherals like keyboards and mice, thus enhancing its versatility.[60]

**Choosing the Right Arduino Board**

There is a wide variety of Arduino boards available in today's market, including options like Free Duino and NetDuino. The ideal approach for selecting the most suitable

Arduino board is to carefully examine and differentiate the brand names on the original boards. Finding affordable Arduino boards is easily achievable through online retailers and electronic stores. These boards come in various versions and specifications.

All these boards can be programmed using the Arduino IDE software, which enables anyone to write and upload code. However, each board differs in terms of inputs, outputs, speed, physical dimensions, voltage requirements, and more. The operational voltage for these boards typically ranges from 3.7V to 5V.[60]

**Raspberry Pi**

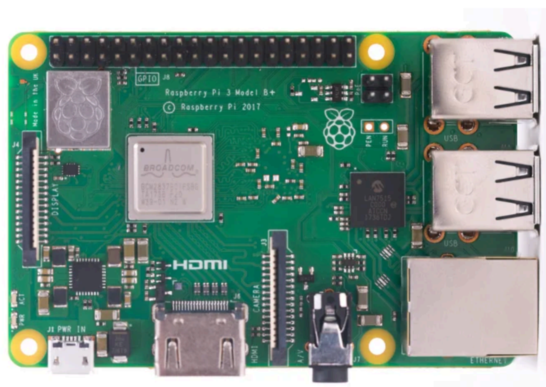


**Figure 2.29** Raspberry Pi

The Raspberry Pi is a single-board computer developed by the Raspberry Pi Foundation. Launched in 2012, the Raspberry Pi has seen several iterations with increasing processing power and memory, while maintaining an affordable price. These compact computers run Linux and provide GPIO (general-purpose input/output) pins, allowing users to control electronic components, explore the Internet of Things, and engage in physical computing projects. The Raspberry Pi is widely used for learning

programming, building hardware projects, home automation, and even industrial applications.[61]

**Power Supply**

**Figure 2.30** Power Supply

A power supply is a hardware component that supplies power to an electrical device. It receives power from an electrical outlet and converts the current from AC (alternating current) to DC (direct current), which is what the computer requires. It also regulates the voltage to an adequate amount, which allows the computer to run smoothly without overheating. The power supply an integral part of any computer and must function correctly for the rest of the components to work.[62]

**Circuit Breaker**

**Figure 2.31** Circuit Breaker

Circuit breaker is a type of switching mechanism used to regulate and protect an electrical power supply. It can be controlled manually or automatically. A fixed contact and a moving contact are its two primary contacts. Normally, the connections are closed, allowing current to pass through the system. A mechanism that releases accumulated potential energy separates the contacts in the event of a failure, such as an overload or short circuit. Circuit breakers protect electrical circuits from damage caused by overcurrent, short circuits, or overload. They interrupt the flow of current when a fault occurs and restore it when the fault is cleared.[63]

**ESP32**

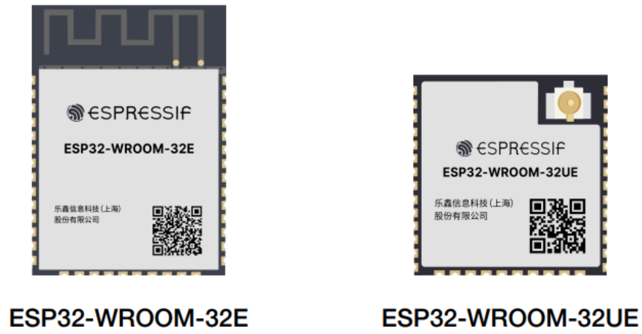


**Figure 2.32** ESP32

An ESP32 device in Arduino refers to a development board that uses the ESP32 chip, which is a powerful microcontroller with built-in Wi-Fi and Bluetooth capabilities. The ESP32 is often used in IoT (Internet of Things) projects due to its ability to connect to the internet and communicate wirelessly. When used with the Arduino IDE (Integrated Development Environment), the ESP32 can be programmed to perform various tasks, such as reading sensor data, controlling actuators, and sending/receiving data over the internet.[64]

**Relay Module**

**Figure 2.31** Relay

Relay is an electromechanical device that uses an electric current to open or close the contacts of a switch. The single-channel relay module is much more than just a plain relay, it is composed of components that make switching and connection easier and act as indicators to show if the module is powered and if the relay is active or not.[65]

**Jumping Wire**

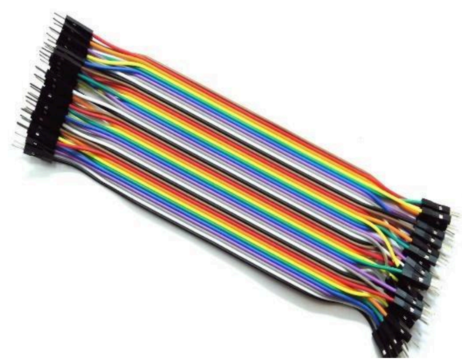

**Figure 2.34** Jumping Wire

Generally, jumpers are tiny metal connectors used to close or open a circuit part. They have two or more connection points, which regulate an electrical circuit board. Their function is to configure the settings for computer peripherals, like the motherboard. Suppose your motherboard supported intrusion detection. A jumper can be set to enable or disable it. Jumping wires are electrical wires with connector pins at each end. They are used to connect two points in a circuit without soldering.[66]

**Relay Board**

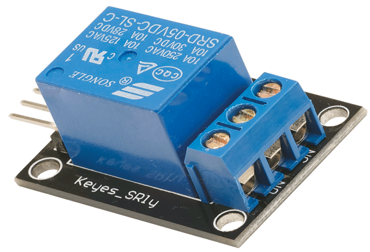


**Figure 2.35** Relay Board

A Relay is a simple electromechanical switch. While we use normal switches to close or open a circuit manually, a relay is also a switch that connects or disconnects two circuits. But instead of a manual operation, a relay uses an electrical signal to control an electromagnet, which in turn connects or disconnects another circuit.[67]

**Contactor**


**Figure: 2.36** Contactor

A contactor is an electrical device which is used for switching an electrical circuit on or off. It is considered to be a special type of relay. However, the basic difference between the relay and contactor is that the contactor is used in applications with higher current carrying capacity, whereas the relay is used for lower current applications. Contactors can be field mounted easily and are compact in size. Generally, these electrical devices feature multiple contacts. These contacts are in most cases normally open and provide operating power to the load when the contactor coil is energized. Contactors are most commonly used for controlling electric motors. [68]

**Stepper Motor**

**Figure 2.37** Stepper Motor

A stepper motor is an electric motor whose main feature is that its shaft rotates by performing steps, that is, by moving by a fixed amount of degrees. This feature is obtained thanks to the internal structure of the motor, and allows to know the exact angular position of the shaft by simply counting how many steps have been performed, with no need for a sensor. This feature also makes it fit for a wide range of applications.[69]

## 2.2 RELATED LITERATURE

The proponents to several studies related to the design of the present project. Different theories and principles related to the design of the greenhouse, ventilation, and hydroponic. In order to provide justification for the feasibility of the studies, the following research and studies related to the project design are presented and reviewed.

### FOREIGN STUDIES

The study of Miao, C. et al. (2023) was conducted to comprehensively understand the impact of light intensity on the growth and quality of different crops and to develop precise lighting schemes for specific cultivars. Lettuce and Spinach were used in this experiment, using a light-emitting diode (LED) under intensities of 300, 240, 180, and 120 μmol m−2 s−1 to gather information on growth and quality of the plants. The light intensity received by the plant changes as the plant grows taller; therefore, the computer-based LED plant supplementary lighting control system was adjusted to match the desired experimental light intensity after the measurement of growth parameters.

