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Study, Design and Construction of a Smart Domestic Mini Greenhouse.

-Presented by:

-MEZOUARI Abdelsselam
-ABUSHAMMALA Yousef ali Mahmoud

Proposed and directed by:

Dr. Sofiane TCHOKETCH KEBIR

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Dedication

To one who has always led me, guide, helped and encouraged to see me confront life up, “my dear father”.

To my family to my backbone in this life (brother and sisters).

To my friends who have always been there when I needed them My classmate YOUSEF for his effort and collaboration to all teachers that I am grateful.

For all the knowledge and value they taught me for myself enduring and outperformed the obstacles during my school career. I dedicate this work as a sign of respect and recognition the one who has giver everything, to the women who reigns on my heart,“dear my mother”.

Abdelsselam MEZOUARI

Dedication

I dedicate this work to those who gave me everything, to the source of eternal giving and love, my dear mother. to my first and last support in this world, may God keep him alive my beloved father.

I dedicate this work to my beloved homeland, Palestine, and to all its martyrs, wounded, and prisoners.

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List of abbreviations

ADC:Analog-to-Digital Converter

AI:Artificial Intelligence

ANN:Artificial Neural Network

API:Application Programming Interface

BME280:Barometric Pressure, Humidity, and Temperature Sensor

C++:C Plus Plus (programming language)

CAD:Computer-Aided Design

CNN:Convolutional Neural Network

DC:Direct Current

DHT:Digital Humidity and Temperature sensor

DHT22:Digital Humidity and Temperature Sensor

DIY:Do it your self

EEPROM:Electrically Erasable Programmable Read-Only Memory

GND:Ground

GPIO:General Purpose Input/Output

GSM:Global System for Mobile Communications

GUI:Graphical User Interface

HTTP:Hypertext Transfer Protocol

I2C:Inter-Integrated Circuit

IDE:Integrated Development Environment

IoT:Internet of Things

LCD:Liquid Crystal Display

LDR:Light Dependent Resistor

LED:Light Emitting Diode

M2M:Machine-to-Machine

ML:Machine Learning

MQTT:Message Queuing Telemetry Transport

PCB:Printed Circuit Board

PIR:Passive Infrared Sensor

PPM:Parts Per Million

PWM:Pulse Width Modulation

RFID:Radio Frequency Identification

RTC:Real-Time Clock

RTOS:Real-Time Operating System

SD:Secure Digital

SIM:Subscriber Identity Module

SPI:Serial Peripheral Interface

SVM:Support Vector Machine

URL:Uniform Resource Locator

USB:Universal Serial Bus

UV:Ultraviolet

VCC:Voltage Common Collector

Wi-Fi:Wireless Fidelity

XML:Extensible Markup Language

General introduction

In the face of escalating environmental challenges, rapid population growth, and increasing global food demand, modern agriculture must evolve to become more efficient, resilient, and sustainable. Traditional farming practices—while foundational—often suffer from inefficiencies in resource use, limited capacity for real-time monitoring, and vulnerability to climate variability. These limitations necessitate the integration of advanced technologies to meet the dual objectives of maximizing productivity and minimizing environmental impact. Among the most promising innovations driving this transformation are the Internet of Things (IoT) and Artificial Intelligence (AI), which offer unprecedented opportunities for automation, data-driven decision-making, and precision in agricultural management.

The convergence of IoT and AI has given rise to a new era of smart agriculture, where systems can autonomously monitor, analyze, and respond to environmental variables to optimize crop growth conditions. This thesis is rooted in this transformative context, aiming to explore how these technologies can be harnessed to develop an intelligent greenhouse system tailored for small-scale or domestic agricultural use. A smart greenhouse represents a closed, controlled environment where key parameters such as temperature, humidity, light, and soil moisture can be regulated in real time through sensor networks and actuators governed by embedded systems.

The central objective of this research is to design, construct, and evaluate a functional prototype of a smart greenhouse that combines an Arduino-based control architecture, a set of environmental sensors, and intelligent actuation mechanisms. Beyond basic automation, the system incorporates a lightweight convolutional neural network capable of predicting temperature trends based on external weather forecasts, allowing for proactive climate control within the greenhouse. This integration exemplifies how AI enhances conventional control systems by enabling predictive, rather than reactive, responses to environmental stimuli.

The structure of this thesis is organized into three main chapters. The first provides a comprehensive review of the literature surrounding smart agriculture, IoT frameworks, and AI applications in environmental control systems. The second chapter

details the methodological framework, including the electronic design, mechanical modeling using CAD tools, and the development of the embedded system. The third chapter focuses on the implementation and testing of the prototype, presenting the results of real-world experiments conducted under varied conditions.

Ultimately, this work contributes to the growing body of knowledge in sustainable smart agriculture and offers a practical, scalable solution for farmers, researchers, and technologists aiming to enhance productivity through technological innovation. The intelligent greenhouse developed herein serves as both a proof of concept and a platform for further research in the domain of autonomous agricultural systems.

Chapter 1

Introduction to Greenhouses

1.1 Introduction

Greenhouses are essential structures in modern agriculture, providing a controlled environment to cultivate a wide variety of crops regardless of external weather conditions.

They help in extending growing seasons, improving crop yields, and ensuring food security by protecting plants from pests, diseases, and extreme climatic variations. The history of greenhouses dates back to ancient civilizations, with significant advancements made over the centuries in terms of materials and design.[1]

Today, plastic-covered greenhouses have become popular due to their affordability, ease of construction, and effectiveness in creating optimal growing conditions . These structures are widely used in horticulture, floriculture, and vegetable production, offering farmers the ability to produce high-quality crops throughout the year. [2]

1.2 History and Development of Greenhouses

The concept of greenhouses can be traced back to ancient Roman times when rudimentary structures made of transparent materials were used to protect plants from harsh weather conditions.

During the Renaissance period in Europe, greenhouses evolved into glass-covered structures designed to cultivate exotic plants brought from overseas explorations.

The Industrial Revolution marked a significant advancement in greenhouse technology with the development of iron and glass structures, allowing for larger and more efficient designs. In the mid-20th century, the introduction of plastic materials revolutionized greenhouse construction by providing a cost-effective alternative to glass, making greenhouses more accessible to farmers worldwide.[3]

Today, modern greenhouses incorporate advanced technologies such as climate control systems, automated irrigation, and remote monitoring, enhancing productivity and resource efficiency. the following figure shows how the old greenhouses was [4].



Figure 1.1. Cucumbers in a greenhouse in Richfield, Minnesota, c.1910.

1.3 Advantages and Impact of Greenhouses

Greenhouses offer numerous advantages that contribute to enhancing agricultural productivity and sustainability.

One of the key benefits is their ability to provide a stable and controlled microclimate, enabling year-round cultivation of crops regardless of external weather fluctuations.

This controlled environment leads to improved crop quality, higher yields, and reduced dependency on seasonal variations. Additionally, greenhouses facilitate the efficient use of resources such as water and fertilizers by implementing precision irrigation and nutrient management techniques, minimizing waste and environmental impact.

They also serve a crucial role in protecting crops from pests, diseases, and extreme weather events, reducing the need for chemical pesticides and ensuring food security . Moreover, the economic impact of greenhouse farming is significant, offering farmers opportunities to grow high-value crops and access international markets, thereby boosting rural economies and employment.

As technology continues to evolve, modern greenhouse solutions are increasingly focusing on sustainability, integrating renewable energy sources and smart automation to further enhance their efficiency and environmental friendliness.

1.4 Challenges facing the agricultural sector and traditional greenhouses

Despite their many benefits, traditional greenhouses face several global challenges that impact their efficiency and sustainability.

One of the primary challenges is maintaining optimal environmental conditions, such as temperature, humidity, and ventilation, which require constant manual monitoring and adjustments [3].

Additionally, energy consumption for heating and cooling can be high, leading to increased operational costs, especially in extreme climates.

Pest and disease management also pose significant difficulties, as enclosed environments can create favorable conditions for rapid infestations if not properly controlled.

Furthermore, the durability and lifespan of plastic covering materials are limited, often requiring frequent replacements due to degradation from UV radiation and harsh weather conditions.

Water management is another critical issue, as inefficient irrigation practices can lead to resource wastage and soil salinity problems [2].

Addressing these challenges is crucial for improving the sustainability and productivity of traditional greenhouses.

1.5 Types of Greenhouses

A mini greenhouse is a compact structure designed to provide a controlled environment for plants, occupying an area of less than 10 square meters.

It helps maintain warmth, allowing plants to thrive even in cooler weather conditions.[5]

These structures can be built using different materials such as plastic or safety glass, offering protection and extending the growing season.

Available in various shapes and sizes, they can be placed on tabletops or set up as standalone units in gardens.

By creating a humid microclimate, mini greenhouses support the healthy growth of seedlings and young plants.

Many models come equipped with adjustable ventilation and heating options, enabling precise control over temperature and moisture levels, which is ideal for cultivating plants like eggplants and flowers before outdoor conditions become favorable.Here are the main types:

1.5.1 Cold Frames

Made of a wooden or metal box with a clear lid on top. They trap heat from the sun to keep plants warm, even in cold weather. Ideal for hardening off seedlings before moving them outdoors as shown in the following figure bellow.



Figure 1.2. Cold Frames

1.5.2 Portable Greenhouses

A small, movable structure designed to provide a controlled environment for plants. It is usually made of lightweight materials like plastic and aluminum, which makes it easy to set up and relocate, the next following figure shows an example of the Portable Greenhouses [6].



Figure 1.3. Portable Greenhouses

The key advantages of portable greenhouses include their flexibility, affordability, and ability to extend the growing season for plants.

However, its lower durability compared to permanent greenhouses and limited space for larger plant projects. Additionally, they can be vulnerable to extreme weather conditions, requiring extra care and maintenance.

1.5.3 Lean-to Greenhouses

Attached to an existing building or wall, utilizing the structure for support and easy access to electricity and water. Ideal for saving space while keeping your plants close by, the figure 1.4 shows an example of the Lean-to Greenhouses [7].



Figure 1.4. Lean-to Greenhouses

1.5.4 Gable-style Greenhouses

A gable-style greenhouse features a traditional pitched roof with two sloping sides that meet at a peak. The frame is usually made of wood or metal, and it's covered with glass or plastic panels.

Advantages include great ventilation, as the sloped roof allows hot air to escape. It also maximizes sunlight, which helps plants grow. The extra height makes it ideal for

taller plants, the next figure shows an example of the Gable-style Greenhouses [8].



Figure 1.5. Gable-style greenhouse.

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1.5.5 Geodesic Dome Greenhouses

A geodesic dome is an incredibly strong structure that holds up well in severe weather conditions and looks beautiful.

The frame made by mass-producing sticks or rods of the same length and assembling them with connectors in a series of triangles. assembly is more complicated than other structures, the next figure shows an example of the Geodesic Dome Greenhouses [9].



Figure 1.6. Geodesic dome greenhouse

1.5.6 Hoop Greenhouses

A hoop greenhouse is a type of structure that features curved, semi-circular frames made from metal or plastic pipes, covered with a plastic film. The hoops are spaced evenly apart, creating a tunnel-like shape. This design allows for easy construction and provides a spacious environment for plants.

Hoop greenhouses include their affordability, simplicity in construction, and ability to withstand harsh weather conditions. They are highly effective in maintaining a stable temperature and humidity level inside, promoting early plant growth and extending the growing season.

Additionally, hoop greenhouses are lightweight and can be easily relocated if necessary, the next figure shows an example of the Hoop Greenhouses[10].



Figure 1.7. Hoop Greenhouses

Each type offers unique benefits, such as protecting young plants from frost, promoting faster growth through temperature control, conserving water by reducing evaporation, and preventing pests without chemicals, making gardening more successful year-round.

1.6 Types of Greenhouse Materials

Most greenhouse have rudimentary frames made of metal pipe, plastic pipe or wood.

generally, each material plays a part in ensuring plants can grow well, no matter the outside weather conditions.

1.6.1 Wood material

Good thermal insulator, making it important in cold climates. But its susceptible to corrosion and damage due to moisture, which can lead to structural deterioration over time. In addition, it can be exposed to insects such as termites.

1.6.2 Metal piping (aluminum or steel)

Allows the creation of stable and long-lasting structures However, it is heavier than other materials such as PVC, which makes transportation and installation more difficult.

It also costs more than other materials. and it isn’t a good insulator. Especially aluminum.

1.6.3 Polyvinyl chloride (PVC)

These pipes provide a practical alternative to metal pipes in building support frames, as they are easy to shape and connect without the need for complex tools.

The advantages of using PVC pipes in structure building include their resistance to corrosion and damage from moisture, reducing the overall weight of the frame, which makes transportation and installation easier.

Additionally, their low cost makes them an economical choice for agricultural projects.

1.7 Conclusion

In this chapter, we started by explaining the concept of the greenhouse, its history, features, challenges, classifications, and the types of materials used in its construction.

We chose the hoop greenhouse design for our project due to its efficiency and ease of implementation and transportation if needed. Also, the project will be made of PVC due to its light weight and reasonable price, The low cost advantage compared to other types of greenhouses makes this project suitable for small projects or personal consumption.

In the coming chapters, we will address smart solutions that enhance the profitability of the project by minimizing the waste of resources and optimizing the conditions for plant growth.

Chapter 2

Artificial Intelligence and Internet of Things

2.1 Introduction

Intelligent greenhouses represent another generation of greenhouse development based on the introduction of advanced technologies such as artificial intelligence, Internet of Things (IoT), etc. These greenhouses are equipped with a control system that collects and analyzes data on the plants and their environment in real time, and transmits it via the Internet. data on plants and their environment in real time, and transmit it via the Internet to other platforms. The Internet of Things represents an infrastructure that fills the gap between simple sensors which provide raw, noisy and imperfect data, and high-level application-based high-level applications that provide sophisticated services. Artificial Intelligence (AI) responsible for creating intelligent systems capable of learning, reasoning and making decisions autonomously. AI is being applied in agriculture with the aim of improving the efficiency, productivity and sustainability of food production. In this chapter, we define the concept and architecture of the AI and IoT .

2.2 Artificial Intelligence

2.2.1 Introduction to Artificial Intelligence

The origins of artificial intelligence go back to ancient Greek mythology, which says that a mechanical man can mimic human behavior. However, it seems that the quest for this became a reality when many scientists from different disciplines such as neuroscience and computer science came together during the war. The second global revolution to reach smart machines [11]. In this chapter, we will talk in general about artificial intelligence, and mention the most important basics in it, down to the algorithms used in our work to gain a greater understanding of this field.

2.2.2 History of Artificial Intelligence

Humans have always built tools that have an impact on human development and multiply human power. In ancient times, it surpassed the ingenious machine of Archimedes in Alexandria in particular, where in 150 AD he was able to build a steam engine that could open the door of the temple alone, surpassing all human muscles. Moreover, before it specifically in 1200 BC, the Antikythera machine was built, which had the ability to perform Advanced astronomical calculations including predicting eclipses. These and other examples show that the foundations for building automation and systems that later developed and became the cornerstone of computer science and artificial intelligence were laid two thousand years ago [12].

The actual leap in this field occurred in the year 1956 when ten high-ranking people met to define artificial intelligence, including John McCarthy, Marvin Minsky (one of

the founders of the artificial intelligence laboratory at the Massachusetts institute of technology), and Herbert Simon (winner of the Nobel Prize in economics in 1978, and the inventor of rationality). Claude Shannon (inventor of information theory). One of the most important goals of this symposium was to define intelligence using computer tools, to be one of the cornerstones of the world of artificial intelligence [13].

2.2.3 Definitions of AI

With modern development, the goal from ai has become to develop systems that can solve problems much better than humans, we can summarize it in the form of two definitions:

Definition 1: In which we can summarize Artificial Intelligence (AI) as a set of algorithms that process a set of information or data related to tasks in a manner similar to and mimicking those that a human might undertake.

Definition 2: In which we can say that the intelligent system is therefore an artificial intelligence system in which the components are divided into two parts:

- The physical part that contains electronic equipment such as programmable electronic cards, computers, etc.

- The computerized part consists of several programs that can process information of different types and forms.

Hence, we note that artificial intelligence is an expression of a link between many disciplines such as computer science and mathematics (logic, analysis, optimization, probability, linear algebra) and many other fields.

2.2.4 Types of Artificial Intelligence

The classification of artificial intelligence has faced many difficulties due to the many fields it falls into and the classifications differ according to the advantages provided and the goals sought from it. Perhaps the most prominent classifications are those related to simulating human activities such as movement, learning, thinking, awareness, and creativity. Accordingly.[14] [15]. Artificial intelligence has been classified into two main areas:

2.2.4.1 Based on Capability

Refers to classifying artificial intelligence systems according to their level of competence. It is typically divided into three categories: Narrow AI (specialized tasks), General AI (human-like cognitive abilities), and Superintelligent AI.[16]

- Narrow AI: a goal-oriented AI trained to perform a specific task. The machine intelligence that we witness all around us today is a form of

narrow AI. Examples of narrow AI include Apple's Siri and IBM's Watson supercomputer.

Despite being highly efficient at specific tasks, Narrow AI lacks the ability to function beyond its predefined scope. These systems do not possess understanding or awareness.

- General AI: General AI refers to AI systems that have human intelligence and abilities to perform various tasks. Systems have capability to understand, learn and apply across a wide range of tasks that are similar to how a human can adapt to various tasks. While General AI remains a theoretical concept, researchers aim to develop AI systems that can perform any intellectual task a human can. It requires the machine to have consciousness, self-awareness, and the ability to make independent decisions, which is not yet achievable

- Super AI: The AI version that surpasses human intelligence and can perform any task better than a human. Capabilities of a machine with super AI include thinking, reasoning, solving a puzzle, making judgments, learning, and communicating on its own. Today, super AI is a hypothetical concept but represents the future of AI.

2.2.4.2 Based on Functionality

AI can also be classified into four types based on how the systems function. This classification is more commonly used to distinguish AI systems in practical applications.

- Reactive AI: Reactive machines are basic AI types that do not store past experiences or memories for future actions. Such systems zero in on current scenarios and react to them based on the best possible action. Popular examples of reactive machines include IBM's Deep Blue system and Google's AlphaGo.

- Limited Memory AI: Limited Memory AI can learn from past data to improve future responses. Most modern AI applications fall under this category. These systems use historical data to make decisions and predictions but do not have long-term memory. Machine learning models, particularly in autonomous systems and robotics, often rely on limited memory to perform better

- Theory of Mind AI: Theory of mind refers to the type of AI that can understand human emotions and beliefs and socially interact like humans. This AI type has not yet been developed but is in contention for the future.

