The High-Altitude Hero

An IoT-Based Automated Greenhouse System

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***Abstract* — Food production at higher altitudes like Mustang and Solukhumbu is highly limited by low temperatures, low humidities, unpredictable weather patterns, and extremely short cropping cycles. These locations are characterized by a distinctive series of agro-climatic issues like frost hazards, inadequate soil water holdings, as well as extensive temperature fluctuations, all of which make conventional agriculture inefficient for sustainable food production and/or financial returns. For each of these hindrances, the authors introduce "High-Altitude Hero," an IoT-enabled intelligent greenhouse system specifically created in response to the requirements of the mountains.**

This innovative greenhouse utilizes a Tinkercad-prototyped system driven by an Arduino Uno microcontroller. It integrates temperature sensors, light detectors, and soil moisture monitors to assess real-time conditions within the greenhouse. Automated responses are programmed to activate actuators such as grow lights, heating elements, servo-controlled vents, and a water pump, thereby establishing a controlled microclimate that supports optimal plant health and growth. The system also includes a frost alert mechanism for enhanced crop safety.

Crops like apples, potatoes, and medicinal herbs well-suited to the high-altitude soil and ecosystem benefit significantly from this precision agriculture approach. This project not only proves the viability of embedded systems in smart farming but also offers a scalable, resilient framework for improving food security and economic sustainability in highland regions.

I. Introduction

Nepal's geography is characterized by extreme topographical variation, from the Terai plains to the high Himalayas. While this diversity creates unique ecosystems, it also poses significant obstacles to agriculture, which remains the backbone of the nation's economy, employing over 65% of the population(" MoAd," 2020) . High elevation areas of Nepal, such as Mustang and Solukhumbu, face severe climatic conditions such as windy weather, low atmospheric pressure, and sparse rainfall. These areas are usually above 2,500 meters in elevation where frost, snow, and unpredictable weather characteristics prevail for most of the year. The soil at such locations is usually rocky and infertile, and the growing season condenses to a few summer months. Conventional subsistence agriculture depending on human power and variable weather provides low productivity and has limited financial security for the subsistence farmers.

In the mountainous and high-altitude regions, farming is predominantly a subsistence activity constrained by a harsh climate. Farmers contend with a brief growing season, limited arable land, poor soil quality, and severe weather events, including nocturnal frost, which can decimate an entire crop overnight(Sthapit, 1997).

Despite such hiccups, the higher altitudes are best suited for the production of high-value crops such as apples, potatoes, barley, and some medicinal herbs best adapted to cooler climatic conditions. However, the lack of greenhouse facilities, inefficient access to real-time monitoring of the environment, and lack of automation has kept the agriculture sector from attaining peak productivity. Now, with the emergence of the Internet of Things (IoT) and embedded automation, the capability of converting remote farming methods to avail precise control over cultivation parameters has never been so opportune nor so attainable.

II. Literature Review

The development of an IoT-based smart greenhouse for high-altitude regions of Nepal is situated at the intersection of climate-resilient agriculture, protected cultivation science, and applied electronics. This review synthesizes existing literature from these domains to establish the theoretical framework and identify the research gap that the proposed system aims to address.

A. Why Protected Cultivation Matters in High-Altitude Farming

The agricultural systems in Nepal's high-altitude regions, such as Mustang and Solukhumbu, are exceptionally vulnerable to climatic constraints. These areas are characterized by short growing seasons (3-5 months), extreme temperature fluctuations (from over 25°C to below -20°C), high levels of solar radiation, and unpredictable weather patterns, including frost and hailstorms(Shrestha and Aryal, 2011). These factors severely limit crop diversity, yield, and food security for local communities. A study by the International Centre for Integrated Mountain Development (ICIMOD) highlighted that climate change is exacerbating these vulnerabilities, with rising temperatures leading to accelerated glacial melt and more erratic precipitation, further threatening traditional farming practices(Wester et al., 2019).

Late spring and early autumn frosts shorten the growing season, limiting crop maturation time. Thinner atmospheres at higher elevations allow greater UV radiation, which can damage plants but also enhance crop quality if managed. Intense weathering and erosion also degrade soil fertility, and cold climates slow downs soil formation. That's the reason Protected cultivation, particularly through greenhouses, offers a controlled environment to mitigate these challenges, enabling sustainable crop production. There have been several instances that highlights the effectiveness of protected cultivation in high-altitude regions particularly noting: Himalayan Smart Greenhouse(Dorji, 2025) , Colorado Mountain Gardening(Binkley, 2015) and Himalayan Apple Farming(Chapagain et al., 2023)**.**

In light of challenges, protected cultivation has emerged as a key strategy for adaptation. Farmers in the region have started using basic poly-tunnels and low-tech passive solar greenhouses, which seem promising in extending the crop-growing period and shielding plants from early frost damage(SK Jha et al., 2022). However, these passive structures often fail to provide adequate protection during extreme cold snaps and offer limited control over the internal microclimate.

B. Evolution of Greenhouse Technology and Environmental Control

Greenhouse technology has evolved from simple passive structures to highly sophisticated, automated systems. The core principle of a modern greenhouse is the creation of an optimal microclimate by precisely controlling parameters such as temperature, humidity, light intensity, and soil moisture. The automation of these controls is central to what is now known as a "smart greenhouse."

Early greenhouses relied on passive methods, such as glass structures to trap heat, but lacked precise control over environmental parameters(Jensen and Malter, 1995). The introduction of automated systems in the 20th century marked a turning point, with mechanical ventilation and heating systems improving temperature regulation(Bartzanas et al., 2005). The advent of microcontrollers and IoT technologies has further revolutionized greenhouse management. The use of microcontrollers like the Arduino or Raspberry Pi has democratized this technology, making it possible to build low-cost yet effective control systems. The group of people in 2019 (Farooq et al., 2019) took a closer look at IoT-driven greenhouse setups. They highlighted how various sensors tracking things like temperature, humidity, light, and CO_2 are being used alongside actuators such as fans, heaters, and irrigation units to maintain optimal growing conditions.