Crunchy (exhibiting the non-heading trait) developed tipburn when exposed to the light intensity of 300 μmol m−2 s−1, whereas tipburn and leaf shrinkage were observed in Deangelia (semi-heading lettuce cultivar) under both 240 μmol m−2 s−SS1 and 300 μmol m−2 s−1. The spinach cultivar, Shawen, exhibited leaf curling under all LED light intensities, impeding normal growth. These results indicated that although higher light intensity is beneficial for increasing yield and quality, the light intensity should be regulated as per the specific variety. Light intensity is an important factor and should be

optimized for specific crop species and cultivars to achieve healthy growth in plant factories.[70]

In the study of J. Zhou (2022), the interaction between light and temperature is crucial for the growth and development of lettuce. The optimal light range for photosynthesis and yield varies with temperature. At low temperatures (15 °C), a light intensity of 350–500 $\mu mol \cdot m^2 \cdot s^{-1}$ is recommended. For medium temperatures (23 °C), a light intensity of 350–600 $\mu mol \cdot m^2 \cdot s^{-1}$ is suggested. At high temperatures (30 °C), a light intensity of 500–600 $\mu mol \cdot m^2 \cdot s^{-1}$ is advisable. Additionally, light intensity should be reduced during the late growth stage for lettuce grown at medium and high temperatures. This study suggests that a balanced combination of light intensity and temperature can optimize lettuce photosynthesis and yield in greenhouses and plant factories.[9]

Based on the study of the Government of Newfoundland and Labrador (2020) that a lettuce plant is truly a crop that grows in a cold environment. The climate limitations for lettuce are focused on ensuring a suitable water supply throughout its growth stages and preventing exposure to temperatures exceeding 30°C. It is strongly recommended to maintain an environmental temperature below 30°C to prevent the occurrence of flowering or bolting, which imparts a bitter taste to the lettuce plant.[71]

The study of Sanders, C. (2018) stated that the cultivation of lettuce in greenhouses is negatively impacted by high temperatures, especially in hot climates. Therefore, developing an efficient method to regulate the internal temperature of greenhouses is crucial to maintaining crop productivity throughout the year. The optimal air temperature for lettuce plants, classified as cool-season vegetables, in a plant factory

or temperate zone is between 22 and 26 °C. However, it has been suggested that the ideal temperature for growing lettuce in tropical environments is between 22 and 30 °C, or even 33 °C for other leafy vegetables like mustard greens.[72]

Furthermore, it's crucial to note that the optimal temperature range for lettuce cultivation falls between 60 and 65°F according to the study of Kumsong, N. et al. in 2023, as this leafy green is inherently adapted to thrive in cool growing conditions. Despite its preference for cooler climates, lettuce exhibits a degree of resilience, demonstrating the ability to endure occasional temperature spikes of 80 to 85°F for short durations, provided that the nights maintain a refreshing coolness. This resilience underscores the adaptable nature of lettuce, allowing it to withstand temporary deviations from its ideal growing conditions while maintaining its overall health and vitality.[73]

The study of B. Frestya et al. 2021 entitled "The effect of hydroponics systems on the growth of lettuce", used different kinds of experimental methods consisting of 5 treatments. A = Hydroponic Installation of the Nutrient Film Technique (NFT), B = Hydroponic Installation of Deep Film Technique (DFT), C = Hydroponic Installation of EBB and FLOW or Tidal Systems, D = Installation of Aeroponic Hydroponic Systems, and E = Installation of Floating Assembling Hydroponic System. They used these methods to measure the effectiveness of each system in increasing the growth of plant height, and leaf number. Different hydroponic systems affect the growth of lettuce, namely plant height and number of leaves. The NFT hydroponic system is 6% -10% more efficient in increasing the yield of lettuce. The NFT and RFS systems are recommended for use in hydroponic lettuce production.[74]

The study of G. M. Barbade, et al. (2021), entitled “Automatic Water Tank Filling System with Water Level Indicator” primary goal is to conserve water by using an automatic water level controller and indicator. The water level controller works by using the fact that water can conduct electricity due to minerals in it. This allows it to control circuits, turning them on or off as the water level changes. The carbon sensor also plays a role, sensing water without direct contact to trigger the LED light and turn off the pump once the tank is full. There have been several approaches to constructing an automatic water level control with a switching device, but all of them require human intervention. This project uses electrical control to build an automatic water level control system with a switching device for both overhead and underground tanks to replace the water without human intervention. When the water tank falls below a certain level, the system turns off the electric pump and shuts down the water pump. When the tank is full, the system turns off the electric pump and shuts down the water pump.[75]

The study of Demi, et. al, 2019, proposed a system that utilizes sensors to measure pH and TDS levels in the nutrient film technique (NFT) to maintain the quality of hydroponic plants. This system monitors the nutrient solution's pH (acidity or basicity) and total dissolved solids (TDS) using pH and TDS sensors. A control system is employed to manage nutrition controllers such as pH down, pH up, and AB nutrition by turning them on or off. Depending on the specific conditions, various pumps (for pH up/down, TDS up/down, and nutrition A/B) and a chiller are activated or deactivated to maintain optimal conditions. This approach aims to ensure plants grow in the best possible environment, resulting in healthier and more robust crops..[76]

The study of Danita, et.al, 2018, used Internet of Things (IoT) for monitoring the temperature and humidity to ensure the good yield of plants. The sensors used here are YL69 moisture sensor and DHT11 (Temperature & Humidity sensor). From the data received, Raspberry PI3 automatically controls Moisture, Temperature, Humidity efficiently inside the greenhouse by actuating an irrigating pipe, cooling fan, and sliding windows respectively according to the required conditions of the crops to achieve maximum growth and yield. The recorded temperature and humidity are stored in a cloud database (Thing Speak), and the results are displayed in a webpage, from where the user can view them directly.[77]

The study of Ardiansah et al, 2020. conducted research in the field of agriculture. They used IoT for crop management as a media for monitoring and controlling, especially in greenhouses and is called Precision Farming. In the Internet of Things, the data that has been acquired by the hardware will then be transmitted wirelessly. The wireless connections used are Bluetooth, ZigBee Protocol, and Wi-Fi, where Bluetooth and Zigbee connections have a short distance between 10 - 100 meters, while Wi-Fi has a longer distance especially when connected to the Internet.[78]

**LOCAL STUDIES**

The article of Semilla et al. (2018) entitled “Indoor production of loose-leaf lettuce (Lactuca sativa L.) using artificial lights and cooling system in tropical lowland” used controlled environment agriculture (CEA) for farming set-up in the Philippines. It is a controlled environment developed using locally available materials, light emitting diodes (LED) as sole-source of light and cooling system for temperature manipulation.

This study was conducted to determine the optimal temperature and light intensity requirements for growing loose-leaf lettuce in lowland tropics.[79]

In addition, the study constructed three chambers with an area of 2.5m 2.5m x 6.0m and ceiling height of 2.5m. Each chamber was equipped with two 1hp window-type air-conditioning units (AC) operated alternately for 12 hours, two 70-watt circulating fans, and two sprinkler foggers. They employed ECOLUM LED T8 tube lights with a daylight color temperature of 6500K were used to produce PPF. Light intensities of 50, 100 and 150 μmol m-2 s-1 were tested under temperature settings of 25 °C and 18 °C. Carbon dioxide and relative humidity were maintained at recommended levels. No significant difference in productivity was observed under 25 °C and 18 °C. Also, no significant difference in productivity was observed between plants in two temperature settings and plants outside.[79]

The study of D. Jose (2020) stated that lettuce plant lettuce plants demonstrate a remarkable ability to adapt in areas with relative humidity that ranges from 65% to 85%. The study suggests lettuce varieties can be carefully selected based on their tolerance to specific environmental conditions.[80]

The study of Albius, J et. al, 2018. “Solar-Powered Multi-Network Greenhouse: Automated Mushroom Monitoring and Management System Using Microcontrollers and IoT-Based Applications”. utilized microcontrollers and Internet of Things applications to power the Solar Powered Multi-Network Greenhouse and create an automated system for managing and monitoring mushrooms. Due to the fact that mushrooms are more susceptible to temperature changes, particularly in tropical nations like the Philippines, this study creates an automated system whose composition is managed by a greenhouse

monitoring device utilizes an Arduino IDE microcontroller several extremely powerful sensors that provide precise metrics for monitoring systems and improved agricultural control management. There was discussion of the many approaches that could be used to regulate variables and preserve stability values appropriate for mushroom farming. To guarantee the device's accuracy and operation, a number of experiments and testing were conducted on the prototype. Similarly, performance tests were carried out to regulate and track the requirements of the mushroom with regard to temperature, relative humidity, and light. The equipment is accurate, functional, and capable, according to the results. According to the study, installing a CCTV system to continuously monitor the greenhouse's exterior and interior would improve it. In addition to being in a more isolated location, the greenhouse might also enhance some application functions.[81]