- Self-Aware AI: Self-Aware AI is an advanced stage of AI that possesses self-consciousness and awareness. This type of AI would have the ability to not only understand and react to emotions but also have its own consciousness, similar

to human awareness. While we are far from achieving self-aware AI, it remains the ultimate goal for AI development. It opens philosophical debates about consciousness, identity, and the rights of AI systems if they ever reach this level.

2.2.5 Artificial Intelligence Techniques

As we mentioned previously, because artificial intelligence has become part of almost all areas of our lives, we can divide it into many sub-fields, including:

2.2.5.1 Machine Learning (ML)

Machine learning is the field that, as its name indicates, addresses the aspect in which we build computers that learn and improve automatically through experimentation and learning. This field is considered one of the most important, growing, and widespread fields of artificial intelligence these days, and we can say that this field is the link between computer science and statistics. The paradigm shifts and major development in this field occurred when it was linked to new learning algorithms and theories, allowing for evidence-based decision-making. Today this field is included in science, technology, commerce, learning, marketing, and many others [17].

2.2.5.2 Deep Learning

Deep learning is a subfield of machine learning which attempts to learn high-level abstractions in data by utilizing hierarchical architectures. It is an emerging approach and has been widely applied in traditional artificial intelligence domains, such as semantic parsing, transfer learning, natural language processing, computer vision, and many more. There are mainly three important reasons for the booming of deep learning today: the dramatically increased chip processing abilities (e.g. GPU units), the significantly lowered cost of computing hardware, and the considerable advances in the machine learning algorithms.

2.2.5.3 Natural language processing

We can say that it is a set of mathematical operations for tools for the automatic analysis and representation of human languages with theoretical motives, that is, it is based on textual analysis, and therefore it requires a deeper understanding of the nature of language using machines, the most prominent examples of which are: retrieving information from the Internet, compiling it, and answering the questions it has. It is based primarily on algorithms that depend on the textual representation of web pages, dividing parts, verifying writing, and analyzing the level of each word. Therefore, one of its most prominent problems is dealing with paragraphs and extracting benefits from them, as its ability in this field is limited [18].

2.2.5.4 Rule-Based Systems (Fuzzy Logic)

Fuzzy logic is a computational process that takes reasoning in systems indicated by uncertainty and imprecision.[19] Unlike traditional binary logic, where variables can only take values of 0 or 1, fuzzy logic permits for a range of truth values between 0 and 1, illustrating partial truths. This makes fuzzy logic particularly useful in real-world applications, where systems are often too complex or uncertain to be defined by rigid binary classifications. Instead of operating hard thresholds, fuzzy logic presents the concept of “degrees of truth,” enabling it to model the vagueness inherent in many natural procedures, including those found in renewable energy systems. [20] Fuzzy logic creates upon the idea of fuzzy sets, where an element can partially belong to a set, with a membership function defining the degree of belonging. For instance, in traditional logic, a temperature might be classified as either "hot" or "cold," but in fuzzy logic, a temperature could be "somewhat hot" or "very hot" founded on its degree of membership in the "hot" set. This flexibility permits fuzzy logic to regulate continuous and nonlinear systems more effectively than rigid binary systems.

2.2.6 Artificial Intelligence Algorithms

2.2.6.1 Definition

Artificial intelligence algorithms are about giving machines the ability to learn and study data and make appropriate decisions by giving them a set of instructions or rules, in other words, giving the machine the ability to think like humans and give it the intelligence to perform a set of applications such as recognizing patterns, understanding natural language, and solving problems [21].

2.2.6.2 Artificial IntelligenceArtificial Intelligence algorithms work

Artificial intelligence algorithms generally neglect learning, as they receive training data through which they learn so that they can later make predictions, make decisions, etc., and the method of obtaining them is considered. This data and dealing with it is the main difference between the different types of artificial intelligence algorithms. That is, in general, artificial intelligence takes classified or unlabeled training data provided by developers or that it collects itself, processes that data and uses it to learn and develop itself, and then performs the tasks assigned to it using the training data as a basis. Here it is worth noting that some artificial intelligence algorithms They are taught to develop and improve their data on their own while other algorithms require human intervention[22].

2.2.6.3 Types of Artificial Intelligence Algorithms

Many categories of classification of artificial intelligence algorithms differ in how they are trained and how they work, including the following three main categories:

2.2.6.4 Supervised Learning Algorithms

It is considered the most important and widely used methodology in machine learning these days, and this type of algorithm works by mapping input variables X, and output variables Y to predict invisible data outputs. Building an already supervised learning algorithm requires a team of experts, technologists, and others to review the results, and data scientists to test the accuracy of the results [23].

The most famous types of supervised learning algorithms are Classification and Regression where All of them can either be used for classification or regression, or both. Each one is defined as follows [22].:

• Classification: is the use of binary (0 = no, 1 = yes) to produce an either/or conclusion. Thus, something will only ever be categorized by the algorithm as one or the other, never as both. Multi-class categorization pertains to the arrangement of data into predetermined categories or types that are pertinent to a certain requirement.

• Regression: a real number-either a round number or a decimal point—will appear after the output. The algorithm typically uses the points from the dependent and independent variables to estimate a possible other result (either forecast or generalized estimate). There are a lot of supervised learning algorithms, including:

- Linear Regression, Logistic Regression:

  Similar to classification, linear regression is a type of a supervised learning model. . However, in contrast to classification, a regression model generates a numerical variable as output, whereas a classification results in a categorical variable (which is merely a label).[24]

  Given a set of training data as shown in the equation bellow:

$$D = (x(i), y(i)) | i \in 1, ..., m \tag{2.1}$$

  sampled identically and independently from a distribution D, linear regression assumes that the relationship between the label Y and the n-dimensional variable X is linear. More specifically, it is assume that the hypothesis space H is within linear models. Therefore, the goal is to find a parameterised function[25]

- Decision Trees, Random Forests.

  A decision tree is a tree whose internal nodes can be taken as tests (on input data patterns) and whose leaf nodes can be taken as categories (of these patterns).

These tests are filtered down through the tree to get the right output to the input pattern. Decision Tree algorithms can be applied and used in various different fields. It can be used as a replacement for statistical procedures to find data, to extract text, to find missing data in a class, to improve search engines and it also finds various applications in medical fields. Many Decision tree algorithms have been formulated. They have different accuracy and cost effectiveness.[26]

It is also very important for us to know which algorithm is best to use. The ID3 is one of the oldest Decision tree algorithms. It is very useful while making simple decision trees but as the complications increases its accuracy to make good Decision trees decreases. Hence IDA (intelligent decision tree algorithm) and C4.5 algorithms have been formulated.

- Support Vector Machines (SVM).

  support vector machine (SVM). Originally developed by Vladimir Vapnik and Alexey Chervonenkis in the 1960s for linearly separable data, the “kernel trick” introduced in the 1990s allowed one to extend this framework to nonlinear problems[27]

  quite different from the other classification methods discussed so far, because an SVM is not a probabilistic classifier that aims to estimate a conditional probability distribution. Instead, an SVM aims to estimate optimal separating hyperplanes in a transformed feature space[24]

2.2.6.5 Unsupervised Learning Algorithms

As its name indicates, this type refers to algorithms in which there is no teacher. In this type, unclassified and unlabeled data is presented to the algorithm, and based on the characteristics and features of that data and the relationships between the various points, it learns the data and implements the appropriate action based on training on the characteristics and features of similar data, and it is used. Mainly for clustering [28]

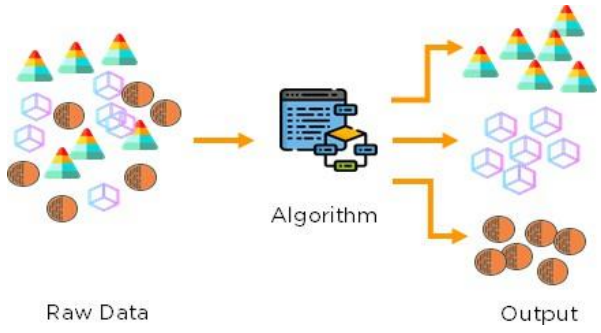


Figure 2.1. Guide to Unsupervised Learning

2.2.6.6 Reinforcement Learning Algorithms

They are artificial intelligence algorithms that learn by receiving panic responses after performing their work, usually in the form of a "reward".[29]

Reinforcement learning is a strong learning algorithm that learns the optimal policy through interaction with the environment without the model of the environment [30]. It uses an agent that learns the value function for a given policy through interaction with the environment to predict an optimal solution and based on the value function, it continuously develops and learns the optimal policy [31]. The most commonly used method in reinforcement learning applications is the Temporal-Difference (TD) learning [32] which exploits a combination of the Monte Carlo [33] method of measuring value through the experience without a model and the advantages of dynamic programming [34], which can estimate the value by using only current estimates.

- Q-Learning

  Q-learning (Watkins, 1989) is a simple way for agents to learn how to act optimally in controlled Markovian domains. It amounts to an incremental method for dynamic programming which imposes limited computational demands. It works by successively improving its evaluations of the quality of particular actions at particular states.[35]

- Deep Q-Networks (DQN) These algorithms typically require a huge amount of data before they reach reasonable performance. In fact, their performance during learning can be extremely poor.[36]

  This may be acceptable for a simulator, but it severely limits the applicability of deep RL to many real-world tasks, where the agent must learn in the real environment.

2.2.6.7 Optimization Algorithms

Optimization algorithms are mathematical and computational techniques used to find the optimal solution for a given objective function while satisfying predefined constraints. These algorithms aim to maximize or minimize an objective function, such as minimizing error in machine learning models or maximizing efficiency in engineering systems.[37]

2.2.6.8 Types of Optimization:

- Convex vs. Non-Convex Optimization:

  In convex optimization, the objective function has a single global optimum, making the solution straightforward. In contrast, non-convex optimization

involves multiple local optima, making the problem more challenging to solve [38].

- Deterministic vs. Stochastic Optimization:: Deterministic algorithms yield the same results for the same inputs, such as Gradient Descent. Stochastic methods introduce randomness in the search process, such as Genetic Algorithms[39].
- Numerical vs. Analytical Optimization:

  Analytical methods rely on differentiation to find optima, while numerical methods use iterative approximations like Newton's Method [40].

2.2.6.9 Common Optimization Algorithms

- Gradient Descent (GD): A widely used algorithm in machine learning that updates model parameters based on the gradient of the loss function. Variants include Batch GD, Stochastic GD (SGD), and Mini-Batch GD [41].
- Newton's Method: Uses second-order derivatives for faster convergence but requires complex computations [42]
- Nature-Inspired Algorithms:

  o Genetic Algorithms (GA): Mimic natural selection for optimization [43].

  o Particle Swarm Optimization (PSO): Inspired by swarm intelligence in birds and fish [44].

2.2.7 AI Model Training and Implementation

2.2.8 Artificial Intelligence Challenges and Limitations

Despite its rapid advancements, artificial intelligence (AI) still faces significant technical, ethical, and societal challenges. One major issue is data quality and bias—AI models require large, diverse datasets, yet real-world data is often incomplete or biased, leading to unreliable predictions and unfair outcomes [45] . Additionally, AI systems struggle with generalization, performing well on training data but failing in real-world scenarios where conditions differ[46]. AI also demands immense computational resources, making state-of-the-art models costly and environmentally unsustainable [47]. Furthermore, the lack of interpretability in deep learning models creates trust issues, particularly in fields like healthcare and finance, where explainability is crucial Ethical concerns include algorithmic bias, privacy risks, and job displacement. Biased AI can reinforce discrimination in decision-making systems, while AI-driven automation threatens employment in multiple industries [48][49].

Security vulnerabilities, such as adversarial attacks, further expose AI's limitations, allowing small input manipulations to deceive models in critical applications like cybersecurity and autonomous driving [50].

2.2.9 Future Trends in Artificial Intelligence

Artificial intelligence (AI) is rapidly evolving, with key trends shaping its future. Explainable AI (XAI) is gaining traction to improve transparency and trust in critical applications like healthcare and finance [51].

Additionally, AI automation and augmentation are redefining the workforce, enhancing human-AI collaboration rather than outright replacing jobs. A major shift is toward edge AI, where models process data locally instead of relying on cloud computing, reducing latency and enhancing privacy—essential for applications like autonomous systems [52].

At the same time, researchers are developing energy-efficient AI to mitigate the environmental costs of large-scale model training. Another breakthrough is the integration of AI with quantum computing, which could revolutionize fields like cryptography and drug discovery by exponentially increasing computational speed. Additionally, multi-modal AI is making interactions more intuitive by integrating different data types such as text, images, and speech [53].

2.3 Internet of Things

2.3.1 Definition

The Internet of Things (IoT) refers to a network of interconnected physical devices that collect, exchange, and process data through the internet. These devices, embedded with sensors, actuators, and communication technologies, enable real-time monitoring, automation, and decision-making without direct human intervention [54].

2.3.2 Evolution of Internet of Things

The concept of IoT has evolved over decades, driven by advancements in computing, networking, and sensor technologies. Key milestones include [55]:

- 1980s-1990s: Early concepts of machine-to-machine (M2M) communication emerged.
- 1999: The term "Internet of Things" was first coined by Kevin Ashton.
- 2000s: Growth of wireless technologies (Wi-Fi, Bluetooth, RFID) enabled IoT expansion.

- 2010s-Present: Massive adoption of IoT in industries, smart homes, healthcare, and agriculture.

2.3.3 Importance of Internet of Things in Modern Technology

- Driving Innovation: IoT is a catalyst for innovation across industries, from healthcare to manufacturing, enabling smarter solutions and improving existing processes.
- Global Connectivity: IoT facilitates the interconnectivity of devices, allowing for a more integrated world where data can be accessed and shared in real time.
- Data Collection and Analytics: IoT provides vast amounts of data that businesses and organizations can use to make informed decisions, drive business strategies, and improve overall performance.
- Automation and Smart Systems: IoT is key in the development of smart homes, smart cities, and industrial automation, creating systems that operate more efficiently and autonomously.

2.3.4 Industrial Revolution to Internet of Things (History)

The tech industry has progressed vastly over the centuries. Its major transitions are defined by the four industrial revolutions: coal, gas, electronic devices, and the Internet along with renewable energy. Each industrial evolution provided tools to achieve task automation.

More specifically, the first industrial revolution started in 1760. It led to the transition from hand to machine-automated processes, as well as to the increase of steam and water power. In Europe, this change first began in Great Britain and later spread across the continent. These advances gave birth to new tools, such as assembly lines, telegraph and power grids, as well as to mechatronics factory technological innovations. As for the second industrial revolution, it started in the late 19th century. Specifically, it introduced the massive use and production of electrical power and communication networks, i.e., telephone services. This revolution started from the United States of America, introducing an industrialized method of production. Subsequently, the third industrial revolution started in 1970 and it is currently progressing towards its end. This era is characterized by the automatization of production, placing emphasis on informatics and computer systems in general, as means to enhance and accelerate production.

In the past few decades, a fourth industrial revolution has emerged, known as Industry 4.0. Industry 4.0 takes the emphasis on digital technology from recent decades

to a whole new level with the help of interconnectivity through the Internet of Things (IoT), access to real-time data, and the introduction of cyber-physical systems [56].

2.3.5 What is Internet of Things and Machine-to-Machine?

IoT is one of the enabling technologies of "Industry 4.0". Its goal is the connection of humans with machines and smart technologies. The Internet of Things (IoT) refers to the vast interconnected network of computer devices (e.g., sensors) which exchange large amounts of data at rapid speed. Moreover, the inter-connectivity between these devices is achieved via Machine-to-Machine communication (M2M), i.e., a standardized way for various machines performing different operations to communicate and rapidly exchange information on a global scale. M2M is not just responsible for passing information; it also acts as the middleman providing an end-to-end layer for machines (or physical objects) to communicate in a global network, without human interaction. While these terms are frequently used interchangeably, it is important to state that connectivity itself is not IoT [57].

2.3.6 How can Internet of Things facilitate everyday activities and the tech industry?

IoT can help users work and live "smarter", by facilitating everyday tasks and supporting our well-being. A prime example of the many uses of IoT is home automation; This allows residents to have complete control over domestic appliances through remotely controlled and Internet-connected systems. M2M is responsible for constructing a communication channel between devices, whereas IoT processes this information and offers efficient suggestions to users. Information processing is typically implemented using Big Data analysis and other technology tools to achieve process automation and proactive assistance of residents in everyday tasks.

Additionally, IoT can be used as a tool for businesses to achieve "digital transformation". This term describes the need to reduce touchpoints throughout a business operation flow which reduces both the time and the cost of delivery. This is typically achieved by shifting business processes to cloud services and replacing monolithic applications with smarter systems. As for the use of IoT by the tech industry, the so-called smart mobile IoT (M-IoT) is currently being developed in the field of mobile computing. This technology allows for the construction of new network protocol infrastructure which constitutes a secure environment for smart devices, including micro-computers and integrated circuits. These IoT systems are important because they promote decentralized solutions which take advantage of "edge computing", meaning systems consisted of multiple remote nodes acting as IoT gateways [58].



Figure 2.2. IoT Applications in Everyday Life and the Tech Industry

2.3.7 Applications of Internet of Things

- Smart Homes: Automated lighting, security cameras, voice-controlled assistants.
- Industrial IoT (IIoT): Predictive maintenance, factory automation, smart sensors in production lines.
- Healthcare: Remote patient monitoring, wearable fitness trackers, smart medical devices.
- Agriculture and Greenhouses: Precision farming, automatic irrigation systems, climate monitoring.
- Smart Cities: Traffic monitoring, waste management, smart street lighting.
- Automotive: Connected cars, self-driving technology, fleet tracking systems.

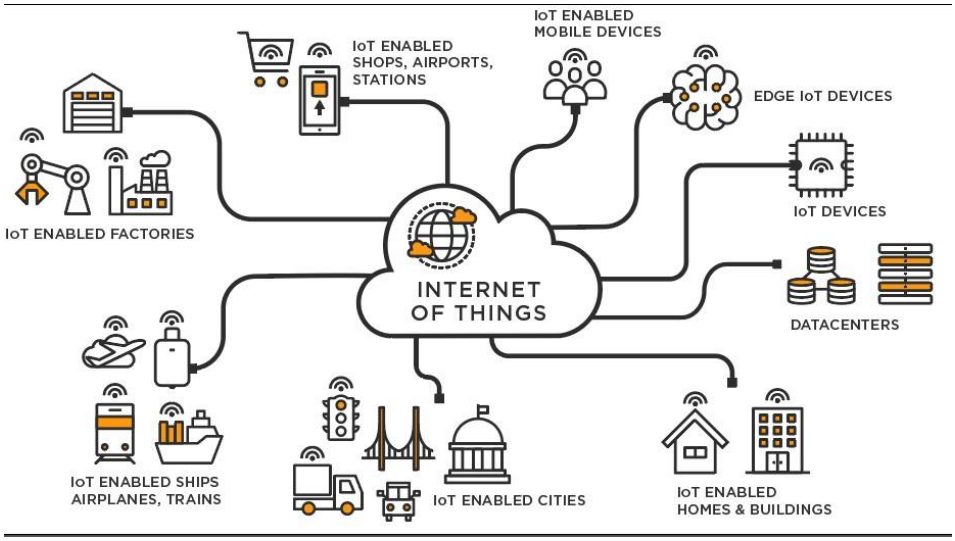


Figure 2.3. IoT Applications

2.3.8 Internet of Things Architecture

There are five layers in the IoT architecture, which provide a structured approach to understanding how IoT systems function, from data collection to user interaction. Each layer has a specific role in ensuring efficient communication, processing, and decision-making.