In high-altitude contexts, greenhouse technology has evolved to address specific challenges like frost and intense UV radiation. People have introduced a solar-powered smart greenhouse for Himalayan regions, incorporating sensors and actuators to extend the growing season. However, their reliance on solar energy limits applicability in low-light conditions. IoT-based systems have further enhanced environmental control by enabling remote monitoring and data analytics. Boursianis (Boursianis et al., 2021) reviewed smart irrigation systems, noting the integration of IoT with sensors and actuators to optimize water use. The "High-Altitude Hero" builds on these advancements by integrating multiple sensors and actuators into a cost-effective system tailored for high-altitude conditions. Unlike earlier systems that focused on single parameters or required expensive hardware , this project uses an Arduino Uno R3 to deliver a practical solution for small-scale farmers.

C. The Role of IoT in Modernizing Agriculture

The Internet of Things (IoT) has become a transformative force in modern agriculture, bridging the gap between traditional farming practices and sustainable, data-driven innovation. Through the integration of sensors, actuators, and communication networks, IoT enables real-time monitoring and intelligent automation of various agricultural processes—ranging from crop health assessment to efficient resource utilization.

Soil moisture sensors, detect water needs, triggering automated irrigation systems to deliver precise amounts, reducing waste(Ray et al., 2017). Sensors monitor soil nutrient levels, enabling targeted fertilization, which minimizes chemical runoff and enhances soil health(Elijah et al., 2018). A study by (Danita et al., 2018) showcased an IoT-based greenhouse system that optimized environmental conditions, improving crop yields by 15%. IoT also enables farmers to monitor and manage operations remotely, enhancing efficiency and responsiveness. IoT networks, such as LPWAN, support long-range communication which is ideal for remote farms(Mekki et al., 2019). Greenhouses stand to benefit immensely from IoT technologies, especially in challenging environments such as high-altitude regions where precise climate control is crucial for crop survival. IoT systems helps automate ventilation, heating, and irrigation based on sensor data which is crucial for creating environment necessary for plant growth(Saha et al., 2023).

IoT is revolutionizing agriculture through precision farming, remote monitoring, and automation capabilities .Despite challenges such as cost and connectivity, the rise of affordable technologies and ongoing innovation hold the promise of making IoT solutions accessible to farmers everywhere, paving the way for more sustainable and resilient food systems.

D. Contextual Challenges and Opportunities in Nepal

While global trends offer valuable frameworks, effective solutions must be adapted to the specific context of local realities. In Nepal's hilly and mountainous regions, agriculture is shaped by a distinctive blend of environmental extremes and socio-economic constraints. Frost is a primary and devastating constraint, capable of causing total yield loss overnight, particularly for high-value horticultural crops(Malla, 2008). This makes an automated frost detection and response system a feature of critical importance, rather than a mere convenience.

Water management presents another critical challenge. High-altitude regions face intense monsoon rains followed by extended dry periods, resulting in both severe soil erosion and acute water shortages. These conditions underscore the urgent need for efficient and adaptive irrigation systems(Maskey et al., 2023). Traditional irrigation methods are often inefficient, particularly in high-altitude regions where water is scarce and difficult to manage. Compounding this issue is the "feminization of agriculture", a result of widespread male out-migration for employment which places a disproportionate labor burden on women, who are frequently tasked with fetching water(Upadhyay, 2005). In this context, an automated irrigation system not only conserves precious water but also alleviates the physical burden on women, promoting both efficiency and social equity.

Technology adoption in these regions faces significant socio-economic barriers. These include limited financial capital to invest in new technologies, inadequate access to technical support and training, and fragmented land holdings(Timsina et al., 2024). Therefore, the affordability and open-source design of the proposed system are crucial to its potential adoption in resource-constrained, high-altitude communities. While challenges such as cost, connectivity, and technical literacy remain, there is a growing interest in leveraging modern technologies at the local level. This is reflected in emerging research on IoT-based monitoring systems tailored to specialized crops such as mushrooms and citrus, which demonstrates both the feasibility and the relevance of such innovations in Nepal's diverse agricultural landscape.

E. Innovative Features

These days, smart greenhouse systems do a lot more than just keep tabs on temperature and humidity, they're packed with advanced tech that's completely changing how we automate agriculture. Besides basic climate management, sophisticated smart greenhouses are integrated with several innovative functions. Machine learning algorithms now optimize crop production through predictive analytics, with AI-based forecasting models achieving energy savings of approximately 15% through data-driven predictive control(Jeon et al., 2024). These systems use big sets of data and computer power. Small farms may find this too costly.

Implementing AI in greenhouse systems poses important problems related to data quality requirements and computation complexity. A single model for predicting all variables of interest produces uneven predictions. Some variables receive accurate predictions, but others do not perform well. This lowers the general dependability of systems that help with decisions(Morales-García and Cecilia, 2023) . One of the innovation is represented by computer vision systems, which allow for the immediate monitoring of crop health and the detection of disease without any human intervention("Smart Greenhouses," 2025a). Cutting-edge deep learning frameworks, more specifically convolutional neural networks (CNNs), have achieved stunning accuracy rates in the domain of plant disease detection. Some models, like InceptionV3, push the accuracy envelope to 95.6% for the task of identifying crop diseases from mere image data.

On the other hand, computer vision systems have substantial constraints imposed by environmental variability and image quality in greenhouse settings. They perform poorly under rapidly changing lighting conditions or when using non-orthogonal views of objects, and are further hampered by the small, nearly monoclonal appearance of some plant phenotypes when the effect of real time, non-destructive, plant tracking is taken into account("IJSRET," 2025). These systems are effective only if they are built upon standard datasets and benchmarking protocols, which are still very inconsistent across the different agricultural contexts.

Robotic integration is a big step toward having totally autonomous agricultural operations. The ROYA robot shows what this can be, embodying innovation and including element that can have different modes of operation. It has 360-degree Virtual Walk cameras (think how you could use such a camera in any context to make very wide observations), and it has very good object detection capabilities (which makes sense, since robotics must understand the environment in very complex ways)("Smart Greenhouses," 2025b).