The study of Mastul, A et, al, 2023, "The Use of IoT on Smart Agriculture in the Philippines". The study examines the advantages of using Internet of Things (IoT) technologies with modern agriculture, with a particular focus on the Philippines to evaluate the effects of IoT on precision steering, automated irrigation, field mapping, weather monitoring, livestock tracking, greenhouse automation, and crop monitoring. They used IoT-based livestock tracking to guarantee the welfare of the animals and effective breeding methods. Making educated decisions for crop protection and risk management is made easier with the help of IoT-based weather monitoring. IoT-enabled automated irrigation lowers water waste while enhancing crop health. During planting and harvesting, resource management is improved by precision steering systems. Automation in greenhouses minimizes manual labor while optimizing growing conditions for plants. IoT-based field mapping enables site-specific management, increasing

sustainability and yield. Comprehensive plans for IoT integration in Philippine agriculture are necessary regardless of the benefits because problems like internet connectivity and early investment are still present.[82]

The study of J. Anthony (2018) entitled “Auto GMS: An Automated Greenhouse Monitoring System of Abiotic Factors for Leafy Vegetables Production” conducted at Oriental Mindoro, shows that they were able to automate greenhouse processes by using multiple highly sensitive sensors to monitor the current working condition of their greenhouse. Additionally, they added SMS functionality to their system to provide real time updates to the end user about their system. These integrations were powered by the wifi module installed and the LCD screen display to provide information to the user. Internet of things (Iot) was greatly showcased as the integration of a user's GSM phone to the system for monitoring. Arduino uno were used to monitor and automate processes together with solenoid valves controlled by the relays to switch on or off for water intake to the irrigation system.[83]

The study of R. Amy (2020) entitled “Automated pH Monitoring and Controlling System for Hydroponics under Greenhouse Condition” conducted at Tarlac, Philippines, demonstrate a system for automatic monitoring and controlling was created in order to regulate the pH level of the water in the system by adding acid and base solution. A minimum pH of 6.0 and a maximum pH of 6.54 were observed. The pH level of the nutrient solution was maintained at a range of 6.0-6.8 level which is the recommended range for hydroponic lettuce production. It was determined that the automated pH monitoring and controlling system was effective after a performance evaluation and

validation finished. By lowering labor costs and enabling real-time pH monitoring, this device helps farmers produce more crops and make more revenue.[84]

## 2.3 SYNTHESIS

The comprehensive review of the literature presented in Chapter 2 underscores the transformative potential of automation and advanced technologies in the field of agriculture, with a particular focus on greenhouse management systems. This synthesis brings together key findings from the studies reviewed, demonstrating both the current state and future possibilities of technology-enhanced agriculture.

The development of automated control systems in greenhouse management is supported by many studies that look at how automation, hydroponics, and IoT technologies can work together to improve farming efficiency. A key part of this research is the use of automation in agriculture, which cuts down on the need for manual labor while boosting productivity.

### Foreign Studies

The experiment of C. Miao et al, aimed to study how light intensity affects the growth and quality of lettuce and spinach in a plant factory. They used LED lights at different intensities and controlled the light using a computer-based system. Results showed that high light intensity can be good for yield and quality, but it needs to be managed carefully. They used crunchy lettuce and it had tipburn at 300 μmol $m^{-2}$ $s^{-1}$, while Deangelia lettuce had tipburn and leaf shrinkage at 240 and 300 μmol $m^{-2}$ $s^{-1}$. Shawen spinach had leaf curling at all intensities, which affected its growth. This study

highlights the importance of optimizing light intensity for different crops and varieties. By doing so, planting facility can ensure healthy growth and better-quality produce.

The study of J. Zhou et al, highlights the critical role of temperature over light intensity in influencing lettuce photosynthesis and growth. Optimal lettuce cultivation requires prioritizing temperature management, with specific light intensity recommendations tailored to varying temperatures. At lower temperatures (15 °C), a light intensity of 350–500 μmol·m−2·s−1 is beneficial, while medium temperatures (23 °C) require 350–600 μmol·m−2·s−1, and higher temperatures (30 °C) are best supported by 500–600 μmol·m−2·s−1. Additionally, reducing light intensity during the late growth stage for medium and high-temperature conditions is advantageous. The study emphasizes that a strategic balance of light and temperature can enhance lettuce photosynthesis and yield in controlled environments.

The study by the Government of Newfoundland and Labrador (2020) emphasizes that lettuce thrives in cold environments. The primary climate considerations for cultivating lettuce involve maintaining a consistent water supply and avoiding temperatures above 30°C. Keeping the environmental temperature below 30°C is crucial to prevent flowering or bolting, which can cause the lettuce to develop a bitter taste. Ensuring these conditions supports optimal growth and quality of lettuce crops.

The study of Sanders, C. discussed the efficient methods to regulate greenhouse temperature are crucial for maintaining crop productivity year-round. Lettuce is classified as a cool-season vegetable, with the optimal air temperature for growth in a plant factory or temperate zone being between 22 and 26 °C. However, in tropical environments, the

ideal temperature for lettuce cultivation is suggested to be between 22 and 30 °C. The findings provide insights to the researchers on optimizing temperature according to the type of lettuce being grown in the greenhouse.

The study by Kumsong, N. et al., stated that lettuce is adapted to thrive in cool growing conditions, with an optimal temperature range for cultivation between 16°C and 19°C. Despite this preference, lettuce can withstand occasional temperature spikes of 27°C to 30°C for short durations, as long as the nights remain cool. This resilience allows lettuce to adapt to temporary deviations from its ideal growing conditions while maintaining its health and vitality.

The study of Frestya et al. compared five hydroponic systems (NFT, DFT, EBB and FLOW, Aeroponic, Floating Assembling) to see which is best for lettuce growth. They measured plant height and leaf number to determine effectiveness. Plant height is mainly influenced by water and light availability. This study shows ways to reduce water usage and enhance nutrient delivery, highlighting their potential to improve greenhouse practices by creating optimal growth conditions with minimal resource waste. Water shortage can slow growth and reduce yields. By using these advanced methods, greenhouse management can become more efficient and sustainable, demonstrating the significant benefits of automated control systems and hydroponic techniques. This study becomes a reason for the proposed study to choose the NFT system in hydroponics.

The study of G. M. Barbade et al, entitled "Automatic Water Tank Filling System with Water Level Indicator," focuses on conserving water by implementing an automatic water level controller and indicator. Utilizing water's conductivity due to minerals, the

system controls circuits to turn them on or off as the water level fluctuates. A carbon sensor detects water levels without direct contact, activating an LED light and stopping the pump when the tank is full. However, the study above uses carbon sensor to measure the water level, while the proposed study will be using water flow sensor and float switch.

The study of Demi, et. al, proposed a system for measuring pH and TDS in the nutrient film technique (NFT) using sensors to maintain the quality of hydroponic plants. They used a control system to turn on or off the nutrition controllers, such as pH down, pH up and AB nutrition. Depending on the specific condition, various pumps (pH up/down, TDS up/down, nutrition A/B) and the chiller are activated or deactivated to maintain the desired conditions. The study helps the researchers in using pH and TDS sensors and adapting the process of turning valves on or off.

The research by Ardiansah et al. (2020) explores the application of IoT in agriculture, particularly in greenhouse settings, under the concept of Precision Farming. This approach leverages IoT for real-time monitoring and control of crop management. The study highlights the use of various wireless technologies for data transmission, including Bluetooth, ZigBee, and Wi-Fi. Bluetooth and ZigBee are effective for short-range communication (10-100 meters), whereas Wi-Fi enables longer-range connectivity, especially with Internet access. This integration of IoT in agriculture facilitates enhanced precision and efficiency in crop management practices.

The study of M. Danita et al., implemented IoT sensors, specifically the YL69 moisture sensor and DHT11 temperature & humidity sensor, to monitor and ensure

optimal conditions for plant growth. A Raspberry Pi3 was used to control irrigation, cooling, and ventilation systems based on the sensor data. The system recorded temperature and humidity data, which were stored in a cloud database (ThingSpeak) and displayed on a webpage for user access. The study becomes a guide for the proposed study to use DHT11 to measure temperature and humidity.

**Local Studies**

The study of M.G. Semilla et al, in the Philippines utilized Controlled Environment Agriculture (CEA) for indoor lettuce production, focusing on identifying optimal temperature and light intensity conditions for cultivating loose-leaf lettuce in tropical lowlands. The CEA setup used locally available materials, LED lights as the main light source, and a cooling system for temperature control. They constructed three chambers, each equipped with air conditioning units, circulating fans, and sprinkler foggers. The findings suggests that the temperature setting is play a significant role in cultivation of lettuce, highlighting the potential of CEA for year-round lettuce production in tropical climates.