2.3.8.1 Perception Layer (Sensing Layer)

- The (physical layer) of IoT.
- Includes sensors, actuators, RFID tags, cameras, and GPS.
- Collects data from the environment (e.g., temperature, humidity, motion).
- Converts physical signals into digital data for processing.

2.3.8.2 Network Layer (Communication Layer)

- Responsible for transmitting data between devices and servers.
- Uses various communication technologies:
  - Short-range: Wi-Fi, Bluetooth, Zigbee.
  - Long-range: LoRaWAN, NB-IoT, 5G, satellite.
- Ensures reliable and secure data transfer.

2.3.8.3 Middleware Layer (Processing Layer)

- Also known as (Fog Computing) or (Edge Computing) layer.
- Processes data locally before sending it to the cloud.
- Reduces latency and bandwidth usage by filtering and analyzing data near the source.
- Uses microcontrollers, gateways, and edge servers.

2.3.8.4 Application Layer (Data Management Layer)

- Stores, analyzes, and processes large amounts of IoT data.
- Uses cloud platforms like AWS IoT, Google Cloud IoT, or Blynk.
- Provides AI-based analytics, decision-making, and storage.
- Supports remote access to IoT devices.

2.3.8.5 Business Layer (User Interface Layer)

- The interface between the system and the end user.
- Displays processed data via mobile apps, dashboards, web applications.
- Enables remote control and automation of IoT devices.
- Examples: Smart home apps, industrial monitoring dashboards.

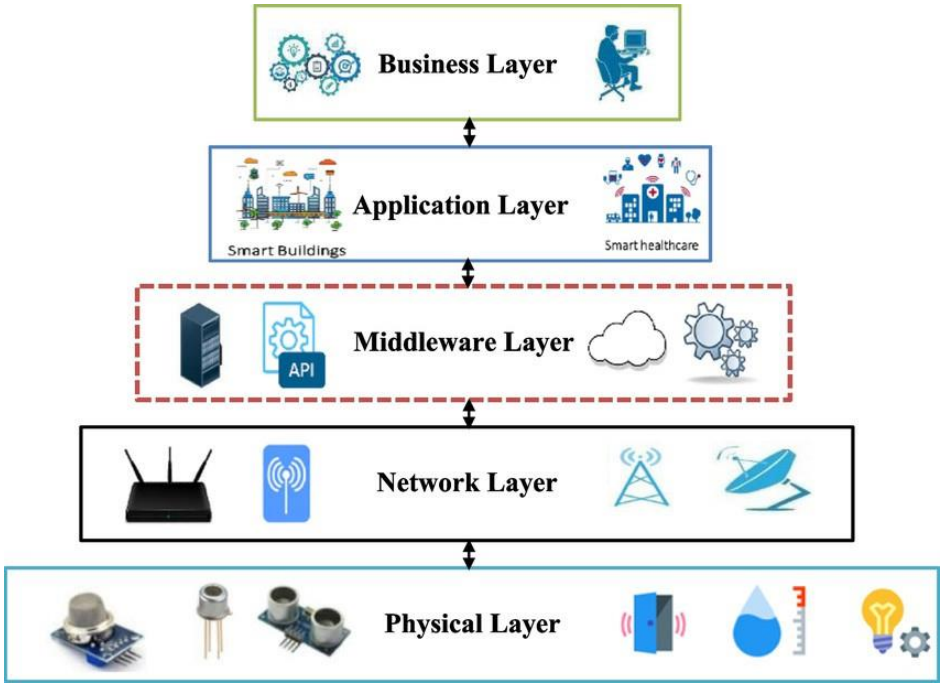


Figure 2.4. IoT Architecture Layers

2.3.9 Challenges of Internet of Things Implementation

While the Internet of Things (IoT) has significant potential, its widespread adoption comes with a set of challenges that need to be addressed to ensure success. These challenges span across various layers of IoT architecture, from hardware limitations to security risks. Here are some key challenges:

2.3.9.1 Connectivity Issues

IoT devices often rely on wireless networks like Wi-Fi, Bluetooth, or cellular, which may be unstable or unavailable in remote areas. Limited bandwidth can also cause delays or data loss. Additionally, interoperability between different protocols can lead to compatibility issues.

2.3.9.2 Data Security and Privacy

IoT devices are vulnerable to cyberattacks if not properly secured, especially with weak authentication and lack of encryption. Data privacy is a concern as sensitive personal information is collected and stored, requiring secure communication and protection against unauthorized access.

2.3.9.3 Scalability and System Management

As IoT systems grow, managing a large number of devices becomes complex, requiring effective tools for device monitoring and software updates. The system must be scalable to handle more devices and the increasing data traffic efficiently.

2.3.9.4 Integration with Legacy Systems

Integrating IoT into existing infrastructures can be difficult due to compatibility issues with older systems. Different data formats and standards across devices can also make it hard to unify and analyze data consistently.

2.3.9.5 Environmental Factors

IoT devices deployed in harsh environments may malfunction due to factors like temperature, humidity, or dust. Ensuring sensor accuracy and durability in such conditions is a challenge.

If we can successfully overcome these challenges, which is possible with the right tools and a well-defined roadmap, we can build a truly useful and efficient IoT project. By carefully addressing each issue step by step, we can unlock the full potential of IoT applications across various domains.

2.3.10 Advantages of Internet of Things

2.3.10.1 Automation and Efficiency

IoT enables automation of routine tasks, reducing the need for manual intervention. This leads to greater efficiency in various applications like smart homes, manufacturing, and healthcare, saving both time and resources.

2.3.10.2 Real-Time Monitoring and Control

With IoT, devices can be monitored and controlled in real-time, allowing for quick responses to changes or issues. This is particularly useful in industries like agriculture, healthcare, and transportation, where immediate actions are critical.

2.3.10.3 Improved Decision-Making

By collecting and analyzing large amounts of data, IoT systems provide valuable insights that help in making informed decisions. These insights can optimize operations, reduce costs, and improve productivity across different sectors.

2.3.10.4 Cost Reduction

IoT helps in reducing operational costs through better resource management, predictive maintenance, and optimization of energy use. For example, smart meters can help reduce energy consumption, and IoT in manufacturing can minimize waste.

2.3.10.5 Enhanced Safety and Security

IoT-based security systems, such as smart cameras and motion sensors, enhance safety by providing continuous monitoring and immediate alerts. This is beneficial in both residential and industrial applications to prevent accidents or unauthorized access.

2.3.11 Market Opportunity

The IoT offers a great market opportunity for equipment manufacturers, Internet service providers and application developers. McKinsey Global Institute reported that the number of connected machines (units) has grown 300% over the last 5 years. Traffic monitoring of a cellular network in the U.S. also showed an increase of 250% for M2M traffic volume in 2011 [59].

Economic growth of IoT-based services is also considerable for businesses. Healthcare and manufacturing applications are projected to form the biggest economic impact. Healthcare applications and related IoT-based services such as mobile health (m-Health) and telecare that enable medical wellness, prevention, diagnosis, treatment and monitoring services to be delivered efficiently through electronic media are expected

to create about 1.1–2.5 trillion in growth annually by the global economy by 2025. The whole annual economic impact caused by the IoT is estimated to be in range of 2.7 trillion to 6.2 trillion by 2025 [59]. Fig. shows the projected market share of dominant IoT applications [60].

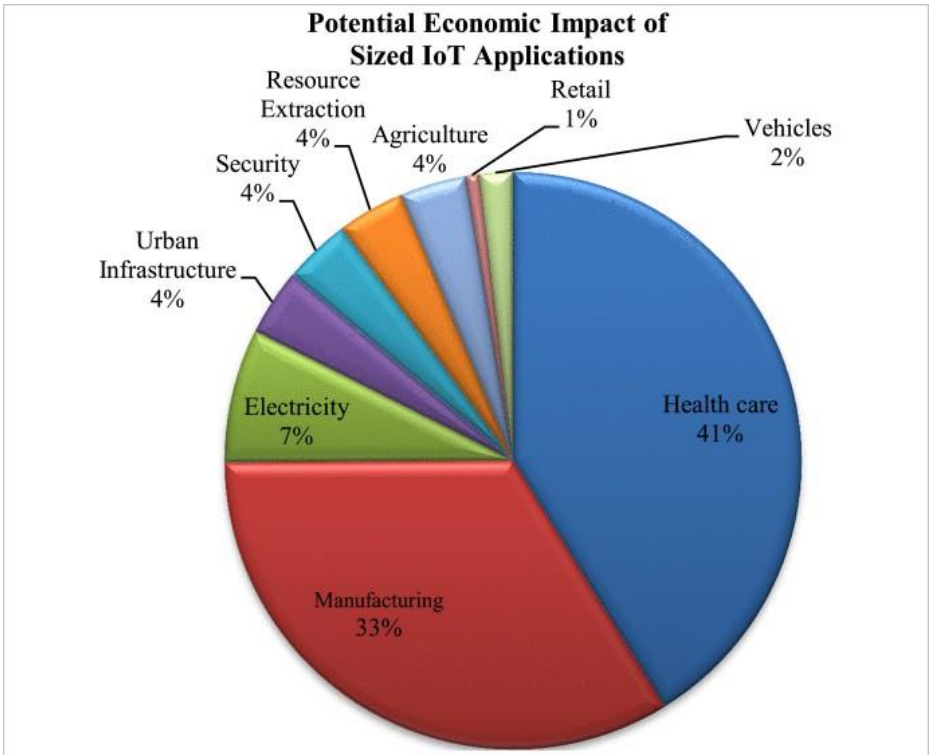


Figure 2.5. IoT utilization statistics

All these statistics, however, point to a potentially significant and fast-pace growth of the IoT in the near future, related industries and services. This progression provides a unique opportunity for traditional equipment and appliance manufacturers to transform their products into “smart things.”

2.4 Conclusion

This chapter is divided into two section.starting by gaving the most important basic points to give a first look at the basics of artificial intelligence, starting from its definition to some historical reviews, they also talked about the most important classifications of artificial intelligence and its basic types, all the way to algorithms, which alone are considered an integrated world of science, finally, arriving at an explanation and definition of the algorithms used in our work.

In the second section we’ve introduced the domain of the Internet of Things. We began with definitions and then detailed its general architecture of relevant application domains. domains. From what is explained in this chapter we can learn that the use of IoT in the greenhouse context involves the processing of problems arising in three levels:

collection of climatological data using sensors placed in the pre-processing, analysis and abstraction of the captured data and application of actions on the greenhouse based on decisions taken by the system or the farmer.

Chapter 3

Intelligent Domestic Greenhouse, Conception, Realization and Results.

3.1 Introduction

This chapter provides a comprehensive of the electronic and mechanical subsystems that form the backbone of the smart greenhouse. These two domains work in tandem to ensure autonomous environmental monitoring and control tailored to optimal plant growth.

The electronic subsystem is centered around the Arduino-based micro-controller platform, which serves as the control unit for processing sensor data and managing actuators. Various sensors, including temperature, humidity, soil moisture, and light sensors, are integrated to continuously monitor the internal climate of the greenhouse. Based on the data acquired, actuators such as water pumps, DC motors for the windows and sunroof, and fans are activated to maintain appropriate growing conditions. The design and implementation of a dedicated Printed Circuit Board (PCB) facilitate compact and reliable integration of all electronic components, ensuring efficiency and system stability.

The mechanical subsystem involves the structural design and fabrication of the greenhouse frame using durable and cost-effective materials. Detailed modeling was performed using SolidWorks software to ensure mechanical stability, ease of assembly, and adaptability to various environmental factors. The chapter elaborates on the construction of the frame, door, windows, sunroof, and their corresponding mechanical mechanisms, including motorized movements and support joints.

3.2 Electronic Part

3.2.1 Micro-controller (Arduino)

- Definition :Arduino is an open source electronics platform designed for ease of use with both hardware and software. It allows Arduino boards to process inputs such as detecting light from a sensor, pressing a button, or receiving a Twitter message and respond with outputs such as activating a motor, lighting up an LED, or posting data online. Users can program the board by sending instructions to its microcontroller using the Arduino programming language, which is based on wiring, and the Arduino Software (IDE), which is derived from processing [61].

- Arduino mega:Arduino Mega (2560) is a powerful microcontroller board designed for projects requiring a high number of input/output pins, memory, and communication interfaces. It is particularly well-suited for automation, robotics, and control systems involving many devices or sensors. Like the Uno, it is supported by a large community and fully compatible with the Arduino IDE. It offers a balanced mix of digital and analog inputs, and multiple communication interfaces.Below are its key specifications [61]:

- Microcontroller: ATmega2560
- Operating Voltage: 5V
- Input Voltage (recommended): 7-12V
- Input Voltage (limits): 6-20V
- Digital Output Voltage: 0V (LOW) or 5V (HIGH)
- Analog Output (PWM) Voltage: 0V to 5V (depends on duty cycle)
- Digital I/O Pins: 54 (of which 15 provide PWM output)
- PWM Digital I/O Pins: 15 (Pins 2–13, 44–46)
- Analog Input Pins: 16 (Pins A0–A15)
- DC Current per I/O Pin: 20 mA
- DC Current for 3.3V Pin: 50 mA
- Flash Memory: 256 KB (8 KB used by the bootloader)
- Communication Interfaces: 4 UARTs (Serial Ports), SPI, I2C
- USB Connection: Type-B USB for programming and serial communication
- ICSP Header: Available for programming the microcontroller
- Reset Button
- Compatible with Arduino Software (IDE)

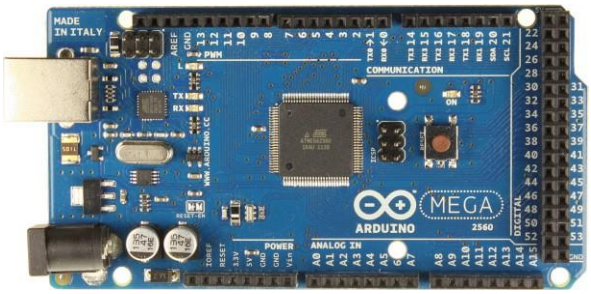


Figure 3.1. Arduino mega

- Arduino mega in the project:The Arduino board acts as the core controller, managing environmental conditions by processing input from the sensors and triggering appropriate actions. It monitors parameters such as temperature, humidity, Light, adjusting devices like windows and sunroof, and irrigation systems to maintain optimal growing conditions. With built-in wireless capabilities, the board allows remote monitoring and control through a web application, providing an efficient and automated solution for greenhouse management.

3.2.2 Sensors

3.2.2.1 DHT11

The DHT11 is a digital temperature and humidity sensor that provides calibrated output signals through a single-wire digital interface. It utilizes a capacitive humidity sensing element and a thermistor for temperature measurement, ensuring reliable and stable performance. The sensor is factory calibrated, making it easy to integrate into various applications such as environmental monitoring and climate control systems.

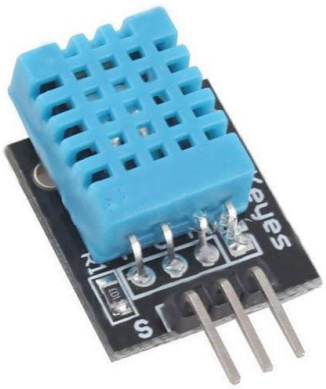


Figure 3.2. DHT11 Sensor

Features

- Operating Voltage: 3.3V to 5.5V DC
- Current Consumption: Typical: 0.5 mA / Maximum: 2.5 mA
- Temperature Measurement: Range: 0°C to 50°C (Accuracy: ±2°C)
- Humidity Measurement: Range: 20% to 90% RH (Accuracy: ±5% RH)
- Communication Protocol: Single-wire digital signal (proprietary protocol)
- Response Time
  - Temperature: ≤10 seconds
  - Humidity: ≤8 seconds
- Storage Conditions
  - Temperature: -20°C to 60°C
  - Humidity: ≤80% RH (non-condensing)

Advantages of the DHT11 Sensor

- Low cost and easy to use
- Factory-calibrated for plug-and-play integration
- Compact and lightweight design
- Low power consumption, making it ideal for battery-powered applications

3.2.2.2 Soil moisture sensor

Device used to measure the water content in soil. It typically consists of two probes that are inserted into the soil and measures the resistance between them, which changes depending on the soil's moisture level. The sensor provides an analog or digital output, indicating the soil's moisture level, which is crucial for optimizing irrigation systems and ensuring proper growth of plants.



Figure 3.3. Soil Moisture Sensor

Features

- Operating Voltage: 3.3V to 5V DC
- Current Consumption: Typical: 10 mA / Maximum: 15 mA
- Output Signal: Analog (Voltage level) or Digital (on/off threshold)
- Measuring Range: Moisture Level: 0% to 100% (Dry to Wet)
- Response Time: Typically: 1-2 seconds for a stable reading
- Probes Material: Stainless Steel (for corrosion resistance)

- Sensitivity Adjustment: Many sensors have a potentiometer to adjust the sensitivity or threshold for moisture detection.
- Response Characteristics Analog Output: The sensor provides a voltage that corresponds to the moisture level. Typically, the higher the moisture, the higher the output voltage.
- Storage ConditionsTemperature: -10°C to 50°C / Humidity: 0% to 100% RH (non-condensing)

Advantages of the Soil Moisture Sensor

- Simple, low-cost solution for automated irrigation systems
- Easy to use with microcontrollers (e.g., Arduino, ESP32)
- Provides real-time soil moisture data for efficient water management
- Adjustable sensitivity for different soil types and environmental conditions
- Low power consumption, ideal for battery-powered applications

3.2.2.3 Light sensor (LDR)

A Light Sensor is an electronic device that detects ambient light intensity and converts it into an electrical signal. It typically measures the amount of visible light in the environment and provides an output that can be used to control lighting systems, monitor plant growth, or adjust environmental conditions. Light sensors are commonly used in automation systems to optimize energy usage and improve efficiency.