Nevertheless, robotic systems are facing the limits in the field application in the greenhouse, including the mechanical reliability and maintenance. Issues such as contamination of drive transmission and vulnerability of engine to higher resistance has been recorded in research. The two broad issues preventing growers to implement automation are ROI and trust: technology must be cost-effective enough, to work well and be palatable in use and easy to fix("Where are all the robots?," 2024).

F. Future Trends

The future of smart farming is shifting to hyper-automated combination and forecastive intelligence through Artificial Intelligence (AI) and Machine Learning (ML). Market projections demonstrate robust growth expectations, with the global smart greenhouse market anticipated to expand from USD 2.3 billion in 2024 to USD 5.7 billion by 2033, representing a compound annual growth rate of 10.4%("Smart Greenhouse Market Size, Growth and Forecast 2033," n.d.). In the future, systems will not only respond to the prevailing conditions but forcast the subsequent ones. As an example, ML models trained to work on camera image data can be used to diagnose diseases in plants before the human eye would see them so that an intervention could be executed early enough. The systems will no longer act on present situations but will anticipate future states. An example is that ML models trained on image data in camera may be used to forecast plant diseases even before the human eye can see the signs and hence timely intervention(Hassan and Maji, 2022).

The technology of digital twins is a new and important step forward for the smart greenhouse applications, allowing for a completely virtual model of a greenhouse environment that can be used for all-powerful predictive analysis and optimization of said environment. The generation of a digital twin can be done in tandem with the greenhouse construction, using smart materials and components that carry AI engine capabilities, with the end-effector coming from the digital engine of the predictive models carried by the AI in the components(Zhang et al., 2025). Even so, the use of digital twin technology is not without big hurdles, such as complex data integration and demanding computational requirements. In the field of agriculture, there are several technical challenges to the adoption of digital twins, which should be flaggable as we move forward: data acquisition, data integration, standardization, interoperability, implementation cost.

The emergence of edge computing addresses the latency and internet connectivity problems found in cloud-based architectures. Edge computing allows for the local, real-time processing of sensor data inside greenhouses. Immediate responses to changing environmental conditions can be made without having to rely on the internet. This local computing is particularly valuable for precision farming, where you only want to make a move when certain conditions have been met. You don't want to wait for the internet to relay your instructions("Smart Greenhouses," 2025b). The implementation of edge computing faces restrictions in processing power and storage relative to centralized cloud systems. Initial investment and maintenance for edge computing infrastructure can easily exceed the budgets of many smaller agricultural firms. Hybrid environments also come with the challenge of managing access to a computation resource that isn't all in one place. To be fair, this is an issue that cloud service providers also have to deal with; but in their case, the problem is smoothed over by offering large-scale, high-availability services. If companies in agriculture want or need to operate a hybrid environment, then they have to offer a similar kind of access for their employees(Ciesielska, 2025).

G. *IoT and Security*

The spread of the IoT connection on the basis of smart greenhouse systems poses serious cybersecurity risks that cause a great number of risks to agricultural activities and privacy of the data. Cyberattacks attached to IoT have increased by 400% on annual basis as seen in recent security reports showing how much of a threat area smart farming systems are. There are 10 attacks per device on average on home networks every 24 hours and Bitdefender smart home security solutions block an average of 2.5 million threats, or about 1,736 threats per minute(NETGEAR Security Team, 2024).

Greenhouse control systems that are based on IoT generate and handle large quantities of confidential information about environmental conditions, crop performance indicators, and operating parameters and need strong privacy protection measures. Inadequacy of privacy protection becomes apparent due to real life examples such as recent cases of agri-tech firms gaining unauthorized access to information over IoT devices deployed at large-scale farming operations. Major breaches of privacy were recorded when a company operating in an agro-tech sector hacked into information transmitted by IoT which was employed by huge farming companies to gather detailed information on farming efficiency, the conditions of the soil, watering times and personal details without authorization(Rahaman et al., 2024a).

The known attack vectors show that Wi-Fi deauthentication attacks work by taking advantage of the inherent weaknesses in the IEEE 802.11 protocols. Vulnerabilities in these Wi-Fi standards cause unencrypted management frames to become susceptible to malicious manipulation. A device that has been created to strategically use these bad management frames can do things like disconnect valid, functioning devices from a Wi-Fi network. Consequently, the attack can prevent those devices from sending their sensor data up to cloud systems that, ostensibly, should be acting as the central nervous system for an Internet of Things farm. The potential fallout from such a successful cyberattack runs very deep(Luz and Olaoye, 2024).

Privacy-centered frameworks use advanced encryption methods, safe communication paths, and many authentication factors to ensure that only the right people can see or use sensitive data. These security setups work with key pairs (symmetric and asymmetric), hash functions, and other, shall we say, creative mechanisms for making sure that the data we access, and the data we send, are only accessed and sent by us(Rahaman et al., 2024b). Despite their importance, most modern control systems weren't built to work with AI. Most rely on a mix of analog and digital technologies that have been around for decades. These systems won't just magically become AI-friendly overnight. And if we want to use AI to boost the efficiency of something like a greenhouse, we must ensure the control systems governing that structure can be integrated with AI(“eGRO,” 2025).

III. OBJETIVES

The primary objective of this project is to design and validate a prototype for a low-cost, automated greenhouse system tailored for high-altitude farming in Nepal.

The "High-Altitude Hero" aims to deliver a comprehensive, autonomous greenhouse management solution with the following detailed objectives:

- **To design a closed-loop IoT system for environmental monitoring :** This foundational objective involves using an Arduino Uno as the central controller to continuously read data from temperature, ambient light, and soil moisture sensors. This creates the "sensing" layer of the autonomous system.

- **To integrate multiple actuators into a cohesive control system :** This objective focuses on ensuring that the various output components servo, motor, relay, and buzzer work together seamlessly under the Arduino's control, forming a single, functional, and autonomous unit.

- **To provide automated supplementary lighting** :To compensate for short daylight hours or overcast conditions, this objective involves using a relay-controlled system to turn on grow lights when the photoresistor detects that natural light levels are insufficient for optimal plant growth.