D. Jose's 2020 study emphasized the adaptability of lettuce plants to areas with relative humidity ranging from 65% to 85%. The research suggests that lettuce varieties can be chosen based on their tolerance to specific environmental conditions. This indicates that farmers can select lettuce types suited to their region's humidity levels, potentially enhancing crop productivity and resilience.

The study by Albius et al. focuses on creating a Solar-Powered Multi-Network Greenhouse with an automated system for managing and monitoring mushrooms, which are particularly sensitive to temperature changes, especially in tropical regions like the

Philippines. The system utilizes microcontrollers and Internet of Things (IoT) applications to regulate variables and maintain stable conditions ideal for mushroom farming. The greenhouse monitoring device, managed by an Arduino IDE microcontroller, integrates several powerful sensors to provide precise metrics for monitoring and improving agricultural control management. Performance tests were also carried out to regulate and monitor temperature, relative humidity, and light requirements for mushrooms Additionally, the study suggests installing a CCTV system to continuously monitor the greenhouse's exterior and interior, which could further enhance its functionality, especially in isolated locations. The study helps the researchers to adapt only the utilization of IoT application and Arduino as microcontroller to the system.

The study by Mastul et al. focuses on the use of Internet of Things (IoT) in smart agriculture in the Philippines, aiming to evaluate its effects on various aspects such as precision steering, automated irrigation, field tracking, and weather monitoring, greenhouse automation, and crop monitoring. The study found that IoT technologies can significantly enhance agricultural practices in the Philippines. The study emphasizes the need for comprehensive plans for IoT integration in Philippine agriculture to overcome these challenges and fully realize the benefits of IoT technologies. This study helps the researchers to produce an IoT application in managing hydroponics that can adapt to the generation and to keep the quality of the product.

The study by JE. Anthony in 2018, titled "Auto GMS: An Automated Greenhouse Monitoring System of Abiotic Factors for Leafy Vegetables Production," conducted at Oriental Mindoro, focused on automating greenhouse processes using highly sensitive sensors to monitor the greenhouse's working conditions. The system included SMS

functionality to provide real-time updates to users and was powered by a wifi module and an LCD screen display for user information. The study focuses on the application of integration of Internet of Things (IoT) technology, specifically a user's GSM phone, for monitoring. Arduino Uno microcontrollers were used to monitor and automate processes, including controlling solenoid valves via relays for water intake to the irrigation system. The researchers considered the utilization of Arduino Uno and IoT for monitoring the whole process of the system.

The study of R. Amy (2020) entitled “Automated pH Monitoring and Controlling System for Hydroponics under Greenhouse Condition” demonstrates a system for automatic monitoring and controlling of hydroponics to regulate the pH level of the water in the system by adding acid and base solution. A minimum pH of 6.0 and a maximum pH of 6.54 were observed. The pH level of the nutrient solution was maintained at a range of 6.0-6.8 level which is the recommended range for hydroponic lettuce production. This study provides researchers with valuable insights into the optimal pH levels needed to ensure high-quality lettuce cultivation in the Philippines.

# CHAPTER III

# DESIGN AND METHODS

This chapter discusses the design and methods that have been improved for this project study. It includes the conceptual framework along with the technical design and procedure. Further discussed are the equipment, facilities, and programs used, the data collection and treatment, as well as the required budget to conduct the project study. Also presented are the expected output and a tabulated Gantt chart for the duration of this project study.

## 3.1 CONCEPTUAL FRAMEWORK

This project study focuses on the design and construction of a Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, pH level and TDS monitoring. This framework will guide the research to understand and show how the greenhouse management system can help make farming more sustainable and efficient. Moreover, it was constructed and improved the greenhouse considering the environment of the greenhouse that will affect the crops, such as the temperature, relative humidity and monitoring system. The position, size of the land, temperature, and pH level at the location of the control system installation were also taken into consideration due to its impact to the automated systems performance in the greenhouse.

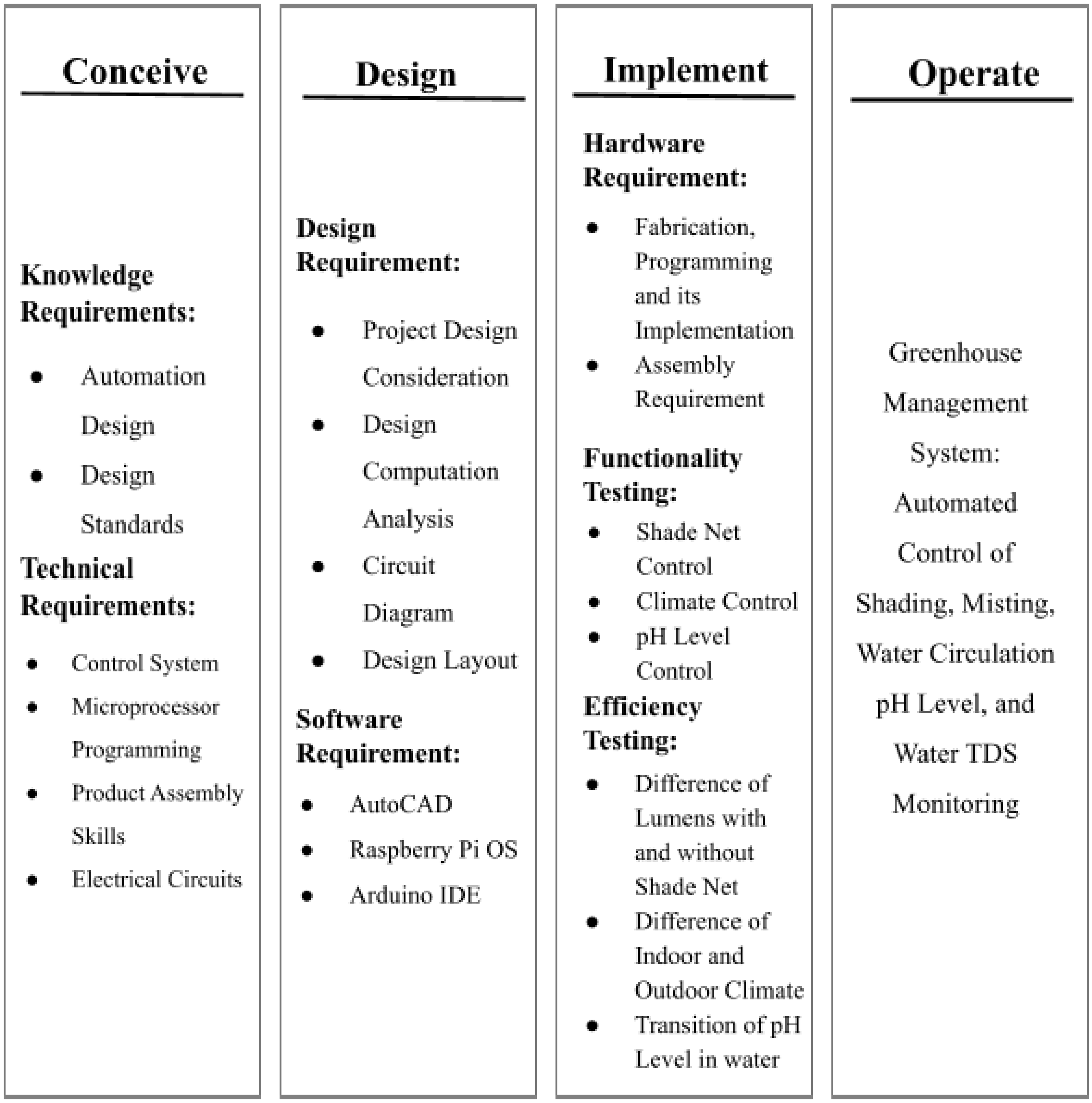


**Figure 3.1** Conceptual Paradigm of the Study

The Conceive Stage's purpose is to acquire essential knowledge for an automated greenhouse management system involving a thorough evaluation of the collaboration between software and hardware. This includes establishing a comprehensive monitoring and control system. Proficiency in programming is crucial for connecting the various elements of the automated system. Expertise in understanding the ideal environmental conditions within the greenhouse, including temperature, humidity, nutrient solution level

and light intensity. Recognizing that any changes in these parameters can have a direct impact on crops indicates the need of taking a comprehensive approach in implementing and managing an efficient automated greenhouse management system.

During the Design Stage, the design and software requirements are determined. The project study contains different design requirements, material specifications and system components, the general description of the project, design standard, design computation and Analysis, design layout, circuit diagram, materials and components, programs and complementation, bills of materials and specification of the study. The monitoring and control system automatic function hinges upon considering the factors mentioned. These factors have been taken to ensure the effective operation of the system.