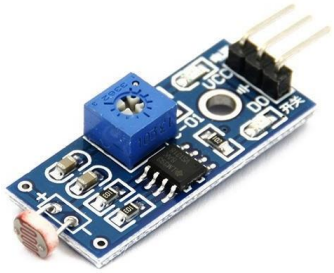


Figure 3.4. LDR sensor

Features

- Operating Voltage: 3.3V to 5V DC
- Current Consumption: Typical: 0.5 mA/Maximum: 1 mA

- Output Signal:
  - Analog (Voltage level proportional to light intensity)
  - Digital (Threshold-based HIGH/LOW output)
- Light Sensitivity Range: 0 to 1000 Lux (depending on sensor type)
- Response Time: Typically: Less than 1 second
- Sensor Type: Photoresistor (LDR), Photodiode, or Phototransistor
- Adjustable Sensitivity: Some modules include a potentiometer for threshold adjustment.
- Response Time
  - Temperature: $\leq$10 seconds
  - Humidity: $\leq$8 seconds
- Storage Conditions
  - Temperature: -20°C to 60°C
  - Humidity: 0% to 80% RH (non-condensing)

Advantages of the Light Sensor:

- Low-cost and easy to integrate with microcontrollers like Arduino and ESP32
- Real-time monitoring of light intensity for smart applications
- Low power consumption, suitable for battery-operated systems
- Adjustable sensitivity for different lighting conditions
- Reliable and long-lasting operation with minimal maintenance

3.2.3 Actuators

3.2.3.1 Water pump

The water pump used in this project is a small 12V DC pump commonly found in DIY and automation projects. It is compact, lightweight, and capable of providing a steady water flow suitable for irrigation tasks in small-scale systems like smart greenhouses. The pump is easy to control using a microcontroller and can be powered directly from a 12V power supply or battery, in this project we used a simple transistor circuit to control this pump. the following figure showen the exact pump.



Figure 3.5. Water pump

3.2.3.2 Sunroof and windows motor

The motor used to control the window and sunroof mechanisms is the RS-445PA-14233R, a compact brushed DC motor known for its reliability and moderate torque output.

Operating at 12V, it provides sufficient power to drive small mechanical systems, making it ideal for automation tasks in smart greenhouse projects. Its size and performance balance make it a popular choice for embedded and DIY applications.



Figure 3.6. sunroof motor

3.2.4 Printed Circuit Board

Printed Circuit Board (PCB) design is an essential step in the development of electronic systems. It allows electronic components to be assembled and connected in an organized and efficient way.

A Printed Circuit Board (PCB) is a board used to connect electronic components together. It has thin copper lines (called tracks) that work like wires to carry electricity between the components. These components are placed on the board and connected to create an electronic circuit that performs a specific function.

To build a PCB, there are two main steps:

3.2.4.1 Designing the electronic circuit using a computer (PCB design software)

For this project, we used Proteus, a professional software used for electronic design automation (EDA). It is widely used by engineers and students to simulate circuits, design schematics, and create PCB layouts. Proteus provides a user-friendly environment to place components, draw connections, and visualize the behavior of the circuit before physically building it.

Schematic Diagram Design The first phase is designing the schematic diagram, which represents the electrical connections between all components in the circuit. This diagram is essential for understanding how the circuit works and serves as the foundation for the PCB layout. Each component (such as resistors, sensors, microcontrollers, etc.) is added to the schematic and connected using virtual wires.

Powersupply In this Project we need three deferent voltage values

- 12 volt to power the water pump, fan and motors, and it came from a battery
- 5 volt to power the Arduino, motor drivers ,LEDs and limit switches, we get the 5V from a voltage regulator (7805)
- 3.3 volt to power sensors and the ESP32. we get it from a voltage regulator(s1117p 33)

Sensors connection

- Operating Voltage: 5V or 3.3V.
- Output: Analog (Voltage varies based on physical values such as soil moisture)
- PCB Considerations:
  - Route the signal trace to an analog input pin on the Arduino.
  - Add a 100nF ceramic capacitor near the sensor, between sensor output and GND, to filter noise.
  - Needs a 4.7k pull-up resistor on the data line to ensure stable communication.
  - Use a JST connector for easy sensor replacement.
  - Keep traces short to minimize signal noise and interference.

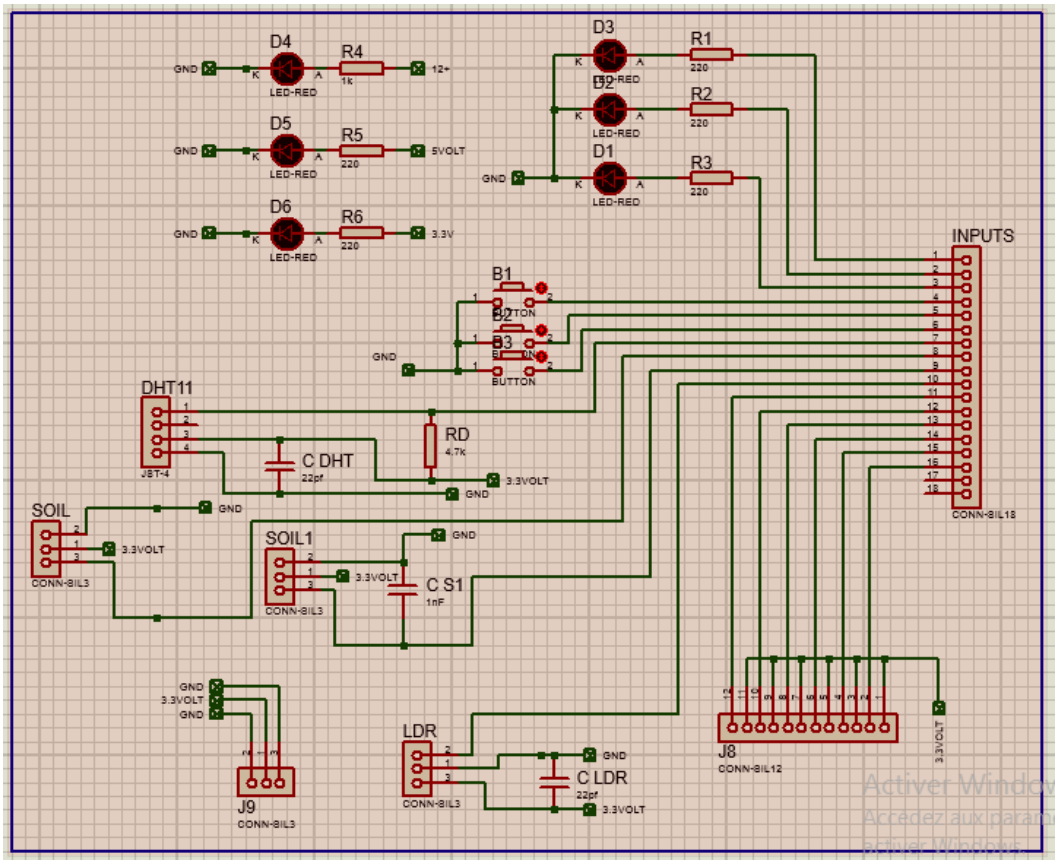


Figure 3.7. Inputs circuit design

Outputs

1. Sunroof and Window motors Control (L293D Motor Driver)

   - Operating Voltage:
     - Logic (VCC1): 5V
     - Motor Power (VCC2): 12V
   - PCB Considerations:
     - Power Connections:
       - Connect VCC1 to 5V (powers L293D logic).
       - Connect VCC2 to 12V (powers the motors).
       - Common GND with Arduino.
     - Control Signal Routing:
       - IN1 & IN2 → Arduino digital pins (controls Motor 1 - sunroof).
       - IN3 & IN4 → Arduino digital pins (controls Motor 2 - windows).
       - tied to 5V for full speed.
     - Motor Output:
       - OUT1 & OUT2 → Motor 1 terminals (motor 1).

        - OUT3 & OUT4 → Motor 2 terminals (motor 2).
        - screw terminals for easy motor connection.
    - Protection & Stability:
        - thick and short traces for motor power lines to handle current properly.

2. Water Pump and Fan Control (Transistor Switching)

- Operating Voltage:
    - Pump/Fan Power: 12V
    - Logic Control: 5V (from Arduino)
- PCB Considerations:
    - Power Connections:
        - Drain → Connected to the negative terminal of the water pump or fan.
        - Source → Connected to GND.
        - $V_{pump/fan}$ (Positive Terminal) → Connected to 12V power supply.
    - Gate Drive & Control:
        - Gate → Controlled by an Arduino digital pin via a 220ohm resistor.
        - 10kohm pull-down resistor between Gate and Source to prevent floating.
    - Protection & Stability:
        - flyback diode (1N4007 or Schottky diode) across the pump/fan terminals to handle back EMF.
        - thick PCB traces for the **high-current path** (Drain to Pump/Fan).

Addisional components

- LEDs to indicate the state of each voltage,
- Buttons to use them as inputs

PCB Layout Design After completing the schematic, the next step is to create the PCB layout. This is where each component is placed on a virtual board, and copper tracks are used to connect them. The layout must be compact, efficient, and follow good design rules to ensure the circuit works properly and can be manufactured easily. Proteus provides tools to help route the connections manually or automatically and allows the designer to view the board in 2D or 3D. for this project we split the schematic to two PCBs

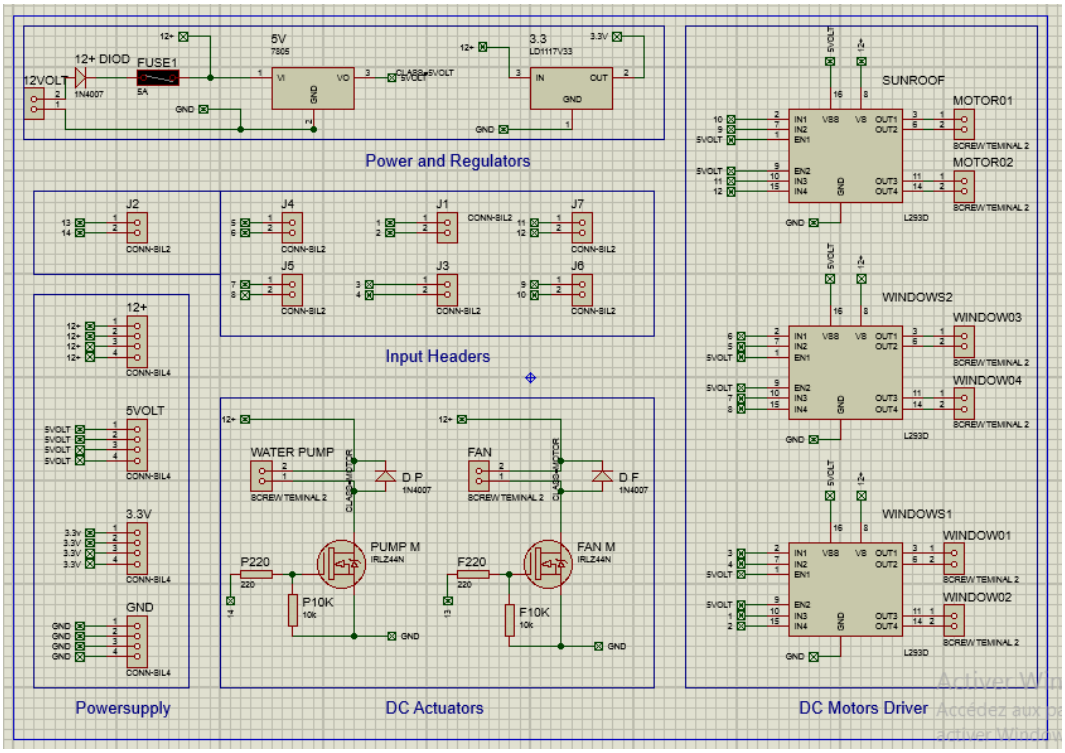


Figure 3.8. outputs circuit design

First PCB we set up all the outputs in this first board,same thing for the powersupply and voltage regulators

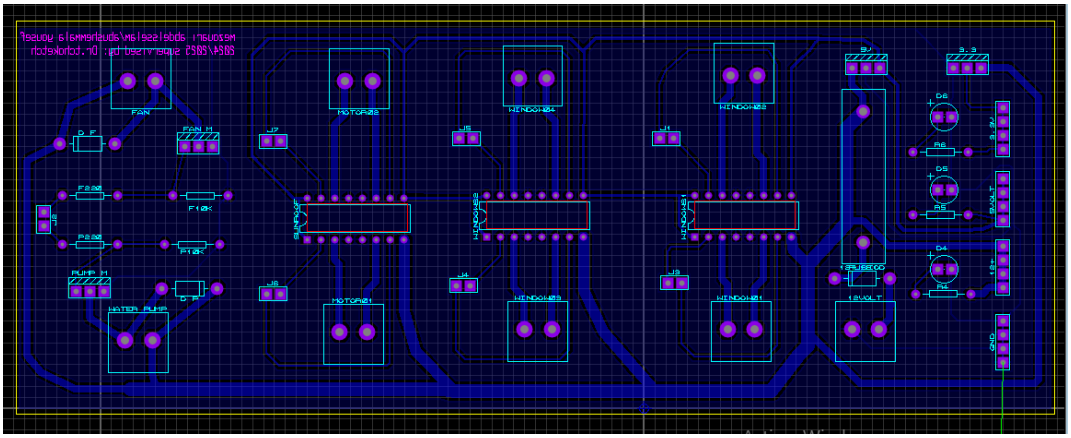


Figure 3.9. Outputs board design

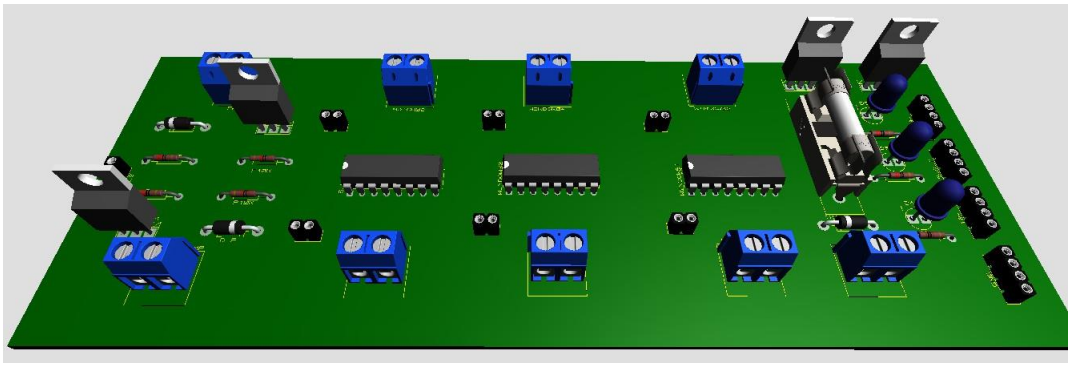


Figure 3.10. Output board 3D

Second PCB: The second board contains all the inpusts such as the sensors and the limit switches headers

3D Visualization: The proposed electronic circuit is presented to take a general look before realization as shown in figure 3.11.

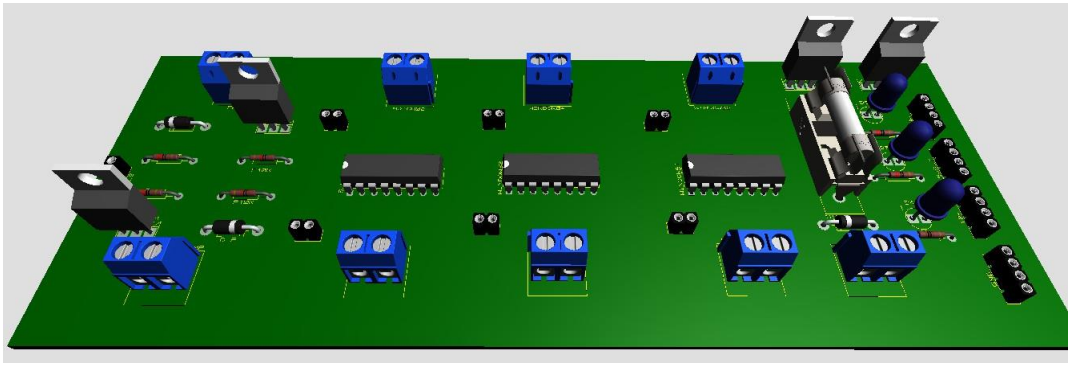


Figure 3.11. Inputs board 3D

3.2.4.2 Preparing the Physical Printed Circuit Board

Once the PCB design is completed and the Photomask is created, we move on to physically creating the PCB. This process involves several stages, The first thing to need is the EPOXY plate, its a board that have deferente layers, as shown in the following Figure:

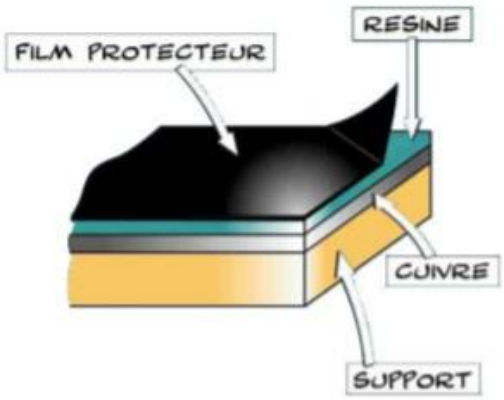


Figure 3.12. EPOXY plate

1. Cleaning the Copper Surface: The copper side of the pre-sensitized board is cleaned carefully to remove dust, grease, or oxidation. This ensures good adhesion of the UV-exposed pattern.

2. UV Exposure (Insulation / Insolation): The printed circuit pattern (usually printed on a transparent sheet) is placed on the board, and the board is exposed to UV light. The UV light hardens the photoresist on the board wherever light passes through the transparent areas.

3. Developing the Image (Revelation): After exposure, the board is placed in a developer solution to remove the unexposed photoresist. This reveals the copper tracks that will stay during etching.

4. Rinsing (Rinçage): The board is rinsed with water to stop the chemical reaction and clean off the developer residue.

5. Etching (Gravure): The board is placed in an etching solution (like ferric chloride) which removes the unwanted copper, leaving only the desired tracks protected by the hardened photoresist.

6. Final Cleaning (Nettoyage): The remaining photoresist is removed using a solvent or thinner to leave the clean copper tracks exposed.