- **To implement a critical frost alarm and response system** :This is the most vital objective for the high-altitude context. The system will be designed to activate a loud piezo buzzer and a simulated heating element when the ambient temperature drops to a near-freezing level (e.g., 4°C), providing an immediate alert and a protective response against crop-destroying frost.

- **To develop a real-time, on-site user interface :** This objective addresses usability. A 16x2 LCD screen will be integrated to provide the farmer with immediate, at-a-glance feedback on current temperature, light, and moisture levels, as well as the status of all automated systems (e.g., "PUMP", "VENT", "HEAT").

- **To validate the integrated system's functionality through simulation.** : The final objective is to prove the viability of the design. The entire circuit and its control logic will be built and tested in the Autodesk Tinkercad environment to confirm that all subsystems function correctly and respond appropriately to simulated environmental changes.

IV. METHODOLOGY

The development of the "High-Altitude Hero" prototype followed a structured methodology encompassing system design, hardware integration, logical framework definition, and virtual validation.

A. System Architecture

The system is architected on a classic Input-Process-Output (IPO) model, centralized around an Arduino Uno microcontroller.

- Input : This level will have three analog sensors to achieve sensing of the surroundings: TMP36 Temperature Sensor to receive data of this thermal property, Photoresistor (LDR) connected as a voltage divider to obtain the data on the amount of the surrounding light, and resistive Soil Moisture Sensor to obtain the data on the volumetric water content.
- Process : The main processing chip is the Arduino Uno. It operates on a microcontroller which uses the programming language C++ through Arduino IDE. This program obtains raw analog measurements of the sensors through its Analog-to-Digital Converter (ADC), analyzes them into more universal forms (e.g. Celsius) and uses a set of specific rules to create control choices, based on them.
- Output: This layer has the actuators which physically change the green house environment. It has a Micro Servo on the vent control (driven by Pulse Width Modulation -PWM), a DC Motor on the water pump (driven by an NPN transistor as a low-side switch), a 5V Relay on the high-power grow lights, a Piezo Buzzer on the audible frost alarm, and a 16x2 LCD to display real time information.

B. Block diagram Demonstration

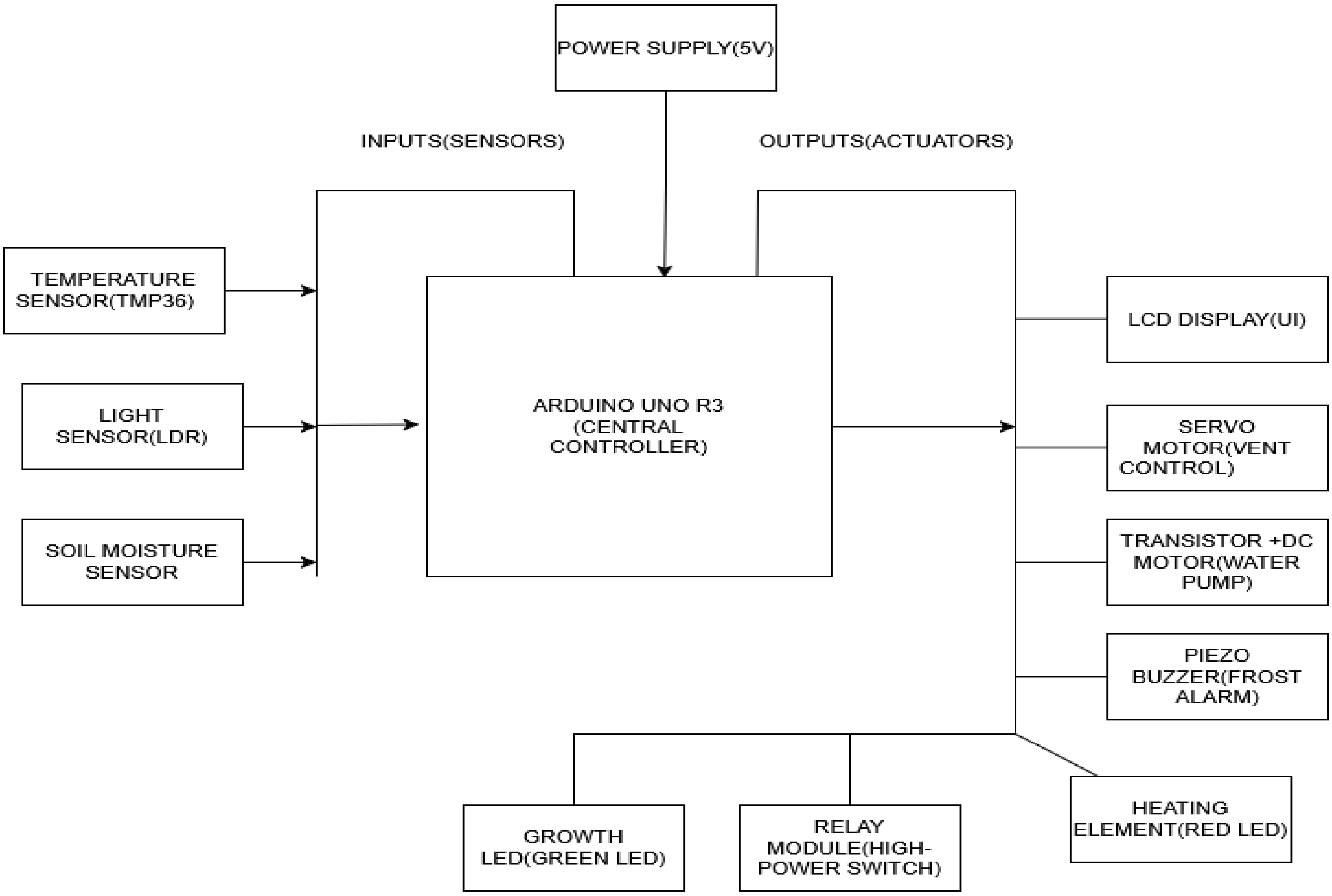


Figure 1:Block Diagram of the prototype based on System architecture.