The implementation of the project construction and programming as well as the fabrication of the output. Functionality testing was also included, which was divided into Climate control test, Nutrient solution monitoring control test, Shade net control test of greenhouse management and the efficiency testing which contains: Difference of outdoor and indoor climate, Flowrate of water outflow & inflow, and Difference of lumens with & without shade net is considered. Lastly, the operation stage was presented as the output of the project study. This project study entitled Greenhouse Management System: Automated Control of Shading, Misting, and Nutrient Monitoring for Sustainable Agriculture.

Furthermore, the materials and equipment used are considered to achieve the effectivity and purpose also the expected output of the project study. To enhance comprehension of the study core principles, the research team crafted a conceptual model encompassing the necessary expertise, as well as the design criteria and prerequisites.

Additionally, the scope covers the construction and programing, along with the architectural planning and physical build of the Greenhouse Management System for sustainable agriculture.

## 3.2 TECHNICAL DESIGN AND PROCEDURE

### VII. Designing Stage

In order to collect the existing information and foundation parts of the prototype, its focus is on the comprehensive development of an automated control system for shading, misting, water circulation, pH level, and TDS monitoring. The design process begins with determining the specific components required for each subsystem, ensuring the system meets the environmental needs of the greenhouse. The computation phase involves calculating necessary parameters such as light intensity, water flow rates, nutrient concentrations, and the power requirements of the solar-powered system. Additionally, material identification is critical to select durable and efficient components like sensors, pumps, microcontrollers, and shading mechanisms that ensure system reliability. A thorough cost analysis is performed to estimate the total expenses for materials, labor, and installation, ensuring that the project remains within budget while achieving the desired functionality. This holistic approach to design not only aligns with automation and greenhouse principles but also addresses the project's efficiency, practicality, and sustainability objectives.

### VIII. Fabrication Stage

In this phase, the development and specifications of the machine are built in accordance with the goals of the research. When choosing materials that satisfy the requirements, a number of variables will be taken into account, such as cost, accessibility

locally, and material specifications. The nearby machine shop will be the location of real manufacture, with materials sourced locally employed in the fabrication process. The many parts of the Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, Water TDS and pH level monitoring control equipment will then be assembled and integrated over time. The final inspection will assess how well the machine operates and how well it follows the standards.

**IX. Preliminary Testing Stage**

The tests will focus on evaluating the core components of the system, such as the shading mechanism, misting system, water circulation, pH level control, and TDS monitoring. These tests aim to confirm that each subsystem functions as expected under real-world conditions. Specifically, the tests will measure the responsiveness of the shading system, the efficiency of the misting and water circulation systems, and the accuracy of the pH and TDS sensors. Preliminary testing is an essential phase after the manufacture of the system, designed to assess its overall operational capabilities and identify any issues. Key parameters, including system response time, resource efficiency, and accuracy, will be evaluated during this stage. Any detected problems will be corrected before proceeding with further testing and integration.

## 3.3 EQUIPMENT / FACILITIES / PROGRAMS

The content outlines the key elements involved in project planning and implementation, with a focus on the necessary equipment and infrastructure. It emphasizes the importance of choosing appropriate software for both programming and designing the system, which is critical in defining aspects such as layout, size, block diagrams, and control mechanisms. The passage also mentions the use of various

software tools for demonstrating the capabilities of the software and displaying the project's results. This indicates a systemic approach to project management, combining both physical and digital resources to achieve project objectives.

## EQUIPMENT

A complete set of equipment is required for the assembly of the automated system within the greenhouse. This includes:

### 1. Fabrication Tools for Mechanical Components

- Welding Machine: For assembling metal parts of the greenhouse structure and mechanical supports for components like the shade net and misting system.
- Cutting Tools: For cutting metal sheets, pipes, and other structural components.

### 2. Electrical and Wiring Tools

- Soldering Station: Essential for connecting electronic components, such as control boards, sensors, and wiring for the automation system.
- Multimeter: For checking voltage, current, and continuity in the electrical system to ensure proper connections.
- Crimping Tools: For connecting wires securely with terminals when installing the greenhouse's electrical and control systems.

### 3. Hydraulic and Plumbing Equipment

- PVC Pipe Cutters and Joiners: For the installation of water circulation and misting systems.

- Nozzle Installers: To install misting nozzles that regulate humidity and cooling within the greenhouse.

**4. Control and Automation Tools**

- Arduino Kit (with compatible sensors and actuators): For the control system of shading, misting, water circulation, and environmental monitoring.
- Relay Modules and Stepper Motors: For automating functions like opening/closing the shade net or adjusting water circulation based on environmental data.

**5. Precision Measuring Instruments**

- Digital Calipers: For precise measurement of fabricated parts and ensuring proper fits, especially in components like shafts or mounting brackets.
- Temperature and Humidity Sensors: To monitor the environment and calibrate the automated control systems for maintaining optimal greenhouse conditions.
- pH and TDS Meters: To measure and regulate the water quality in the hydroponic system, ensuring the proper nutrient balance.

**6. Programming and Debugging Tools**

- Computer with Arduino IDE (or Raspberry Pi setup): For coding and testing the software that will automate the shading, misting, and circulation systems.

## FACILITY

SIMCO, located in San Isidro Batangas City, serves as the primary facility for the research, equipped with two previous advanced hydroponic greenhouse systems. These greenhouses, built with study materials suitable for the local climate, feature automated controls for temperature, humidity, and watering to create optimal growth conditions for lettuce crops. They also have an efficient irrigation system for water and nutrient management in hydroponics. The researchers chose this location to allow convenient access. Another reason for selecting it is because of the support from the beneficiary who will provide a fabricator to help the researcher complete the prototype.

## PROGRAM

Different software and programs were used to achieve the study's results. The layout of the study was presented using AutoCAD software, while data was organized using spreadsheet programs such as Google Sheets during system testing. The Arduino IDE was the programming software that was used to program the Arduino board. It consists of a text editor for writing code, a message area, a text console, a toolbar with buttons for common functions, and a series of menus. To connect the Arduino to the computer, a cable converter and Ethernet cable were used as communicators. As a result, a laptop computer was required, as well as a greenhouse where the automated system was installed.


**Figure 3.1** AutoCad Software

AutoCAD (Computer-Aided Design) is a computer application that is very useful for project layout, design, and taking complex measurements of various lengths and angles in modeling 2D and 3D. The application is extremely useful for idea visualization and dimensioning, especially during the project's planning and design stages. The design was most likely done in 3D in order to view the output in isometry as well as observe the actual construction while using some of the parameters mentioned.

Google Sheets

**Figure 3.2** Google Sheet

Spreadsheet programs, such as Google Sheets and Microsoft Excel, are powerful computer applications that can be used for data organization, computation, analysis, and

storage. Users can create, edit, and format spreadsheets in Google Sheets, as well as import and export data from other sources.

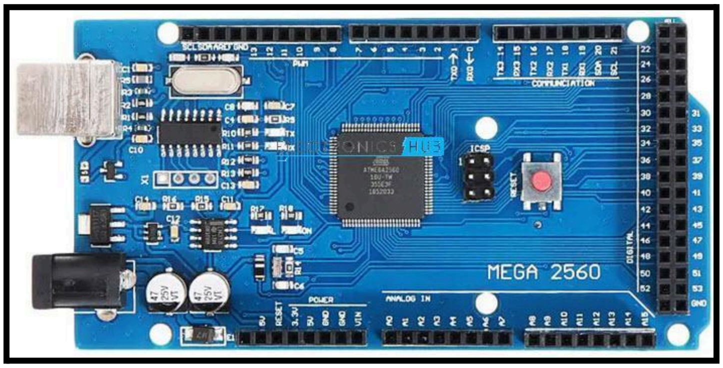


**Figure 3.3** Arduino Mega

The Arduino Mega is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It's a powerful board that's great for projects requiring a lot of I/O pins or complex functionality.


**Figure 3.4** Arduino IDE (Integrated Development Environment)

The Arduino IDE (Integrated Development Environment) is free and open-source software that simplifies code compilation, particularly for those with no prior technical knowledge. It was created by Arduino.cc and is compatible with a variety of operating systems, including MAC, Windows, and Linux. It is based on the Java platform and includes built-in functions and commands for debugging, editing, and compiling code. The Arduino modules available include the Arduino Uno, Arduino Mega, Arduino Leonardo, and Arduino Micro, each of which has a microcontroller on the board that is programmed in the form of code. The editor for writing the code and the IDE are the two main components of the IDE. Code and the compiler are required for compiling and uploading the code.