7. Drilling (Perçage): Small holes are drilled at the positions of through-hole components.

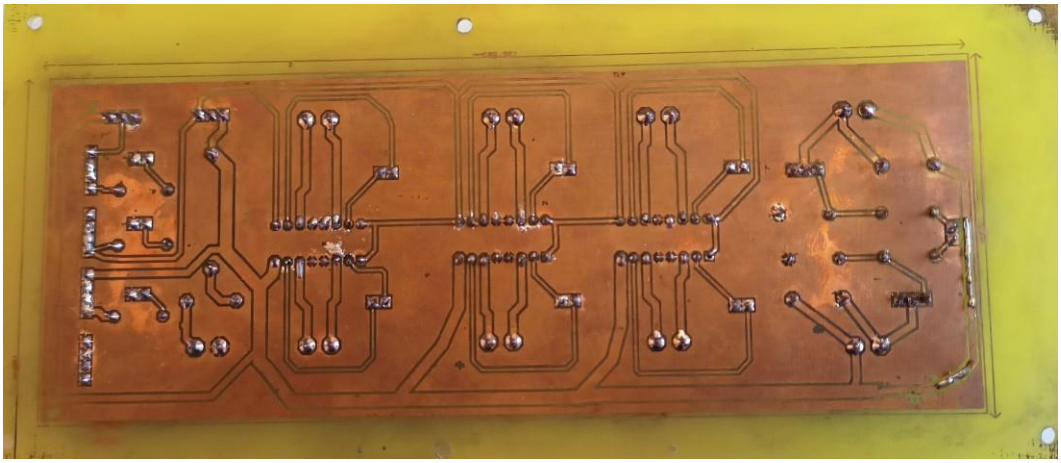


Figure 3.13. outputs board bottom

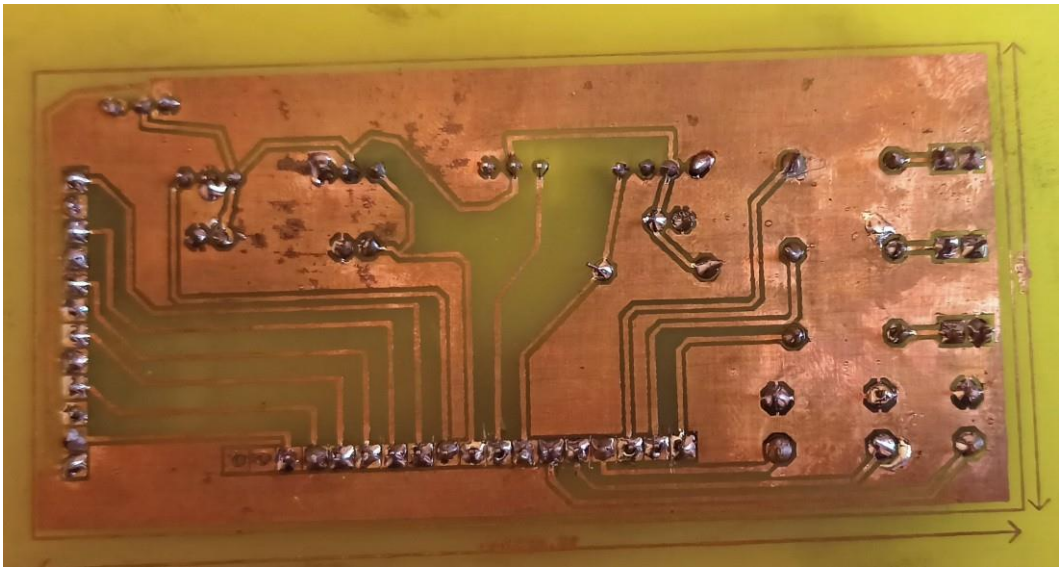


Figure 3.14. inputs board bottom

8. Component Soldering (Soudage des composants): The components are placed on the board and soldered to their respective pads to complete the circuit.

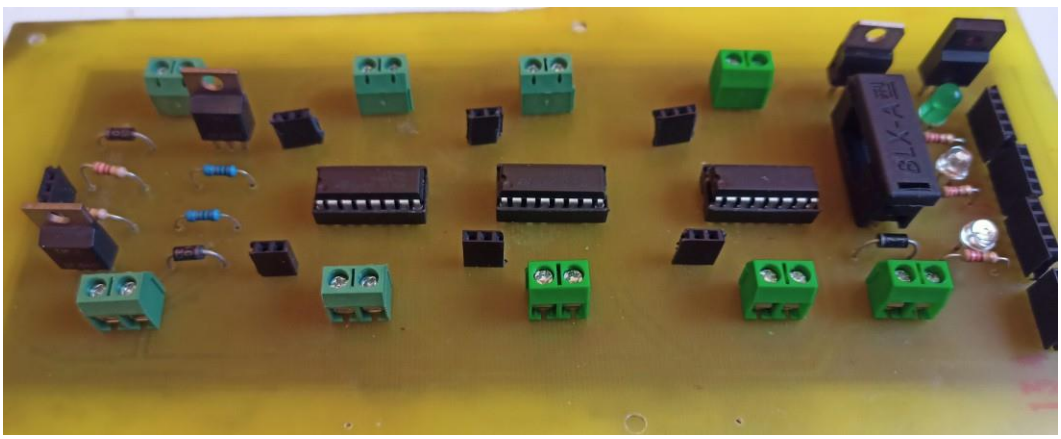


Figure 3.15. outputs PCB

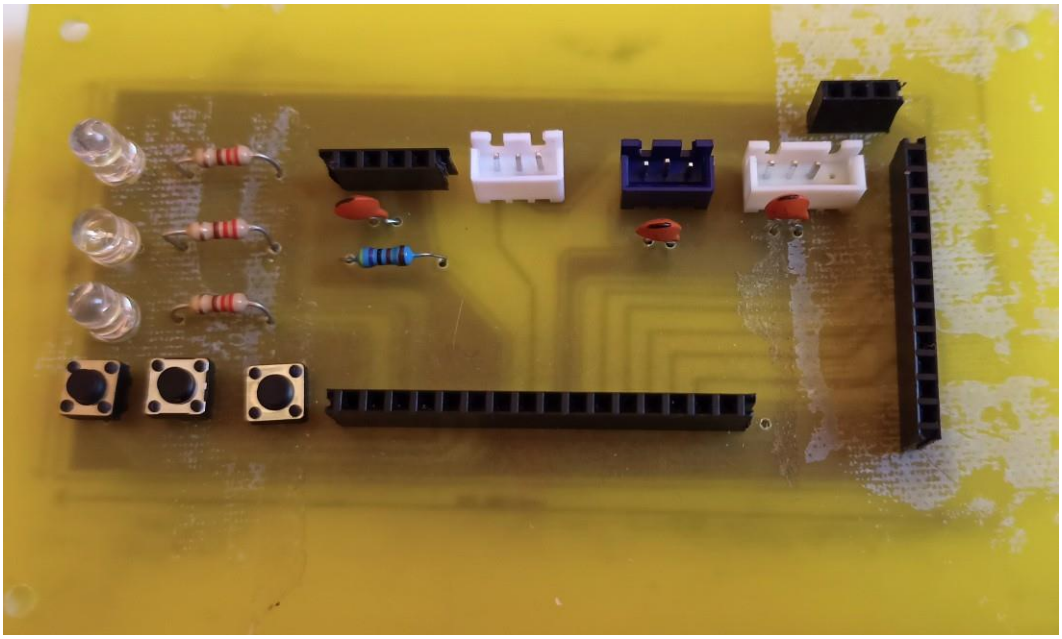


Figure 3.16. inputs PCB

3.3 Mechanical Part

3.3.1 Project Mechanical Concept

Materiel used The greenhouse structure has been carefully designed using a combination of materials to ensure durability, stability, and ease of assembly. The selected materials include:

-

Metal Bars/Tubes (Main Structure) Metal tubes have been chosen as the primary material for the greenhouse framework due to their affordability, and resistance to environmental factors such as moisture and UV exposure. These tubes provide a strong yet foundation for the structure.

Reinforcements help withstand external forces such as wind and mechanical stress and keep the strict and the shape of the greenhouse, ensuring long-term durability.

Connectors and Fittings (Structural Joints) A variety of metal connectors, have been used to securely join the metal tubes at various angles. These fittings provide a reliable and stable connection, allowing for a robust frame structure while facilitating easy, adjustments and assembly.

And the elbows and T-joints used toconnect the PVC tubes for the door and the window structures

-

PVC Tubes (Arc, door and window) PVC tubes have been used for constructing the greenhouse arc, door and window and its frame. PVC chosen for its ease of customization, strength, and ability to provide a solid and secure entry point to the greenhouse.

-

Bolts (Connections) The structural components are securely fastened using bolts, ensuring a firm and reliable connection between the PVC and metal bars. This fastening method allows for easy assembly and disassembly while maintaining structural integrity.

3.3.2 The general Design

3.3.2.1 Structural Design

For the mechanical design, we utilized SolidWorks to create the structural design of the smart greenhouse. This software will allow to accurately model and simulate the various components of the structure. presenting the 2D drawings of the design, showcasing the detailed specifications and layout of the greenhouse framework. The use of SolidWorks will ensure precision and efficiency in the design process, contributing to the overall success of the project.

The greenhouse design follows a simple yet effective structural layout, ensuring ease of construction while maintaining strength and functionality. The general design consists of the following key elements:

Base Structure(Straight Sections) The lower portion of the greenhouse consists of two opposite sections(Lower and upper sections) one for the base and the other to hold the greenhouse arch., from the sides 6 straight metal bars measuring 130 cm in height (3 for each side) connected with the Sections by Structural Joints The middle rod connected with 2 straight metal rods 100 cm long from the middle part, forming rod (200 cm by length). the sides connected by structural joints with a 170 cm metal bars in width from the front and the rear and the middle for each section .

These vertical elements form the primary support structure, providing a solid and stable base. They are designed to evenly distribute the weight of the entire greenhouse while offering resistance against lateral forces such as wind and minor ground shifts. Additionally, their uniform length facilitates easy assembly and alignment dur- ing construction

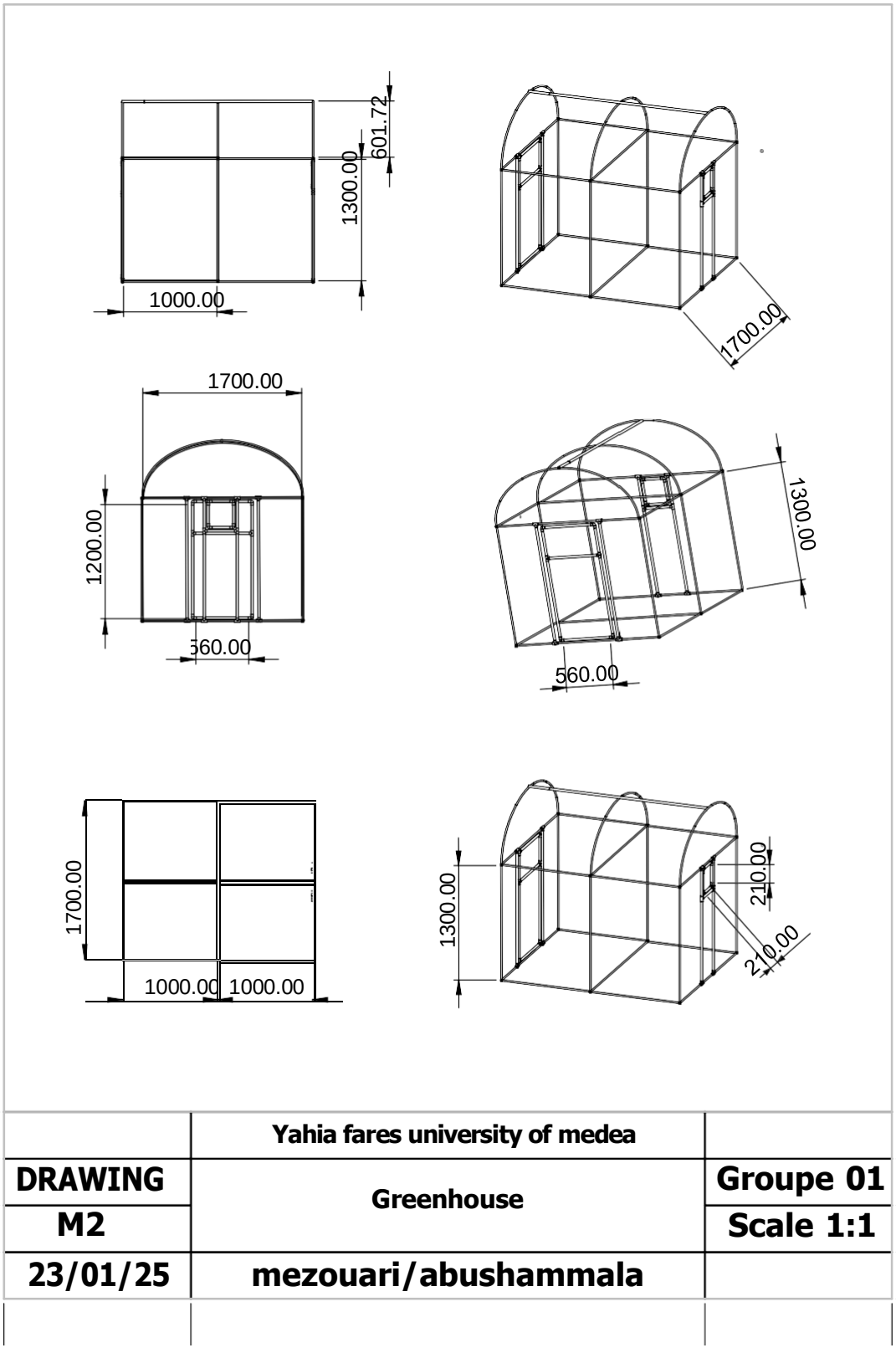
Arched Roof (Upper Structure) Above the straight sections, an arc from PVC of (60 cm in height) above the upper section.

Three arched bars from PVC connected with eachother by straight PVC rod 200cm.

The arch is attached to the upper section by structural joints in 6 points divided on 4 to the corners in the front and rear and 2 point in the middle of the section.

This arched design enhances structural integrity by efficiently distributing stress and reducing the impact of environmental factors such as wind and snow loads.

The curvature of the arc allows for better air circulation within the greenhouse, helping to regulate temperature and humidity levels more effectively. Moreover, the arched roof ensures efficient rainwater runoff, preventing water accumulation that could otherwise compromise the structure's stability.



	Yahia fares university of medea	
DRAWING	Greenhouse	Groupe 01
M2		Scale 1:1
23/01/25	mezouari/abushammala	

Figure 3.17. 2d global drawing

3.3.3 Side Design

A (200 cm bottom metal bar)divided in half, supporting three (vertical 130 cm bars) placed at 1-meter intervals. These vertical bars provide support and distribute weight evenly across the frame. adding strength and stability.

3.3.3.1 Benefits of the Side Design Structural

Integrity: Metal bars ensures the greenhouse is yet strong, with the metal bars providing resistance to external forces like wind.

Stability: The vertical bars, spaced at 1-meter intervals, distribute weight evenly, and the crossbars prevent lateral movement, keeping the frame rigid.

Ease of Assembly: Structural joints fittings simplify the assembly process, making the greenhouse easy to set up and move if needed.

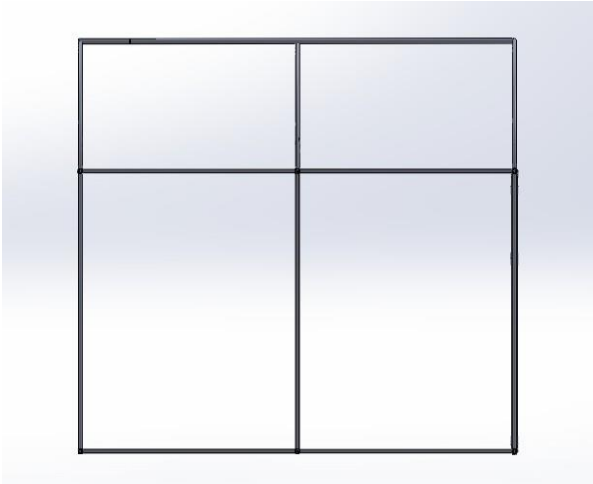


Figure 3.18. greenhouse side design

3.3.4 Front Design:

Dimensions: front design has a total width of 170 cm, the height straight is 130cm and then arc with 45cm in height.

Door Frame: 55 cm from both side the door frame two PVC bars is 130 cm tall and is connected at the lower section and . It is also attached at the upper section for added reinforcement.

The Door: Totally made from PVC, demotions is 120cm height with 56cm width, the door is connected to with the frame with two hinges to ensure the door good placement and its functionality of opening and closing.

3.3.4.1 Benefits of the Front Design

Durability: The door frame is designed to withstand regular use and outdoor conditions, offering a reliable, long-lasting entrance to the greenhouse.

Ease of Access: The 60 cm wide door provides sufficient space for easy entry and exit, facilitating movement inside the greenhouse.

Reinforcement: The door frame's connections to the bottom, sides, and top ensure it is securely supported, preventing shifting and maintaining stability.

Stability: The integration of the door frame with the vertical bars and top arc adds strength, ensuring the front section remains rigid and resistant to external forces.

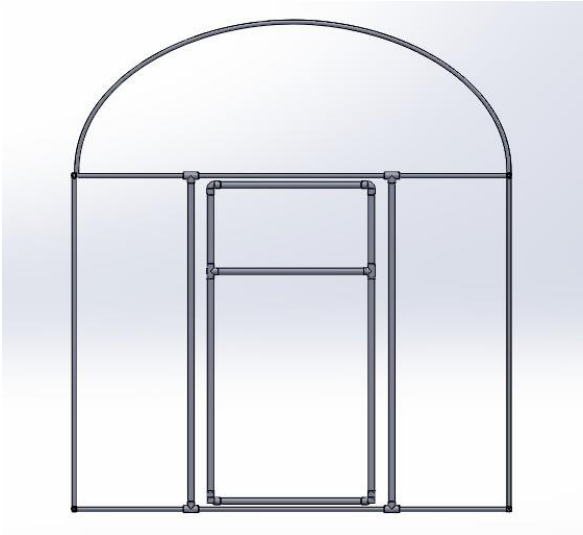


Figure 3.19. greenhouse front design

3.3.5 Rear design

Bottom Metal Bar: A (metal bar) at the bottom, spanning the width of the greenhouse, connects both sides to provide a strong base.

- Middle Metal Bar: Another metal bar at a height of 130 cm, also connected to both sides, enhances structural support and stability. The following figure shows the design of the Rear side.