### 3.4 DATA COLLECTION AND TREATMENT

The proponents employed design and development research which entails the implementation of procedures and methodologies to create a functional prototype. In obtaining necessary information, the researchers gathered data through various methods. The researchers conducted a comprehensive review of related literature and previous studies as the foundation for the project design. Methods such as Internet and E-library research, interviews, and consultation were used to complete this project study.

**Functionality Test**

**g) Shade Net Control**

**Table 3.1** Shade Net Control Functionality Testing

| Shade Net Control Testing | | | | |
|---|---|---|---|---|
| Trial | Temperature (°C) | Luminous Flux (lm) | Shading Motor Status (On/Off) | Remarks (Passed/Failure) |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

This test assesses the effectiveness of the automated shade net control system in the greenhouse. The system is designed to adjust the deployment of the shade net based on real-time monitoring of light intensity and temperature to optimize plant growth conditions. The test involves monitoring the response of the shade net system to changes in external light and temperature conditions. Given its location within a resort, nearby artificial light may trigger the luminous sensor. Therefore, considering temperature is crucial when activating the shading system. The shade net control system operates by deploying and retracting the net with precision based on predefined light and temperature thresholds. A "PASSED" remark is noted if the shading motor starts to take action when temperature is on 30°C and luminous intensity reaches beyond 600 $\mu mol \cdot m^2 \cdot s^{-1}$ or 32,400 lux [9], ensuring that plants receive the optimal temperature and luminous flux for the lettuce plant. Otherwise, the test result is marked as "FAILURE".

**Table 3.2** Shade Net Control Efficiency Test

| Difference of Lumens with and without Shade Net | | | | |
|---|---|---|---|---|
| Trial | Lumens with Shade Net | Lumens without Shade Net | Required Luminous Flux | Remarks (Passed/ Failure) |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

This test is designed to determine the effectiveness of the shade net in managing light exposure within the greenhouse. It involves recording the lumens, a measure of light intensity, inside the greenhouse with the shade net installed and without it. Measurements are taken using a luminosity sensor during multiple trials to ensure reliability of the data. Each trial will note the lumens with the shade net and compare it to the lumens recorded without the shade net. The system is deemed efficient if the light intensity with the shade net falls within the optimal range for plant growth, avoiding both underexposure and harmful overexposure. A "PASSED" remark is noted if the desired luminous flux is achieved, ensuring that plants receive the correct amount of light for healthy photosynthesis without excess stress from over-illumination. Otherwise, the test result is marked as "FAILURE".

### h) Climate Control Testing

**Table 3.3** Humidity and Temperature Functionality Testing

| Humidity and Temperature Functionality Testing | | | | |
|---|---|---|---|---|
| Trial | Humidity (%) | Temperature (°C) | Misting Element Status (On/Off) | Remarks (Passed/ Failure) |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

The method of determining the functionality of the humidity and temperature sensor will be evaluated. These evaluations are intended to provide crucial information to advocates, allowing them to make adjustments and improvements. This assessment comprises three trials under humidity and temperature conditions, where the misting element will activate when the sensors reach any of the set values for humidity and temperature. A "PASSED" remark will be assigned if the misting element activates when the temperature rises beyond 30°C [71] and the humidity drops to 65%[73]. Also testing if the mister shuts down when the 27°C[71] temperature and 85%[73] of humidity were met. However, if not, it will be considered "FAILURE".

**Table 3.4** Humidity and Temperature Efficiency Test

| Difference of Indoor and Outdoor Climate | | | | |
|---|---|---|---|---|
| Trial | Indoor (Temperature & Humidity) | Outdoor (Temperature & Humidity) | Required Humidity & Temperature | Remarks (Passed/ Failure) |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

This test assesses the efficiency of the greenhouse management system in stabilizing indoor climate conditions compared to the fluctuating outdoor environment. The evaluation involves measuring and comparing the temperature and humidity levels inside and outside the greenhouse across multiple trials. Each trial will record the temperature and humidity data from sensors located inside the greenhouse and in the external environment. The result is marked as "PASSED" if the indoor climate remains within the desired data, otherwise, it is noted as "FAILURE".

#### i) pH Level Control Test

**Table 3.5** pH Level Control Functionality Testing

| pH Level Control Testing | | | |
|---|---|---|---|
| Trial | pH Level | pH Downer Pump (On/Off) | Remarks (Passed/Failure) |
| 1 | | | |
| 2 | | | |
| 3 | | | |

This test evaluates the functionality of pH Level Control in the greenhouse management system. The test specifically assesses the control mechanism's ability to maintain the pH condition at predetermined levels. During the test, the pH levels are closely monitored to ensure that the concentrations stay within the required value. For each trial, the pH sensor detects the nutrient level, triggering the pH downer pump to attain the optimal ph level. A "PASSED" remark is assigned if the system successfully activates the pH downer pump when pH level rises to 7 and stops when the pH level is 6. However, if the system fails to activate the valves despite meeting the requirement, a "FAILURE" is noted.

**Table 3.6** Transition of pH Level Efficiency Test

| Transition of pH Level in water | | | | |
|---|---|---|---|---|
| Trial | Initial pH Level | New pH Level | Required pH Level | Remarks (Passed/Failure) |
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |

The evaluation method of pH level control will involve a series of tests to assess the stability and accuracy of the system's ability to maintain optimal pH level concentration. This examination will focus on the system's response under various conditions to ensure consistent pH level. The test consists of three trials. In each trial, we will record the initial pH level and new pH level reading to control whether the valve will activate or deactivate based on the current reading. The pH downer valve will activate once the minimum required pHlevel has been met, and it will deactivate once the maximum required pH level has been attained. A "PASSED" remark will be assigned if the new pH level met the required pH level; otherwise, it will be marked as "FAILURE".

**Performance Test**

**Table 3.7** Weekly Growth Stage of Lettuce

| | Weekly Growth Stage | | | |
|---|---|---|---|---|
| | Week 1 | Week 2 | Week 3 | Week 4 |
| Greenhouse 1 | | | | |
| Greenhouse 2 | | | | |

Table 3.7 presents the growth characteristics of lettuce at different growth stages under two greenhouse systems: Greenhouse 1, which operates with a manual system, and Greenhouse 2, which uses an automatic system. The performance testing is designed to compare these two approaches in managing the growth conditions. The growth conditions will be monitored on a weekly basis from week 1 to week 4 to collect a detailed progression of the lettuce's growth over time. The results will provide valuable insights into the advantages of automation in maintaining optimal conditions for lettuce cultivation compared to manual control.

### 3.5 BUDGET REQUIREMENTS

The researchers make sure that the resources are widely accessible and available in order to properly carry out this study and construct the Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, Water TDS and pH level monitoring control. The financial requirements are also based on the theoretical framework and findings of the researchers. The table below shows the estimated costs for the components, materials and production output.

**Table 3.8** Bill of Materials

| Description | Specification | Quantity | Unit | Unit/Price | Total |
|---|---|---|---|---|---|
| Arduino Mega | ATmega2560/ 6-20V | 1 | pc | ₱ 1,145.00 | ₱ 1,145.00 |
| Contactor | 9-32 A AC | 1 | pc | ₱ 395.00 | ₱ 395.00 |
| DFRobot Gravity | 3.3-5.5 V | 1 | pc | ₱ 2,499.00 | ₱ 2,499.00 |
| DHT11 sensor | 5.5 V/0.2 mA | 2 | pc | ₱ 125.00 | ₱ 1125.00 |
| ESP32 | 78.32 mW | 1 | pc | ₱ 631.00 | ₱ 631.00 |
| Float Switch | 10W | 2 | pcs | ₱ 199.50 | ₱ 399.00 |
| Jumping Wire | Male 20cm | 3 | pcs | ₱ 35.00 | ₱ 105.00 |
| Pulley | 36kN high grade alloy | 1 | pc | ₱ 298.00 | ₱ 298.00 |
| PH4502C module | 5±0.2 V | 1 | pc | ₱ 999.00 | ₱ 999.00 |
| Raspberry Pi | 3.7-5 V | 1 | pc | ₱ 4,720.00 | ₱ 4,720.00 |
| Relay Module | 5V Single | 3 | pcs | ₱ 42.00 | ₱ 126.00 |
| Relay Board | 12V Single Channel | 3 | pcs | ₱ 50.00 | ₱ 150.00 |
| Shaft | 12mm | 2 | pcs | ₱ 353.00 | ₱ 706.00 |
| Shade Net | Anti UV | 1 | pcs | ₱ 499.00 | ₱ 499.00 |
| Solenoid Valve | 2 way/NC | 3 | pcs | ₱ 330.00 | ₱ 990.00 |
| Stepper Motor | 12 V/ 1.7 A | 1 | pcs | ₱ 699.00 | ₱ 699.00 |
| Water Pump | 12 V | 1 | pc | ₱ 1,499.00 | ₱ 1,499.00 |
| TSL2561 Sensor | 3.3V – 5V | 2 | pcs | ₱ 499.00 | ₱ 998.00 |
| Misting Nozzle | 3-12 kg | 1 | set | ₱ 541.00 | ₱ 541.00 |
| Water Flow Sensor | 1-25L/min | 1 | pcs | ₱ 184.00 | ₱ 552.00 |
| | | | | **Total Amount** | ₱ 25,993.00 |

**Table 3.7** shows the list of the expenses of the automated greenhouse management system, which includes the necessary equipment for the automated greenhouse management system and other electronic components. The total required budget for the said prototype amounted to ₱ 25,993.00.