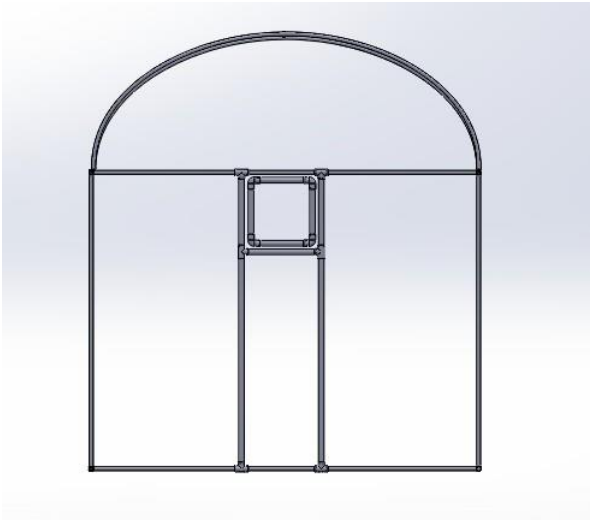


Figure 3.20. greenhouse rear design

Window The widow and its frame are totally from PVC with 35*35 cm for the window.The following figure shows the design of the window.

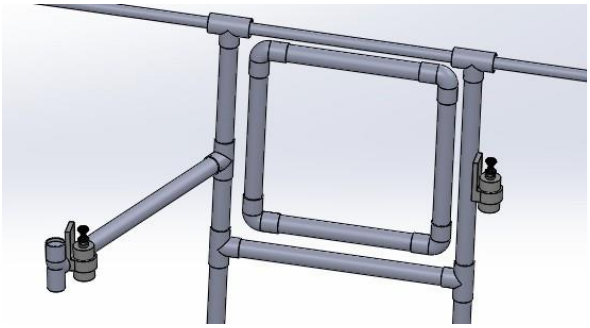


Figure 3.21. window mechanism

3.3.5.1 Benefits of the Rear Side Design

Structural Integrity: The combination of bottom and middle metal bars ensures a strong and well-supported rear frame.

Stability The bars are placed to distribute loads evenly and maintain the overall greenhouse shape.

Durability The use of metal bars provides long-term strength, ensuring the rear structure can withstand environmental conditions.

3.3.6 Arc design

Material: The arcs are made of PVC, which is bent to form the desired curved shape.

Quantity: There are three arcs with 45 cm high above the upper section, each securely connected to the vertical bars on both sides of the greenhouse.

Reinforcement: A metal bar runs across the length of the greenhouse, connecting all the arcs together for added stability.The following figure shows the design of the arc.

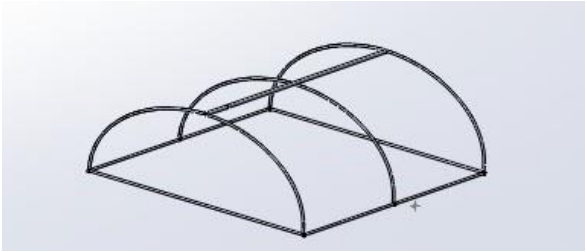


Figure 3.22. greenhouse arc design

Sunroof The fixed motor on the middle bar of the upper section rotate the threaded rod in two directions of rotation which allow closing and opening the sunroof according to the needs of the system.The following figure shows the roof design

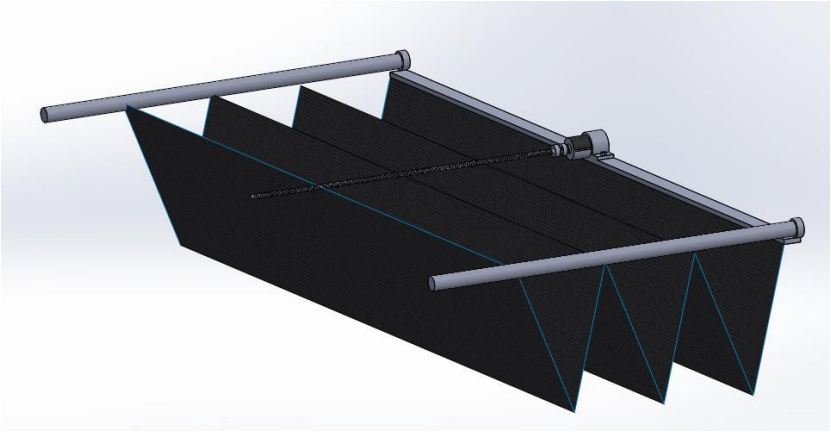


Figure 3.23. sunroof mechanisme

3.3.6.1 Benefits of the Arcs Design

Structural Integrity The PVC arcs provide a lightweight yet sturdy framework, shaping the greenhouse while ensuring flexibility and durability.

Reinforcement The metal bar connecting all arcs enhances strength, preventing movement and ensuring the greenhouse remains rigid under external forces.

Even Load Distribution The arc design helps evenly distribute forces such as wind and weight, reducing stress on any single part of the structure.

Ease of Assembly The flexible PVC material allows for easy bending and installation, making the construction process more efficient

3.3.7 Benefits of the Overall Greenhouse Design

Structural Strength and Stability: The combination of PVC arcs and metal reinforcements provides a lightweight yet sturdy structure. The strategic placement of crossbars and reinforcements ensures the greenhouse can withstand environmental factors such as wind and rain without compromising its integrity. Balanced Weight Distribution: The design effectively distributes weight across the frame, with reinforcement bars at key points to prevent sagging or deformation over time. This ensures longevity and consistent performance. Ease of Assembly and Maintenance: The use of structural joints and PVC fittings (elbows, T-joints, and couplings) simplifies the assembly process, making it easy to con- struct, disassemble, and maintain when necessary. The modular design allows for adjustments or expansions if needed. Cost-Effectiveness: The selected materials,metal bars, are affordable and readily available. The design optimizes resource usage while maintaining durability, making it a cost-efficient solution for small-scale greenhouse projects.

Flexibility and Adaptability: The lightweight nature of PVC allows for flexibility in shaping the structure, accommodating different site conditions. Additionally, the design can be easily adapted to different climate conditions by adjusting ventilation or reinforcement methods.

Weather Resistance: The design incorporates corrosion-resistant materials, ensuring the greenhouse remains functional over extended periods, even under exposure to moisture and varying temperatures.

Optimized Growing Conditions: The arc shape provides ample headroom and allows for even distribution of sunlight and air circulation, creating an optimal environment for plant growth.

Enhanced Accessibility: The spacious 70 cm door allows easy access for users, facilitating movement of tools and materials in and out of the greenhouse without difficulty.

3.4 Domestic Green House Realization

3.4.1 Structure

Assembling: This section comes to present connecting the metal bars by structural joints.

-Structural joint of greenhouse corners:

For each the front side and rear side, assembling three metal bars creating the low section and connect with the upper section. which has a holder for the arc. The following figure shows structural joint of the upper section



Figure 3.24. Structural joint of greenhouse corners

-the structural joint of the middle bars:

One of the most important joints, which in turn provides support and ensures that the general shape of the greenhouse is maintained.

this joint connects between four bars Including the one carries the motor that controls the roof. it also hold the middle arc's bar Which makes it a basic fulcrum for the arch.

The following figure shows how the structural joint connecting the metal bars on the side creating the general shape of the sides.



Figure 3.25. Structural joint of the middle bars

After assembly, the following figure shows the side of the greenhouse and how the bars are connected by structural joints.



Figure 3.26. The side structure

3.4.2 Door

The following figure shows the design of the door and its frame. The frame connects the upper section with the lower section, making the front side more stable and able to resist winds.



Figure 3.27. The door of the greenhouse

3.4.3 Window Mechanism

The window mechanism in the greenhouse uses a straightforward dual-motor system to achieve controlled opening and closing. The system includes two DC motors, each

dedicated to a single direction of movement one for opening the window and one for closing it. Both motors are fixed to the window frame to ensure stability during operation. the following figure describe the window mechanism

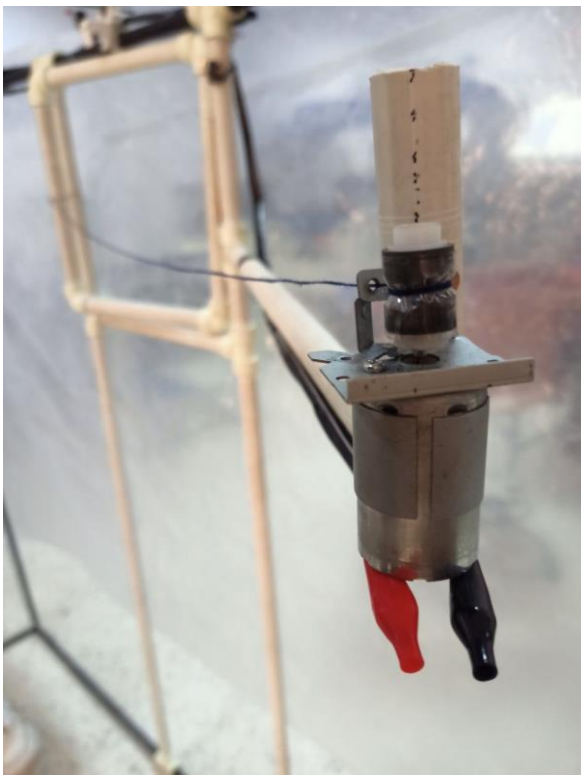


Figure 3.28. opening window Mechanism

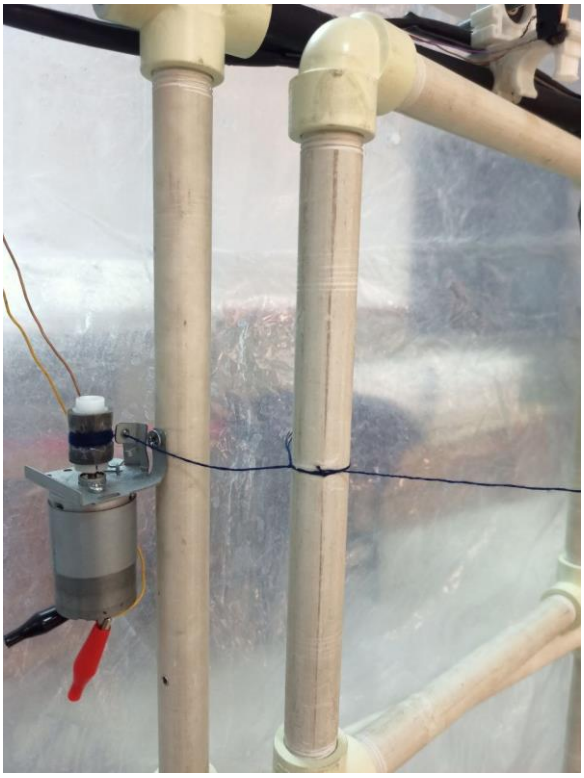


Figure 3.29. Closing window Mechanism

The motors are connected to the window via threads or cords, which pull the window open or closed depending on which motor is activated. To accurately detect the window's position, the system is equipped with two limit switches one at the fully open position and one at the fully closed position. These switches provide feedback to the control system, ensuring the motors stop at the correct time to prevent over-driving or mechanical stress, the following figure shows the limit switch position.

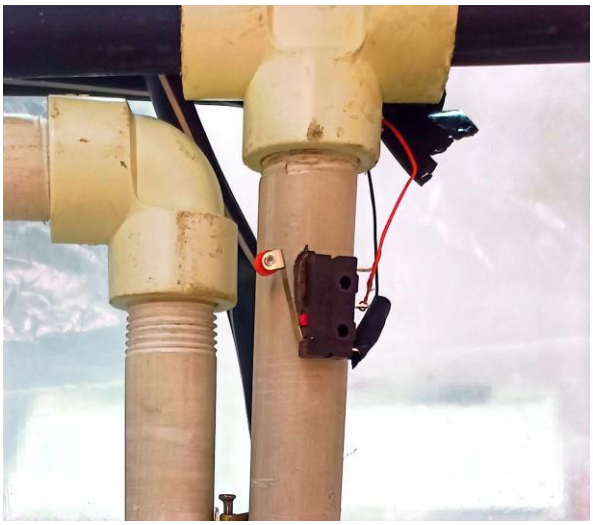


Figure 3.30. window opened limit switch

This simple and effective design allows for reliable automation of window ventilation, enhancing environmental control within the greenhouse.

3.4.4 Sunroof Mechanism

The sunroof system in the greenhouse is based on a simple but effective linear actuator mechanism. It consists of a DC motor connected directly to a threaded rod, both of which are securely fixed to the greenhouse structure.

The sunroof fabric is attached to a nut that is threaded onto the rod, it also connected on each side of the greenhouse to provide a straight linear movement, also there is a support that connected the start points of the fabric to provide a smooth opening or closing of the sunroof and distribute the weight on many points.

When the DC motor is activated, it rotates the threaded rod. As the rod turns, the nut translates along the rod due to the threading. Since the nut is mechanically linked to the sunroof fabric, this movement causes the fabric to either open or close the sunroof, depending on the direction of rotation.The following figures represent the roof when it is open and when it is closed



Figure 3.31. Closed roof



Figure 3.32. Opened roof

we add a limit switch on each side of the sunroof path, to know the position of the sunroof during the opening or the closing so that we can stop the motor at the required point and not damaging the motors through going non stop. The following figure represent the limit switches used and there position in this project.



Figure 3.33. sunroof closed Limit switch

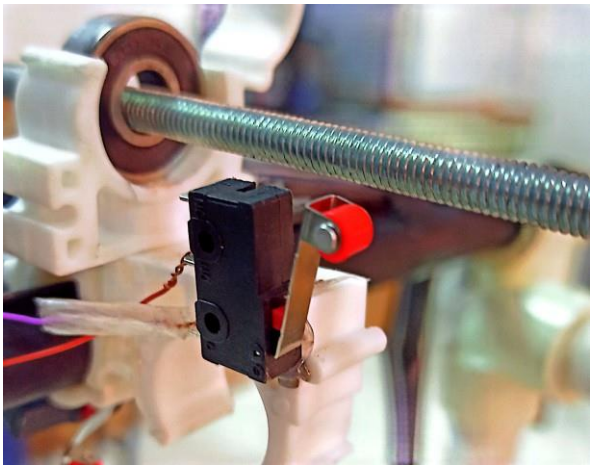


Figure 3.34. sunroof opened Limit switch

This mechanism is cost-effective, easy to maintain and secure due to the limit switches, and provides reliable performance for automated ventilation and light reducing based on environmental conditions.

3.4.5 Distribution of electronic components

Water pump: Works based on the information that comes from Soil moisture sensor.The following figure shows the water pump.

Humidity and temperature sensor DHT11: A digital temperature and humidity sensor is installed under the roof in the middle of the greenhouse so that it can efficiently sense temperature and humidity.The following figure shows the DHT11 location.

Light sensor (LDR): The light sensor is located above the sunroof to sense the light inside the greenhouse. Based on the calculated light, the sunroof is opened or closed according to the plants needs. The following figure shows the location of the light sensor.

Soil moisture sensor: This sensor is implanted in the plant's soil to calculate the plants water needs and control the water pump.The following figure shows the soil moisture sensor location.

3.5 Test, Results and discussions

In this section we are going to explain several experiences we did to test the functionality of our system, make some changes in the values captured by the sensors we are using, so that we can simulate the real outdoor conditions, and also Print the details in the Arduino IDE Serial monitor for better vision.

3.5.1 Normal condition

The plants studied are tomatoes, cucumbers, and lettuce. The following table shows the appropriate values for temperature, light, humidity, and soil moisture for each plant.

Plant	Ideal Temp (°C)	Humidity (%)	Soil Moisture (%)	Light (Lux)
Tomato	21–24	65–85	40–60	10000–25000
Cucumber	24–27	70–90	30–50	15000–30000
Lettuce	15–18	40–60	50–70	5000–15000

Table 3.1. plant-specific parameters

In these cases when the conditions are perfect for the plant selected in the greenhouse, the sensors values are in the good range that means that there is no action should be applied.

```
------------------------
Temperature: 26.30 °C
Humidity: 43.00 %
Lux:   16500
soil    : 597
------------------------
```

Figure 3.35. parameters in the norm conditions

3.5.2 Sunroof functionality

The change in light intensity calculated by the light sensor (LDR) controls the closing and opening of the sunroof, so that the light inside the greenhouse stays in the required values, the high light values can cause damages for the plants so we should close the sunroof, and the low light values can depriving plants of the light needed for growth in this scenario we open the sunroof so that the natural light can get in the greenhouse.

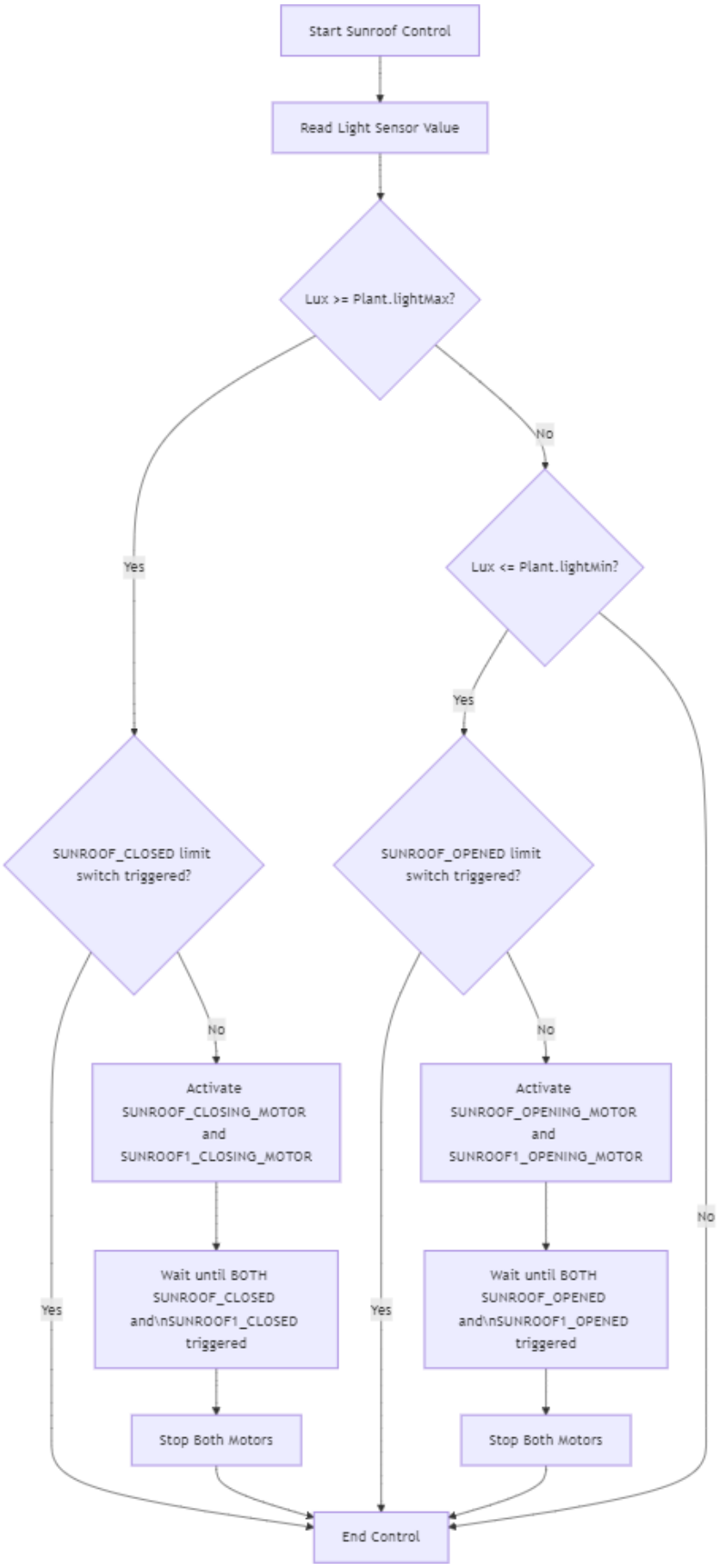


Figure 3.36. Sunroof control flowchart

The appropriate light intensity varies for each plant, we did some experiences to simulate the real life conditions to check the functionality on each case.