**Table 3.9** Bill of Labor Costs

| Description | Costs (Php) |
|---|---|
| Construction Labor | ₱ 15,000.00 |
| Fabrication Labor | ₱ 30,000.00 |
| Programming Labor | ₱ 15,000.00 |
| Total Amount | ₱ 60,000.00 |

**Table 3.8** shows the list of the expenses of the development and installation of the Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, Water TDS and pH level monitoring control, which includes the programming, construction and fabrication of the prototype. The total required budget for the laborer and fabricator amounted to ₱ 60,000.00.

## 3.6 EXPECTED OUTPUT

The expected output is a fully functional greenhouse that can automatically water and harvest lettuce. It is also expected that it can regulate the temperature within the building to maintain the optimal growing condition for lettuce.

**Perspective View**

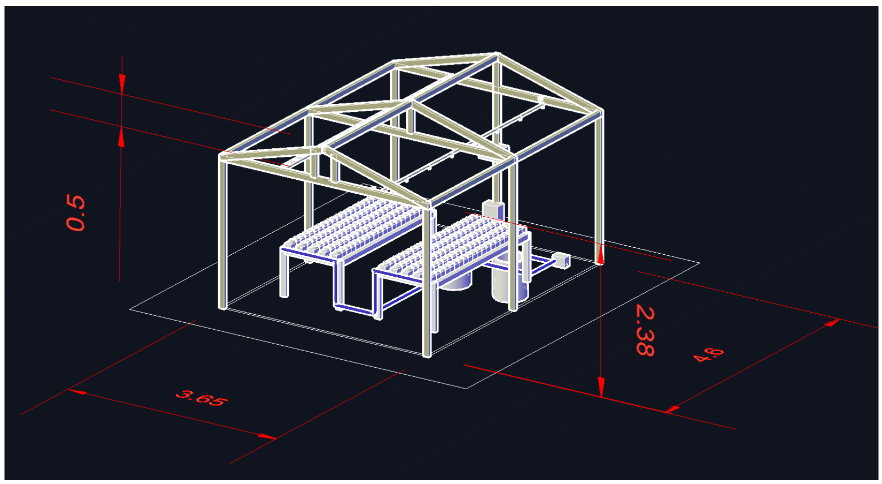


**Figure 3.5** Expected Output with Overall Dimension

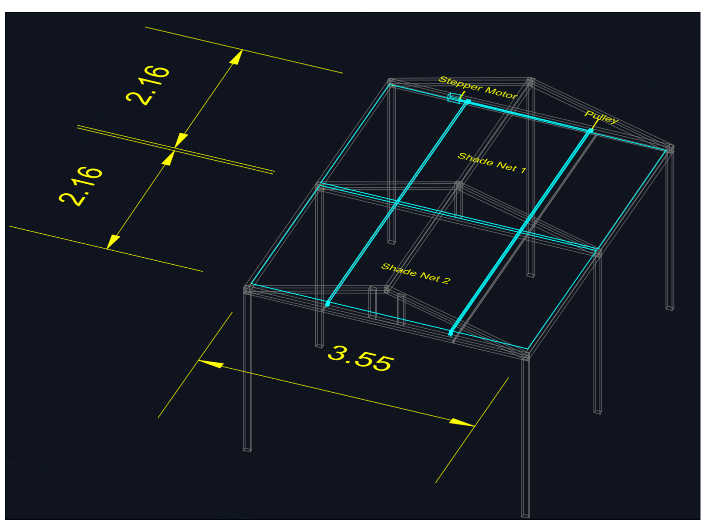


**Figure 3.6** Shading System

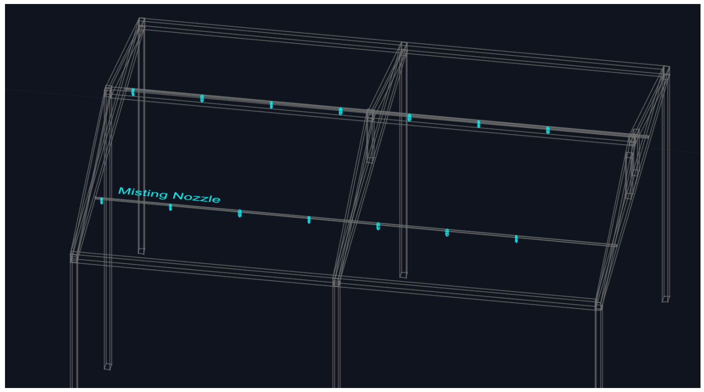


**Figure 3.7** Misting System

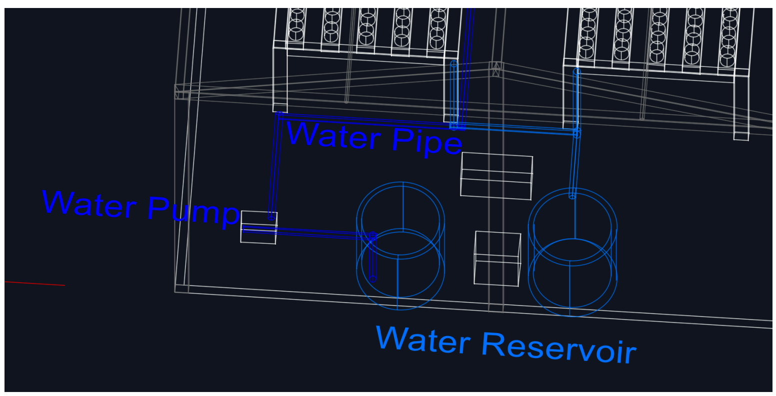


**Figure 3.8** Watering System

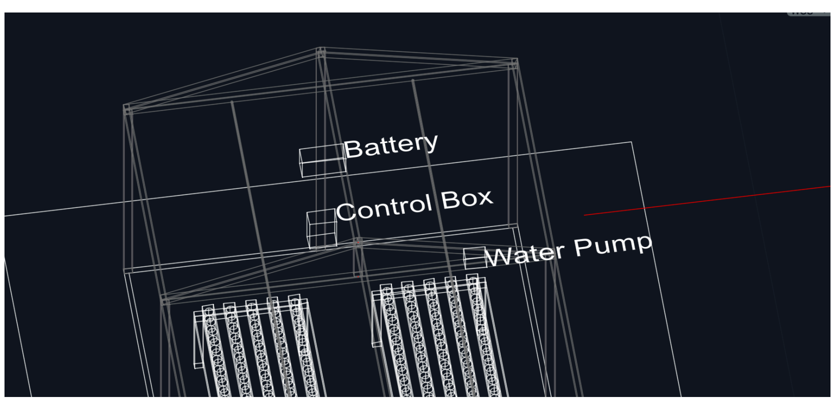


**Figure 3.9** Electronics System

The research aims to design an automated greenhouse management system for sustainable agriculture, specifically focusing on shading, misting, watering, and nutrient monitoring. This project aligns with the objectives of the DOST 6Ps Project by contributing to several key outputs. The innovative aspects of the automated control system could lead to potential patents, indicating an innovation. This would be evaluated based on the progress of the patent application process.

Overall, the research aligns with the goals of the DOST 6Ps Project by not only contributing to the advancement of knowledge in sustainable agriculture but also by potentially leading to practical innovations and solutions that benefit society and the environment.

Creating a greenhouse system positively impacts the economy by increasing crop yields, improving crop quality, creating jobs, and enabling year-round production, which expands market opportunities and can lead to higher profits. Efficient resource use and potential energy savings further enhance economic benefits.

### 3.7 GANTT CHART

The Gantt chart illustrates the work sequence of activities and corresponding duration in designing of the project "Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, Water TDS and pH level monitoring control". It begins with groupings, conceptualization and title proposal in January and February, followed by construction of Chapter I in February to March, and then Chapter II in the month of March. After that if we have a revision of Chapter I and II we will do it in March, Canvassing and Chapter III through the month of April, and the month of May is allotted for manuscript revisions and proposal defense.

**Table 3.10** Gantt Chart

| | January | February | March | April | May |
|---|---|---|---|---|---|
| **Groupings** | | | | | |
| **Conceptualizing** | | | | | |
| **Title Proposal** | | | | | |
| **Chapter I** | | | | | |
| **Chapter II** | | | | | |
| **Revision of Chapter I and II** | | | | | |
| **Canvassing** | | | | | |
| **Chapter III** | | | | | |
| **Revisions** | | | | | |
| **Proposal Defense** | | | | | |

The Table Gantt chart shows the progress of the researchers in every month and what month we started and finished each part of the chapter within the 1st week up to 18th week of Second Semester Academic year 2023-2024.

# CHAPTER 4

# PRODUCT DEVELOPMENT

This chapter encompasses the technicalibes in the construction of the product prototype. This Includes the Product Specification, Product Development, and Simulation and Testing. Design bases are specified in the Product Specification. Methods undertaken in the creation of the prototype are inscribed in the Product Development section, The testing procedures and summary of testing carried out is presented by simulation and testing.



## 4.1 PRODUCT SPECIFICATIONS

**Wire Sizing**

25 – 50 Feet Extension Cords

16 Gauge(1-13 Amps)

14 Gauge (14-15 Amps)

12-10 Gauge (16-20 Amps)

100 Feet Extension Cords

16 Gauge (1-10 Amps)

14 Gauge (11-13 Amps)

12 Gauge (14-15 Amps)

10 Gauge (16-20 Amps)

150 Feet Extension Cords

14 Gauge (1-7 Amps)

12 Gauge (8-10 Amps)

10 Gauge (11-15 Amps)

**[85]**

**SHADING**

**L298N motor driver**

The L298N motor driver is an affordable and straightforward option for controlling stepper motors, particularly suited for small to medium-sized bipolar stepper motors like the NEMA 17. It enables control over both the speed and direction of the motor. The L298N provides the necessary power and control to handle the NEMA 17's requirements, supporting up to 2A per channel and operating between 5V and 35V. [86]

**NEMA 17 stepper motor**

NEMA 17 stepper motors, which are characterized by 1.7 x 1.7-inch faceplate. These motors are distinguished by high torque, which is designed to maximize efficiency while minimizing vibration and noise, making it ideal for precise applications. The availability of customized windings allows these motors to be perfectly designed to specific voltage, current, and torque requirements.

Additionally, the NEMA standard, set by the National Electrical Manufacturers Association, ensures compatibility and safety across a wide range of electrical products, promoting consistency and reliability in power generation and transmission applications.[87]

**TSL2561 [40]**

**MISTING AND WATER CIRCULATION**

Misting Nozzle

Water Pump

**WATER TDS**

DFRobot Gravity: Analog TDS Sensor/Meter

**PH LEVEL MONITORING**

PH4502C module

Analytical Surver Electrode pH Probe

## 4.2 PRODUCT DEVELOPMENT

I2C is critical for enabling devices like sensors and displays to communicate over a two-wire interface (SDA and SCL). This protocol is essential for the development of products that require efficient, low-cost, and minimal wiring communication between

multiple devices. I2C is particularly valuable in complex systems where numerous sensors and components need to interact seamlessly.

## 4.3 SIMULATION AND TESTING

# CHAPTER 5

# RESULTS AND DISCUSSION

## 5.1 DISCUSSION OF RESULTS

## 5.2 SUMMARY OF FINDINGS

## 5.3 CONCLUSIONS

## 5.4 RECOMMENDATION

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# APPENDIX

## APPENDIX A

## LETTER FROM THE BENEFICIARY

BatStateU @120

BATANGAS STATE UNIVERSITY
The National Engineering University

*Propelling Transformations and Accelerating Reforms for National Development*

**College of Engineering – Department of Electrical Engineering**

**San Isidro Multi-Purpose Cooperative (SIMCO)**
Brgy. San Isidro, Batangas City
October 02, 2024

To Whom It May Concern,

Greetings!

We, the researchers, are submitting a proposal for the implementation of a Greenhouse Management System: Automated Control of Shading, Misting, Water Circulation, Ph Level and TDS Monitoring at San Isidro Multi-Purpose Cooperative (SIMCO) located in Barangay San Isidro, Batangas city. As providers of agricultural resources, we hold a strong conviction that the incorporation of hydroponics techniques into cultivation practices will significantly improve the well-being of our farmers and enhance the overall quality of their crops.

The implementation of this automated system, which controls essential greenhouse functions like shading, misting, and nutrient and water monitoring, will improve the overall efficiency of crop cultivation. By addressing key challenges such as maintaining optimal environmental conditions, monitoring pH and TDS levels, and automating watering schedules, the system aims to ensure a sustainable and high-yield operation, benefiting your crops, particularly in hydroponic lettuce farming.

Our approach aligns with sustainable agricultural practices and is designed to contribute to the achievement of your long-term productivity goals while minimizing environmental impact. We are confident that this innovative system will not only restore the functionality of your greenhouse but also contribute to the prosperity of your community's agricultural sector.

We sincerely seek your partnership and approval for this initiative and are grateful for your consideration.

Thank you.

Sincerely,

Signature and Name of Representative

**APPENDIX B**

**CIRCUIT DIAGRAMS**

- DETAILED CIRCUIT DIAGRAMS SHOWING THE ELECTRICAL WIRING, SENSORS, MICROCONTROLLER CONNECTIONS, AND AUTOMATION CONTROL SYSTEMS FOR SHADING, MISTING, WATER CIRCULATION, AND PH/TDS MONITORING.

**APPENDIX C**

**TECHNICAL SPECIFICATIONS**

- SPECIFICATION SHEETS OF THE EQUIPMENT AND COMPONENTS USED (E.G., SENSORS, PUMPS, ARDUINO BOARDS, MOTORS). THIS INCLUDES POWER REQUIREMENTS, DIMENSIONS, AND PERFORMANCE RATINGS.

Computation:

Pumps

Electrical Loads

**APPENDIX D**

**PROGRAMMING CODE**

- FULL SOURCE CODE FOR THE CONTROL SYSTEM, TYPICALLY WRITTEN FOR ARDUINO OR OTHER MICROCONTROLLERS USED TO MANAGE SHADING, MISTING, AND WATER CIRCULATION.

**APPENDIX E**

**FABRICATION DRAWINGS**

- MECHANICAL DRAWINGS OR CAD DESIGNS THAT SHOW THE DIMENSIONS AND ASSEMBLY STEPS OF FABRICATED PARTS, SUCH AS

THE GREENHOUSE FRAME, SHADE NET MECHANISM, OR MISTING SYSTEM.

**APPENDIX F**

**TEST DATA**

- RAW DATA COLLECTED FROM FUNCTIONALITY AND EFFICIENCY TESTS, SUCH AS TEMPERATURE, HUMIDITY, LIGHT INTENSITY READINGS, OR PH AND TDS LEVELS DURING THE TRIAL RUNS.

**APPENDIX G**

**GANTT CHART**

- A DETAILED PROJECT TIMELINE OR GANTT CHART OUTLINING THE STAGES OF DESIGN, FABRICATION, AND TESTING OF THE GREENHOUSE MANAGEMENT SYSTEM.

**APPENDIX H**

**USER MANUAL/INSTRUCTIONS**

- INSTRUCTIONS OR A USER MANUAL FOR OPERATING THE AUTOMATED SYSTEM, INCLUDING HOW TO CALIBRATE SENSORS, ADJUST SETTINGS, AND MAINTAIN THE EQUIPMENT.

**APPENDIX I**

**SAFETY GUIDELINES**

- SAFETY PROTOCOLS FOLLOWED DURING THE FABRICATION AND INSTALLATION OF ELECTRICAL, PLUMBING, AND MECHANICAL SYSTEMS IN THE GREENHOUSE, PARTICULARLY RELATING TO HIGH-VOLTAGE COMPONENTS AND HANDLING CHEMICALS.