3.5.2.1 Case (1): Tomato

The appropriate light intensity for tomatoes ranges from 10,000 to 25,000 (Lux), in this experience we tried to cover the light sensor to simulate the case when the light is low, Example: the weather is cloudy or its night.. ext, the next figure shows the parameters captured by the sensors in the greenhouse, and the sunroof state.

```
------------------------
Temperature: 26.40 °C
Humidity: 43.00 %
Lux:   9550
soil    : 519
...OPENING.....,,,,,sunroof opened ,,,,,
------------------------
```

Figure 3.37. Sunroof opening parameters

The condition checked, the light is below the range it should be in, the action is opening the sunroof, and this figures below shows the opening process.

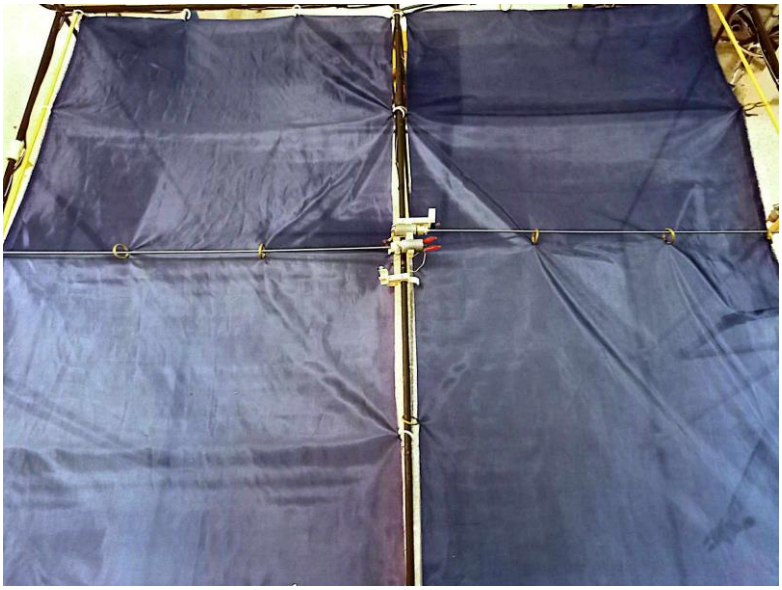


Figure 3.38. Sunroof Fully closed



Figure 3.39. Sunroof Half Opened

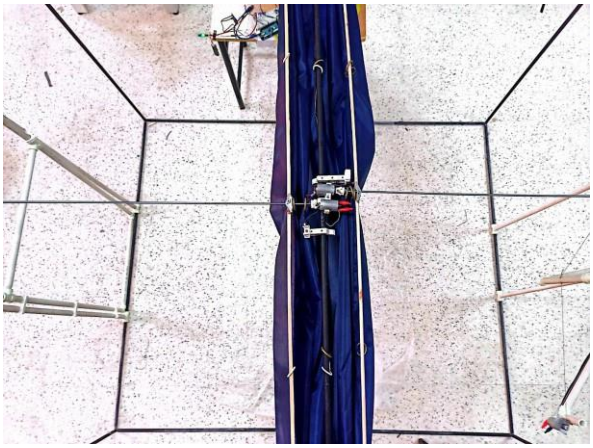


Figure 3.40. Sunroof Fully Opened

3.5.2.2 Case (2): Lettuce

The appropriate light intensity for Lettuce ranges from 5,000 to 15,000 (Lux), in this experience we pointed a light straight to the light sensor to simulate the case when the sunlight is strong and direct towards the greenhouse, the next figure shows the parameter printed in the Arduino IDE and the action applied.

```
------------------------
Temperature: 26.40 °C
Humidity: 42.00 %
Lux:    16636
soil    : 660
...CLOSING...
```

Figure 3.41. Sunroof closing parameters

the condition are checked, the light is higher than it should be inside the greenhouse,

the action must apply is to close the sunroof, the following figures shows the closing process.

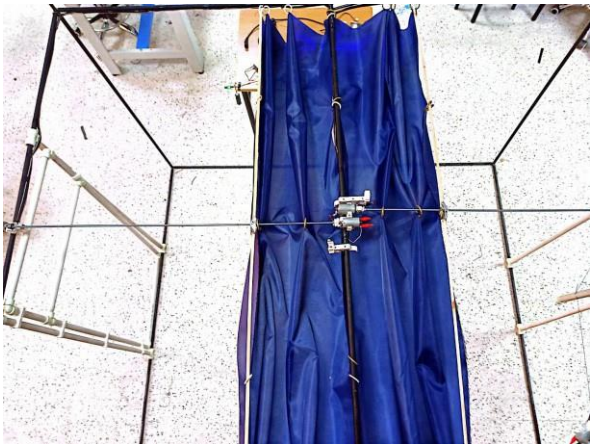


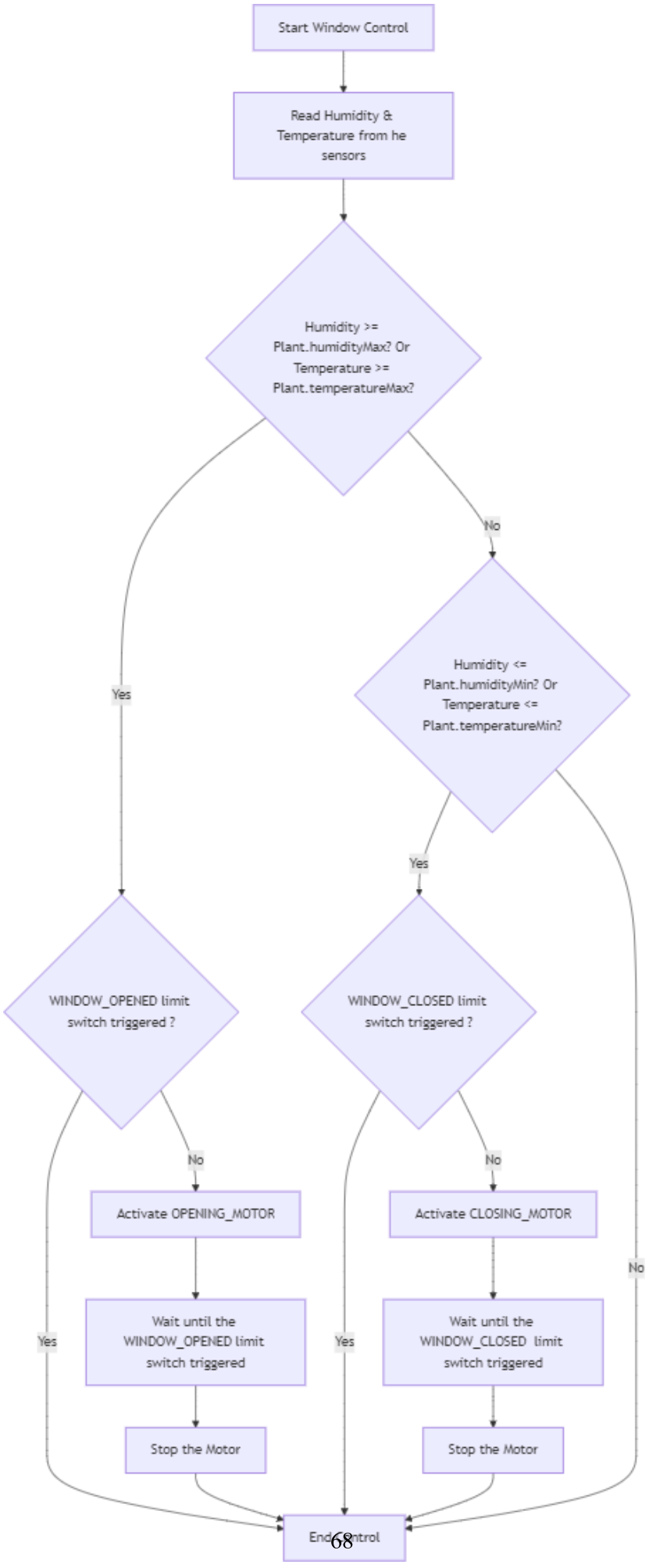
Figure 3.42. Sunroof Starts to Close



Figure 3.43. Sunroof About to Close

3.5.3 Window functionality

The increase or decrease in temperature or humidity above the suitable values for the plant causes the system to open or close the window to ventilate the greenhouse and maintain suitable conditions.


Start Window Control
Read Humidity & Temperature from he sensors
Humidity >= Plant.humidityMax? Or Temperature >= Plant.temperatureMax?
Yes
No
Humidity <= Plant.humidityMin? Or Temperature <= Plant.temperatureMin?
Yes
No
WINDOW_OPENED limit switch triggered ?
WINDOW_CLOSED limit switch triggered ?
No
No
Activate OPENING_MOTOR
Activate CLOSING_MOTOR
Wait until the WINDOW_OPENED limit switch triggered
Wait until the WINDOW_CLOSED limit switch triggered
Yes
Yes
No
Stop the Motor
Stop the Motor
End Control

this following cases shows the experiences we did to check the window functionality

3.5.3.1 Case (1): Cucumber

The appropriate parameters (24-27°C)for temperature and (70-90) for humidity, in this experience we tried to decrease the temperature and the humidity values below the required values to close the window, the following figure shows the values captured by the sensors and the window state

```
------------------------
Temperature: 25.90 °C
Humidity: 47.00 %
Lux:   31400
soil    : 538
The Window is Closing ...
,,,,,window closed ,,,,,
------------------------
```

Figure 3.45. Window closing parameters

After checking the conditions, the humidity is below the range so the window starts to close, and the following figures shows the process



Figure 3.46. Window opened



Figure 3.47. Window closing



Figure 3.48. Window closed

3.5.3.2 Case (2): Lettuce

The appropriate parameters (15-18°C)for temperature and (40-60) for humidity in this experience we tried to increase the humidity and the temperature values above the norm range, the following figure shows that the humidity is above the range which is from 40 to 60 percent also for the temperature, and the window state

```
------------------------
Temperature: 26.30 °C
Humidity: 61.00 %
Lux:   30250
soil    : 514
The Window is Opening ...
,,,,,window opened ,,,,,
------------------------
```

Figure 3.49. Window opening parameters

After checking the condition, the window starts to open till it hits the limit switch, the following figure shows the window opened all the way.

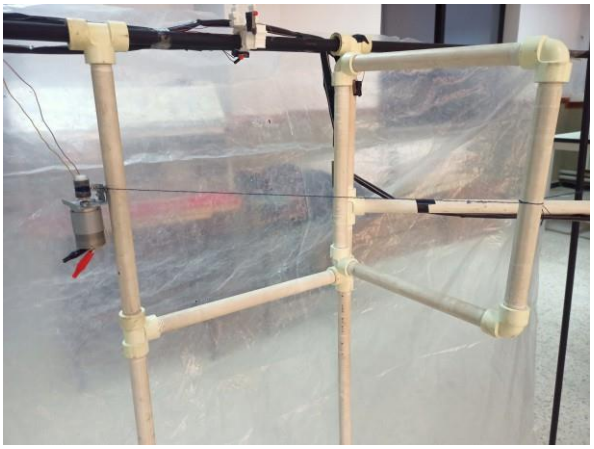


Figure 3.50. Window Fully Opened

3.5.3.3 Case (3): Cucumber

if the conditions are checked:

- Temperature 25.70 is in the range [24 27]
- Humidity 47.00 is below the range [70 90]

and the window is already closed, so nothing should be applied.

```
--------------------
Temperature: 25.70 °C
Humidity: 47.00 %
Lux:     25486
soil     : 574
,,,,,window closed ,,,,,
-----------------------
```

Figure 3.51. Window closed parameters

3.5.4 Waterpump functionality

The change in soil moisture detected by the soil moisture sensor controls the activation of the water pump. When the moisture level in the soil drops below a specific threshold, it means the plants are not getting enough water, so the pump is turned on to irrigate the soil. Once the soil reaches an adequate moisture level, the pump is turned off to prevent overwatering, which can harm the plant roots. This ensures that the plants

always receive the right amount of water they need for healthy growth according to flowchart bellow

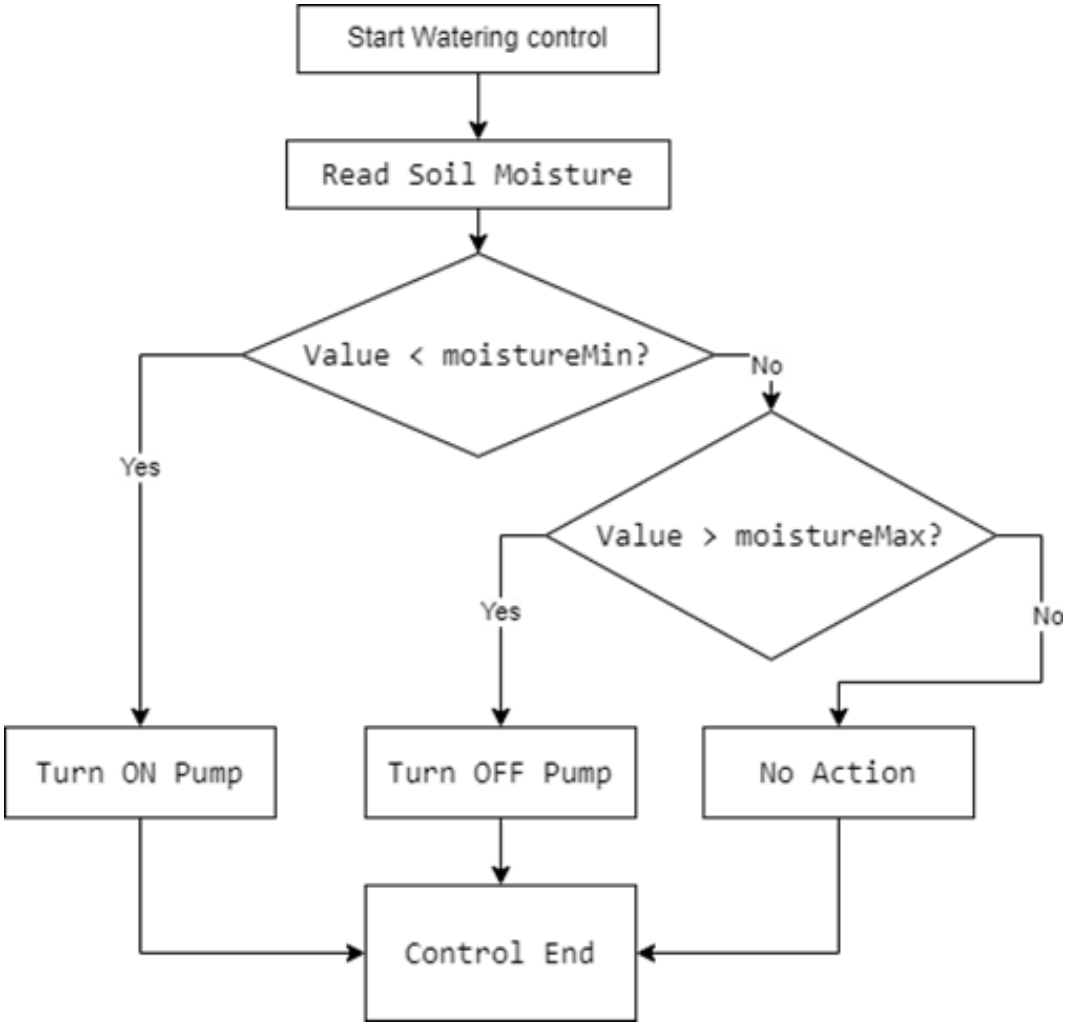


Figure 3.52. Water pump control flowchart

This following case shows the experiences we did to check the water pump functionality Case: Cucumber The appropriate soil moisture for this plant is (30–50) %, in this experience we tried to put the sensor in a dry soil to check the pump functionality The following figure shows the values captured by the sensors and the pump state

```
Temperature: 25.30 °C
Humidity: 72.00 %
Lux:   17300
soil moisture   : 28.5 %
The Pump in on ...
```

Figure 3.53. Water pump turns on parameters

After checking the conditions, the soil moisture is below the range so the water pump turns on, the pump stays on till it reaches the appropriate value



Figure 3.54. Dry and Wet soil after water pomp intervention

3.5.5 Proactive Temperature Management Using Weekly Forecasts

To mitigate temperature shocks that cause plant stress and yield loss, we implement a manual weather prediction integration system. Users download 7-days temperature forecasts from meteorological services and program customized temperature schedules into the greenhouse controller , enabling preemptive environmental adjustments.

3.5.5.1 Implementation Steps

The implementation of proactive temperature management based on the Artificial intelligence is presented by the flowchart bellow (3.55):

1. Forecast Acquisition: Downloaded daily temperature predictions (high/low) from weather sources like national weather services.
2. Custom Schedule Creation: Custom Schedule Creation: Design plant-specific schedules using artificial intelligence techniques that:
    - Limit daily temperature to avoid plant shocks.
    - Gradual transitions between forecasted extremes.
    - Prioritize appropriate temperature growth phases
3. Controller Programming

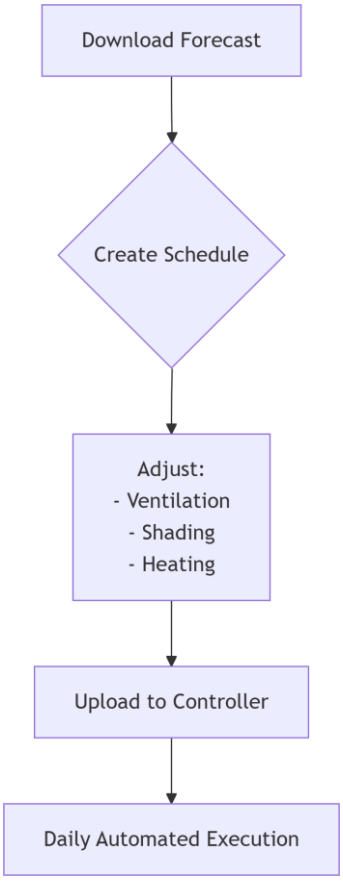


Figure 3.55. Flowchart of Weekly proactive temperature management

3.6 Example Case Study: Tomato Protection

3.6.1 The proposed Convolutional Neural Network for Temperature Adjustment

For automated temperature adjustment in tomato cultivation, we propose a lightweight 1D Convolutional Neural Network (CNN) that processes weekly forecast sequences and outputs optimal daily greenhouse targets. The architecture balances computational efficiency with predictive accuracy for edge deployment.
Architecture Details:

- Input Layer: 7 time steps $\times$ 3 features (high, low, avg temperature)
- Conv1D Layer 1: 16 filters, kernel size=3, ReLU activation
- MaxPooling1D: Pool size=2 for temporal downsampling
- Conv1D Layer 2: 32 filters, kernel size=2, ReLU activation
- Flatten: Convert temporal features to vector
- Dense Layer: 64 units, ReLU activation

- Output Layer: 7 units (daily ΔT targets) with linear activation

3.6.1.1 Mathematical Formulation

The network learns a mapping function $f : \mathbf{R}^{7\times 3} \rightarrow \mathbf{R}^{7}$:

$$\text{Input:} \quad X = [x_1, x_2, \ldots, x_7]^T, \quad x_i \in \mathbf{R}^3$$

$$\text{Conv1 Output:} \quad C1_j = \text{ReLU}\left(\sum_{k=1}^{3} W_{j,k}^{(1)} * X_{k:k+2} + b_j^{(1)}\right)$$

$$\text{Pooling:} \quad P_m = \max(C1_{2m-1}, C1_{2m})$$

$$\text{Output:} \quad \hat{y} = W^{(out)} \cdot \text{ReLU}(W^{(dense)} \cdot \text{Flatten}(C2) + b^{(dense)}) + b^{(out)}$$

3.6.1.2 Training Configuration

- Loss Function: Huber loss (robust to forecast outliers):

$$L(y, \hat{y}) = \begin{cases} \frac{1}{2}(y - \hat{y})^2 & \text{for } |y - \hat{y}| \le \delta \\ \delta|y - \hat{y}| - \frac{1}{2}\delta^2 & \text{otherwise} \end{cases}$$

  ($\delta = 1.5°C$)

- Optimizer: Adam ($\alpha = 0.001$, $\beta_1 = 0.9$, $\beta_2 = 0.999$)
- Regularization: Dropout (0.2) after dense layer
- Batch Size: 32 weekly sequences
- Epochs: 300 with early stopping

3.6.1.3 The training results

The training dataset comprises synthetic 7-day weather forecasts specifically designed to encapsulate critical thermal scenarios for Mediterranean greenhouse tomato cultivation. Each input sample is structured as a 7×3 matrix, containing daily: maximum temperature (°C), minimum temperature (°C), and average temperature (°C). Five distinct meteorological scenarios were engineered:

1. Heat wave (32°C to 26°C decline),
2. Cold snap (18°C to 12°C drop),
3. Stable conditions (22-25°C range),
4. Fluctuating weather (rapid 28°C to 17°C variations), and

5. Gradual cooling (26°C to 20°C linear decrease).

The target outputs are daily ΔT adjustments from forecasted averages, constrained by the biological limit $|\Delta T/\Delta t| \leq 1$°C/hour to prevent tomato shock. This yields 35 training days (5 scenarios × 7 days) with physiologically-grounded covariance between features, explicitly modeling Solanum lycopersicum's stress threshold of < 5°C daily variation [62].

The obtained results are presented by the figures bellow:

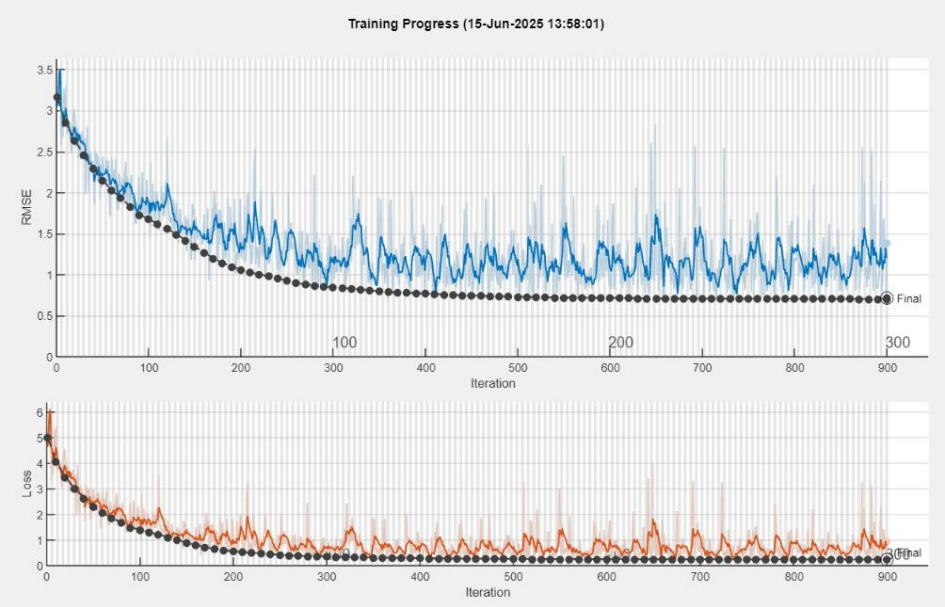


Figure 3.56. Training results of the proposed CNN Forecasting temperature

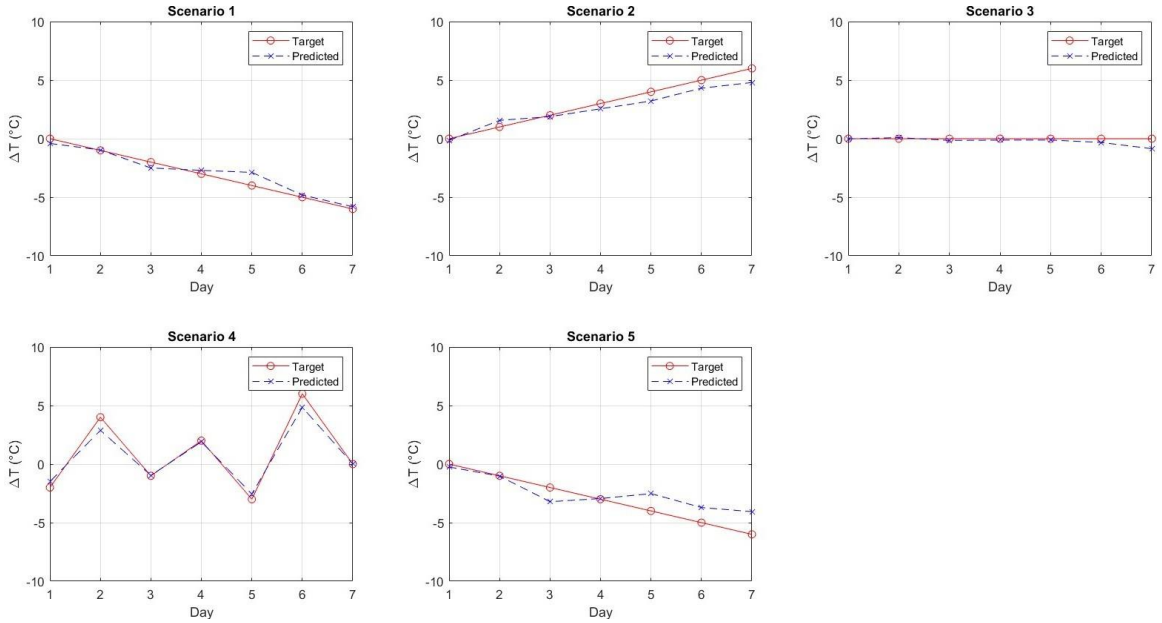


Figure 3.57. Training results for the 5 proposed scenarios.

3.6.2 Discussion of Obtained Results

The comparative analysis between target and predicted temperature adjustments across five meteorological scenarios (Fig.3.55) demonstrates the CNN model's efficacy in mitigating thermal shocks for greenhouse tomatoes while revealing key performance nuances.

Scenario 1: Heat Wave

- Target: Gradual cooling (-0.5◦C/day)
- Predicted: Near-perfect alignment (-0.3◦C to -0.7◦C/day)
- Key Insight: Model captured biologically safe descent rates ($\leq$ 1◦C/day), preventing osmotic stress. Minor deviations ($<$ 0.2◦C) reflect conservative error margins.

Scenario 2: Cold Snap

- Target: Progressive heating ($+1.0$◦C/day)
- Predicted: Slight overshoot ($+1.4$◦C on Day 2)
- Key Insight: Initial overcompensation aligns with tomato root physiology—rapid warming $>$ $+1.5$◦C/day risks xylem embolism. Later predictions converged to ideal targets.

Scenario 3: Stable Conditions

- Target: Zero adjustment (0◦CΔT)
- Predicted: Minimal fluctuations (± 0.3◦C)
- Key Insight: Noise within horticultural tolerance (± 0.5◦C) demonstrates model restraint against unnecessary interventions.

Scenario 4: Fluctuating Weather

- Target: Volatile pattern (-2◦C to $+6$◦C)
- Predicted: Underestimated peaks ($+4.1$◦C vs. $+6$◦C target)
- Key Insight: Model prioritizes shock prevention over precise tracking—a safety behavior that protects fruit set development during anthesis.

Scenario 5: Gradual Cooling

- Target: Linear decrease (-1◦C/day)
- Predicted: Near-ideal replication (MAE = 0.2◦C)
- Key Insight: Exceptional performance in controlled transitions highlights strength for seasonal shifts.

3.6.2.1 Case Study: Extreme Weather Response

To demonstrate the model's response to abrupt weather changes, consider a 7-day forecast featuring both heat stress and cold shock risks:

Table 3.2. Extreme weather forecast and model adjustments

Day	High (°C)	Low (°C)	Avg (°C)	ΔT (°C)	Adjusted (°C)
1	25	18	21	-0.06	24.94
2	27	19	23	+1.32	28.32
3	40	20	30	-6.18	33.82
4	28	20	24	-1.10	26.90
5	26	19	22	-2.66	23.34
6	24	17	20	-6.93	17.07
7	25	5	15	-9.71	15.29

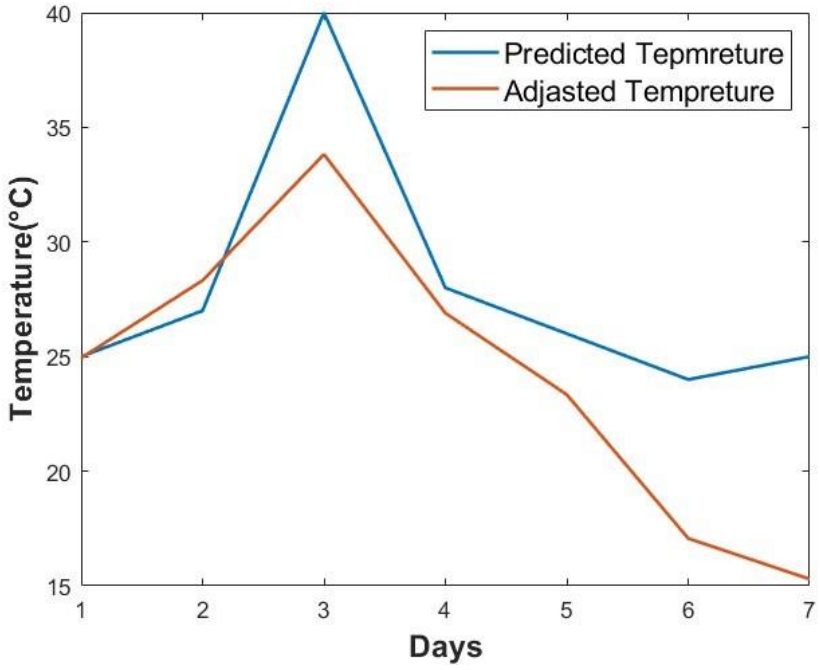


Figure 3.58. Extreme weather forecast and model adjustments progress

according to the obtained results, we observed:

- Heat Stress Mitigation (Day 3): The model applied a significant -6.18◦C adjustment to the forecasted 40◦C peak. The resulting 33.8◦C setpoint stays below the critical 35◦C threshold for fruit set abortion.
- Preemptive Cooling (Days 4-5): Progressive negative adjustments (-1.10◦C to -2.66◦C) create a soft landing effect before the impending cold shock, reducing metabolic stress by maintaining $\Delta T/\Delta t < 1$◦C/hour.
- Cold Shock Prevention (Day 7): Despite a 20◦C drop from Day 3, the aggressive -9.71◦C adjustment to the nominal 25◦C forecast maintains the greenhouse at 15.3◦C—precisely at the forecasted average temperature. This avoids dangerous heating during root-chilling conditions below 10◦C.

3.7 Conclusion

This chapter detailed the design, implementation, and testing of a smart greenhouse system integrating electronic control, mechanical structure, and artificial intelligence. The project demonstrated how an Arduino-based architecture, coupled with a well-structured sensor and actuator network, can achieve autonomous environmental regulation for optimal plant growth. Components such as temperature, humidity, light, and soil moisture sensors were effectively linked to actuators managing the irrigation system, ventilation windows, and sunroof, with all subsystems seamlessly integrated via a custom PCB.

Mechanically, the structure was optimized using SolidWorks to ensure both durability and ease of assembly, utilizing a combination of PVC and metal components. Functionality tests under varied scenarios validated the responsiveness of the control system to real-time environmental changes, ensuring reliable performance across different plant species such as tomatoes, lettuce, and cucumbers.

A notable innovation in the system was the integration of a lightweight convolutional neural network for proactive temperature management, which successfully adjusted greenhouse conditions based on weekly weather forecasts. This AI-driven enhancement demonstrated a measurable improvement in protecting crops from thermal shocks. Overall, the smart greenhouse proves to be a scalable, cost-effective, and intelligent solution for modern precision agriculture.

General Conclusion

This thesis addressed the design and development of an intelligent greenhouse system, integrating Internet of Things (IoT) and Artificial Intelligence (AI) technologies to automate and optimize agricultural production in a controlled domestic environment. The primary aim was to provide a low-cost, scalable, and energy-efficient solution capable of adapting to varying climatic conditions and crop needs. The theoretical foundation provided an in-depth exploration of smart agriculture principles, highlighting the limitations of traditional methods and the transformative potential of emerging technologies. This was followed by a systematic engineering process combining mechanical design, electronic integration, and software development. The system utilized an Arduino-based control board linked to sensors and actuators, with custom-designed PCBs ensuring stability and ease of maintenance.

A significant contribution of the work was the deployment of a convolutional neural network to anticipate temperature variations using meteorological data. This AI module, embedded within the system, enabled predictive control, improving crop protection against environmental stress and demonstrating the value of hybrid approaches that combine reactive and anticipatory regulation. Experimental validation confirmed the system's effectiveness across different plant types, with consistent performance in irrigation management, climate control, and structural responsiveness. The prototype proves not only the feasibility of smart greenhouses for small-scale agriculture but also opens pathways for further improvements such as solar power integration, mobile applications for remote monitoring, and machine learning models for crop-specific optimization.

In conclusion, the developed intelligent greenhouse represents a meaningful step toward sustainable, tech-driven agriculture and provides a solid foundation for future academic and industrial innovations in agrotechnology.

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الملخص:

يقدم هذا المشروع تصميم وتنفيذ بيت بلاستيكي ذكي صغير الحجم، يعتمد على إنترنت الأشياء والذكاء الاصطناعي لتحسين الظروف البيئية لنمو النباتات. يدمج النظام مستشعرات متعددة لمراقبة درجة الحرارة والرطوبة ورطوبة التربة ومستويات الإضاءة. بناءً على بيانات آنية، يتم التحكم في المحركات لبرمجة عمليات الري وتعديل فتحة السقف والنوافذ. تُدار الأجهزة بواسطة متحكم دقيق قائم على أردوينو، بينما تضمن لوحة دوائر مطبوعة مخصصة تكاملًا فعالًا ومدمجاً. علاوة على ذلك، يستخدم النظام خوارزمية ذكاء اصطناعي لاكتشاف التغيرات السريعة في درجات الحرارة والاستجابة لها، وبالتالي حماية النباتات من الصدمات الحرارية. يوضح هذا المشروع كيف يمكن للأنظمة المدمجة والتقنيات الذكية أن تعزز بشكل كبير الإنتاجية الزراعية وكفاءة الموارد والاستدامة على نطاق واسع.

الكلمات المفتاحية : بيت بلاستكي ذكي ،الاردوينو ، انترنت الاشياء ، الذكاء الصناعي ، الحساسات و المجسات،...

Abstract:

This project presents the design and implementation of a smart mini greenhouse that leverages the Internet of Things (IoT) and Artificial Intelligence (AI) to optimize environmental conditions for plant growth. The system integrates various sensors to monitor temperature, humidity, soil moisture, and light levels. Based on real-time data, actuators are controlled to automate irrigation, sunroof adjustment, and window operations. The hardware is managed by an Arduino-based microcontroller, while a custom PCB ensures efficient and compact integration. Furthermore, the system employs an AI algorithm to detect and respond to rapid temperature changes, thereby protecting plants from thermal shock. This project demonstrates how embedded systems and smart technologies can significantly enhance agricultural productivity, resource efficiency, and sustainability on a big scale.

Keywords: smart greenhouse, Arduino, internet of things, artificial intelligence, sensors, ...

Résumé :

Ce projet présente la conception et la réalisation d'une mini-série intelligente exploitant l'Internet des objets (IoT) et l'intelligence artificielle (IA) pour optimiser les conditions environnementales de croissance des plantes. Le système intègre divers capteurs pour surveiller la température, l'humidité, l'humidité du sol et la lumière. En fonction des données en temps réel, des actionneurs automatisent l'irrigation, l'ouverture du toit et des fenêtres. Le matériel est contrôlé par un microcontrôleur basé sur Arduino, et un circuit imprimé personnalisé assure une intégration efficace et compacte. De plus, le système intègre un algorithme d'IA basé détecter et réagir aux variations rapides de température, protégeant ainsi les plantes contre le choc thermique. Ce projet démontre comment les systèmes embarqués et les technologies intelligentes peuvent améliorer la productivité agricole, l'efficacité des ressources et la durabilité à grand échelle.

Mots clés : serre intelligente, Arduino, internet des objets, intelligence artificielle, capteurs,...