C. Boolean Logic

First, let's define logic for the operations:

- Inputs(Sensors)

Temperature Sensor		Light Sensor	
0	If temperature is normal (4°C-30°C)	0	If light is sufficient (>300)
1	If Temperature < Frost Threshold (< 4°C)	1	if Light < Light Threshold(< 300)
1	If Temperature > Hot Threshold (> 30°C)		

Soil moisture Sensor	
0	If Moisture >Dry Threshold
1	If Moisture < Dry Threshold

Table 1:Inputs

- Outputs(actuators)

Heating Element (Red LED)		Grow Light (Green LED)	
0	OFF (Temperature is High)	0	OFF(If there is enough sunlight)
1	ON(Temperature is Low)	1	ON(If there is not enough sunlight)
Water Pump(DC Motor)		Vent(Servo)	
0	OFF (Soil moisture is enough)	0	OFF (If temperature is low or normal)
1	ON (Soil moisture is not enough)	1	ON(If temperature is very high)
Frost Alert(Buzzer)			
0	OFF(If the temperature is high or normal)		
1	ON(If temperature is very low)		

Table 2: Outputs

- Truth Table For Prototype

Cases	Temperature(T) Low	High	Soil Moisture(S)	Light(L)	Heating Element(R)	Growth Light(G)	Water Pump(W)	Vent(V)	Frost Alert Buzzer(B)
1	0	0	0	0	0	0	0	0	0
2	0	0	1	0	0	0	1	0	0
3	0	0	0	1	0	1	0	0	0
4	0	0	1	1	0	1	1	0	0
5	1	0	0	0	1	0	0	0	1
6	1	0	1	0	1	0	1	0	1

7	1	0	0	1	1	1	0	0	1
8	1	0	1	1	1	1	1	0	1
9	0	1	0	0	0	0	0	1	0
10	0	1	1	0	0	0	1	1	0
11	0	1	0	1	0	1	0	1	0
12	0	1	1	1	0	1	1	1	0

Table 3:Truth Table

- Boolean Expressions:

  Opens Vent: $V = TH \wedge \neg B$ or
  -open vents when it's too hot but not when it's frost-cold.

  Heating Element on(Red LED): $R = TL$
  -turn on heating element whenever temperature is low.

  Grow Lights on(Green LED): $G = L$
  - turn on lights whenever ambient light is low.

  Water Pump on(DC Motor): $W = S$
  - run pump whenever soil is too dry.

  Frost Alarm on (Buzzer): $B = TL$
  - sound buzzer only when frost conditions are detected.

(Note: TH=TemperatureHigh , TL=TemeperatureLow)

D. Circuit Diagram

- When the Heating Element Is On(R):

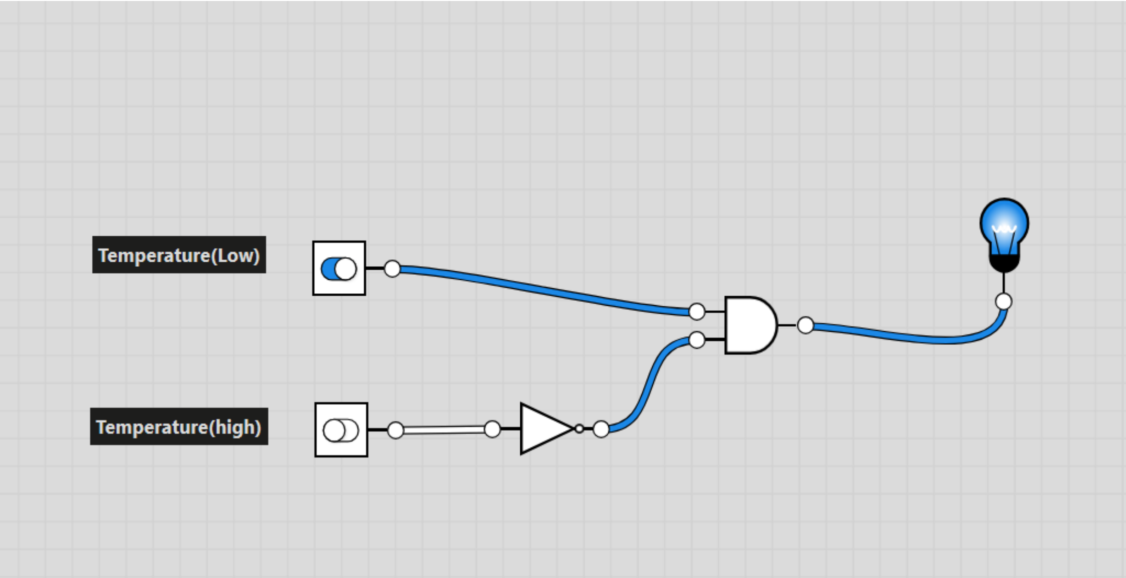


Figure 2: Circuit Diagram when heating element is ON

How it Works:

When the temperature is low (T low = 1, T high = 0):

The AND gate receives 1 from T low.

The 0 from T high is inverted by the NOT gate to become 1.

The AND gate receives 1 and 1, so its output is 1. The Heater light turns ON.

In any other temperature condition (normal or high), the Heater light will be OFF.

➢ When the Growth Light Is on:

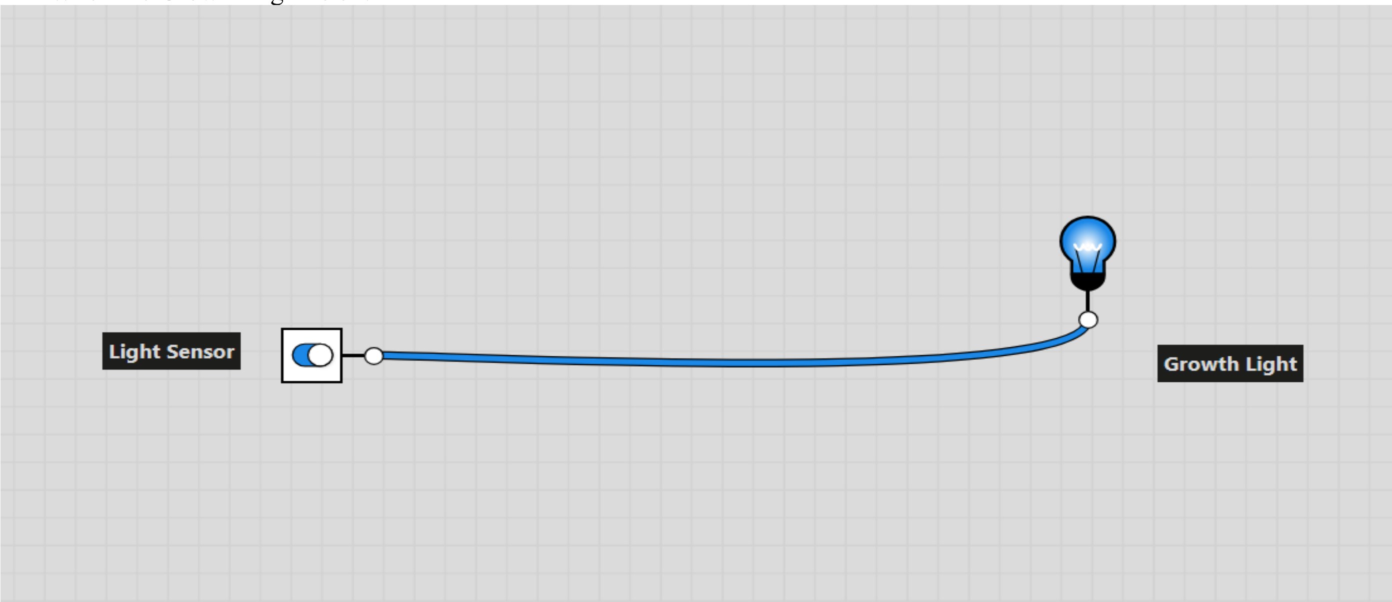


Figure 3:: Circuit Diagram when GrowthLight is ON

How it Works:

When the light sensor is on (L = 1), the Growth Light G will turn ON.

When the light sensor is off (L = 0), the Growth Light G will turn OFF.

➢ When the Water Pump is running:

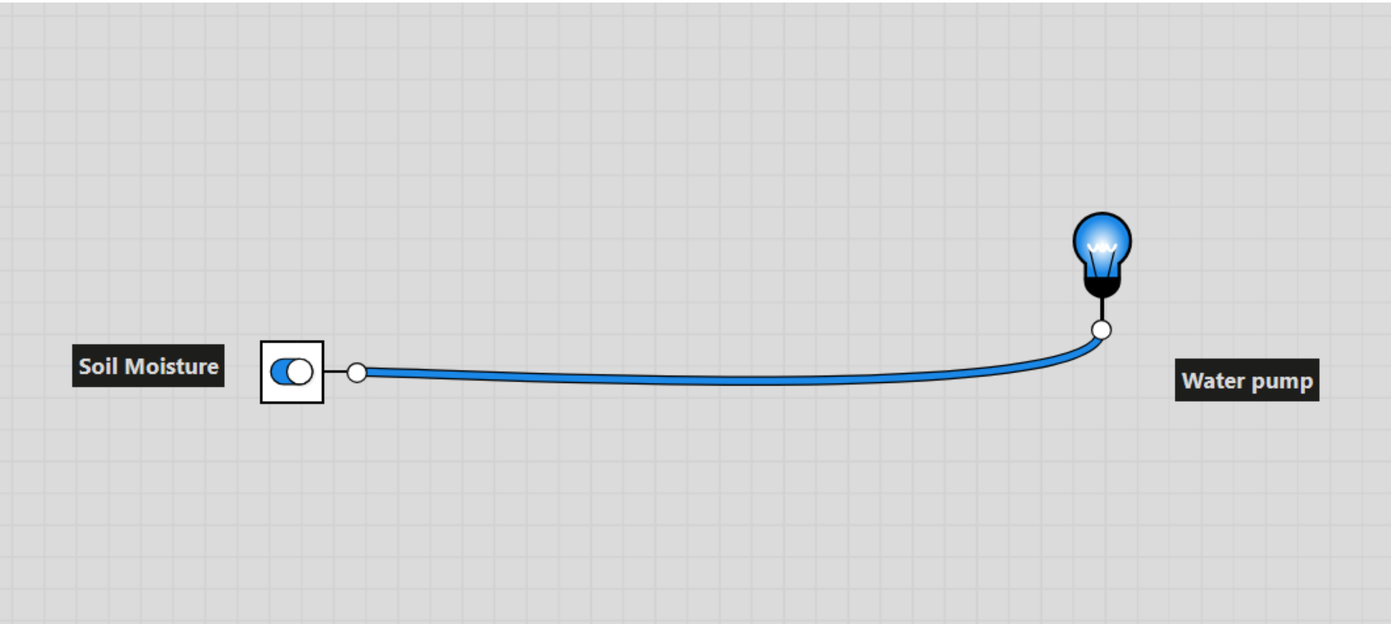


Figure 4:When Water Pump is on

How it Works:

When the soil moisture sensor is ON (S = 1), the Water Pump W will turn ON.

When the soil moisture sensor is OFF (S = 0), the Water Pump W will turn OFF.

- When the Vent is Open:

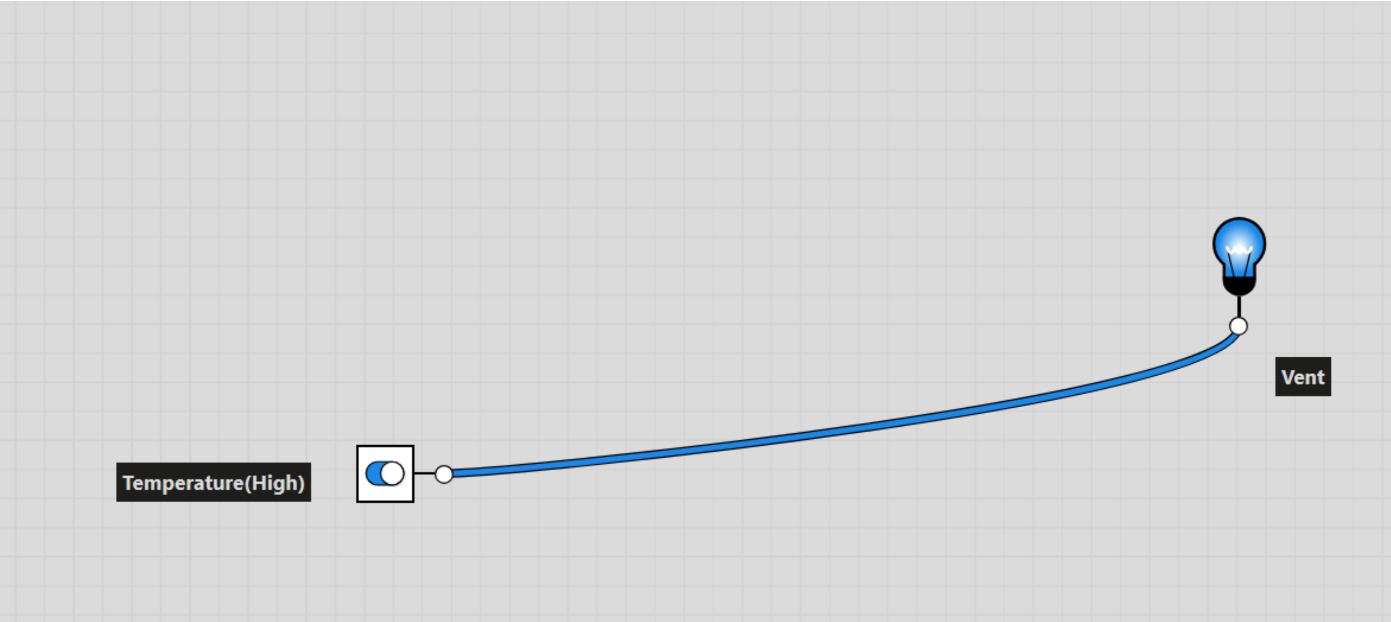


Figure 5:: Circuit Diagram when vent is open

How it Works:

When the high-temperature sensor is ON (T high = 1), the Vent V will OPEN.

When the high-temperature sensor is OFF (T high = 0), the Vent V will remain CLOSED.

- When the Buzzer is on:

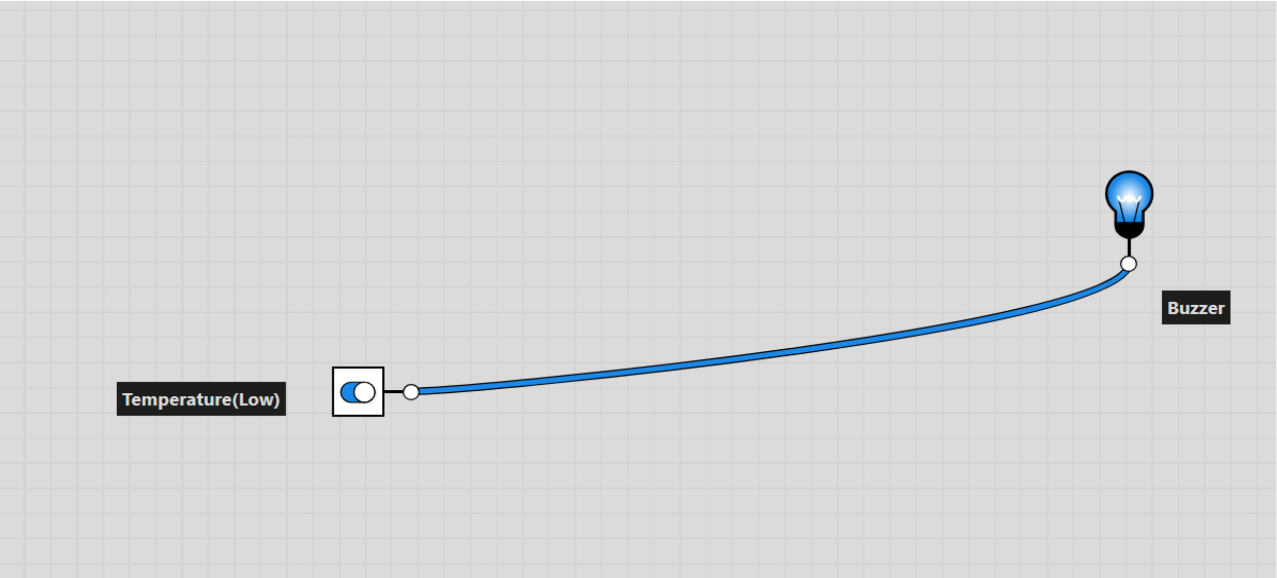


Figure 6:: Circuit Diagram when buzzer is on

How it Works:

When the Low-temperature sensor is ON (T Low = 1), the Buzzer will ring continuously.

When the Low-temperature sensor is OFF (T Low = 0), the Buzzer will stay silent.

- When Both Buzzer and Heating element is on:

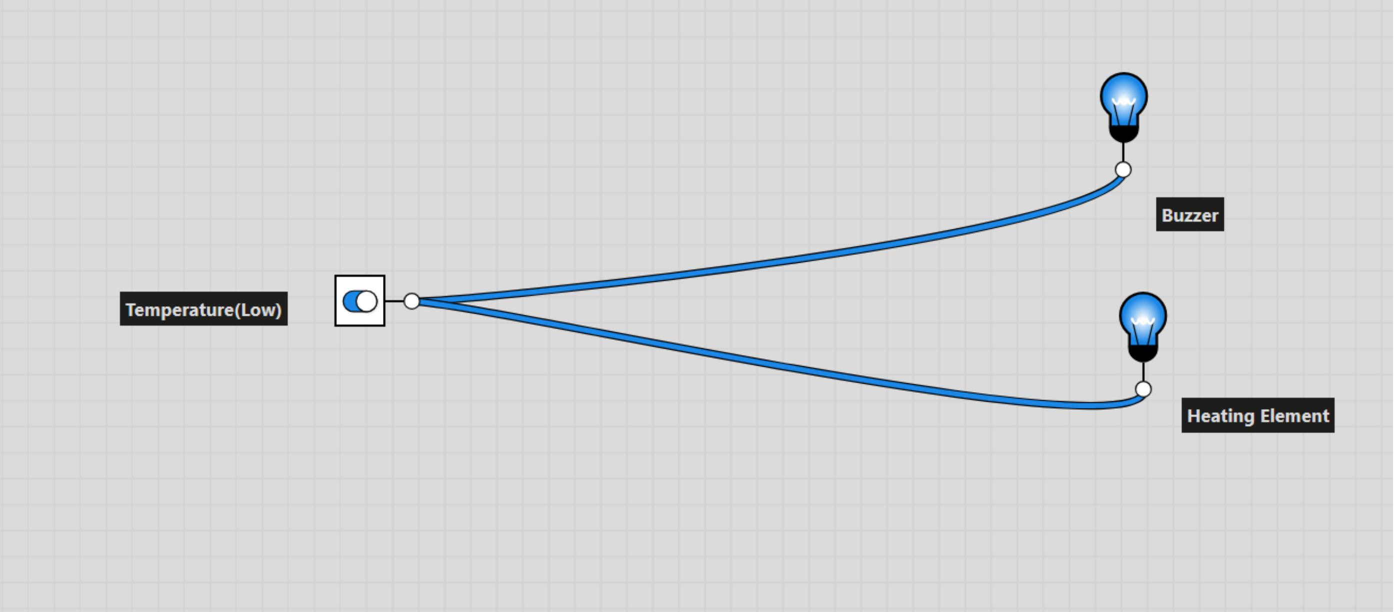


Figure 7:: Circuit Diagram when temperature is low

How it Works:

When the Low-temperature sensor is ON (T Low = 1), the Buzzer will ring continuously and Heating Element will turn ON.

When the Low-temperature sensor is OFF (T Low = 0), the Buzzer will stay silent and Heating Element will turn OFF.

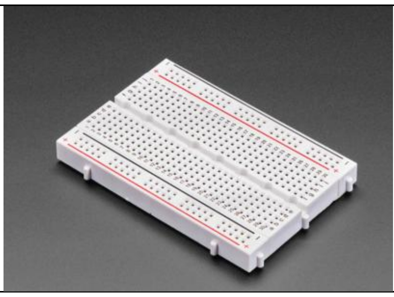
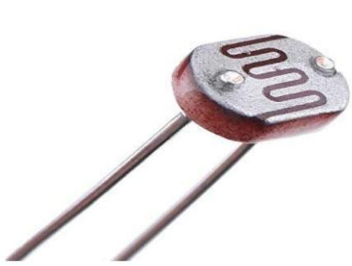
Note: Based on the prototype, every output (Buzzer, Heater, Light, etc.) depends on only a single input, which is why the circuits have been simple direct connections.

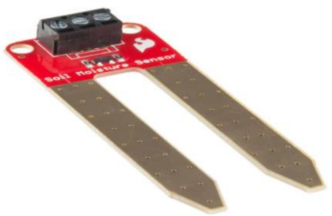
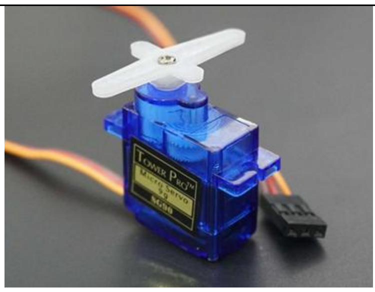
E. Softwares Used For 'The High-Altitude Hero' Prototype

Research And Analysis	
1.	Google Scholar
2.	Google Notebook LM
3.	Elsevier
4.	Research Gate
5.	W3schools
Designing and Blueprint	
1.	Draw.io
2.	Canvas
3.	Logic.ly
Simulation and Testing	
1.	TinkerCad
Programming and Tools	
1.	Aurdino IDE
2.	C++
Writing Article	
1.	M.S Word
2.	Zotero
3.	Grammarly

Table 4: Softwares Used

F. Hardware Required to develop the Prototype

S.N	Picture	Name	Quantity used	Function
1.		Microcontroller	1 x Arduino Uno R3	Monitoring, deciding, and controlling the entire system automatically.
2.		Breadboard	1 x Breadboard Small	Makes it easy to build, test, and power the entire smart greenhouse system in a clean and modular way.
3.		Temperature Sensor	1 x Temperature Sensor [TMP36]	To monitor temperature and react automatically to protect plants from cold or frost.
4.		Photoresistor	1 x Photoresistor (LDR)	To monitor sunlight and automatically turn on grow lights when there isn't enough natural light.

5.		Soil Moisture Sensor	1 x Soil Moisture Sensor	To monitor soil dryness and automatically water the plants when needed.
6.		Micro Servo	1 x Micro Servo	To automatically manage ventilation, helping to keep the greenhouse climate stable.
7.		DC Motor	1 x DC Motor	To automate irrigation system, turning on to pump water when the soil gets too dry.
8.		Piezo Buzzer	1 x Piezo Buzzer	To provide an audible frost alert, helping protect crops from cold damage.
9.		LEDs	2 x LEDs	To give clear visual feedback about the status of heating and grow lights in the greenhouse.

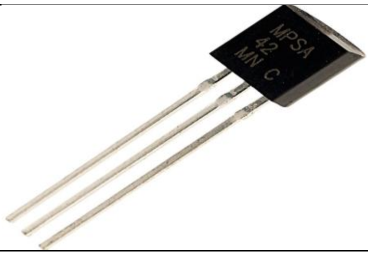
10.		Relay SPDT	1 x Relay SPDT	To safely control the grow lights, simulating real-world switching of high-voltage or high-current equipment.
11.		LCD	1 x LCD 16x2	To display live sensor data and alerts, helping users keep track of the greenhouse environment easily.
12.		Resistor	4 x Resistor	To control current and voltage to protect components and enable accurate sensor readings in the circuit.
13.		Potentiometer	1 x Potentiometer	To help make the LCD easy to read by controlling its contrast.
14.		Diode	1 x Diode	To safeguards your electronics by absorbing harmful voltage spikes from the motor.
15.		NPN Transistor	1 x NPN Transistor	To act as an electronic switch that lets the Arduino safely control the water pump.

Table 5:Hardwares used

G. Final Design Of 'The High- Altitude Hero' Prototype

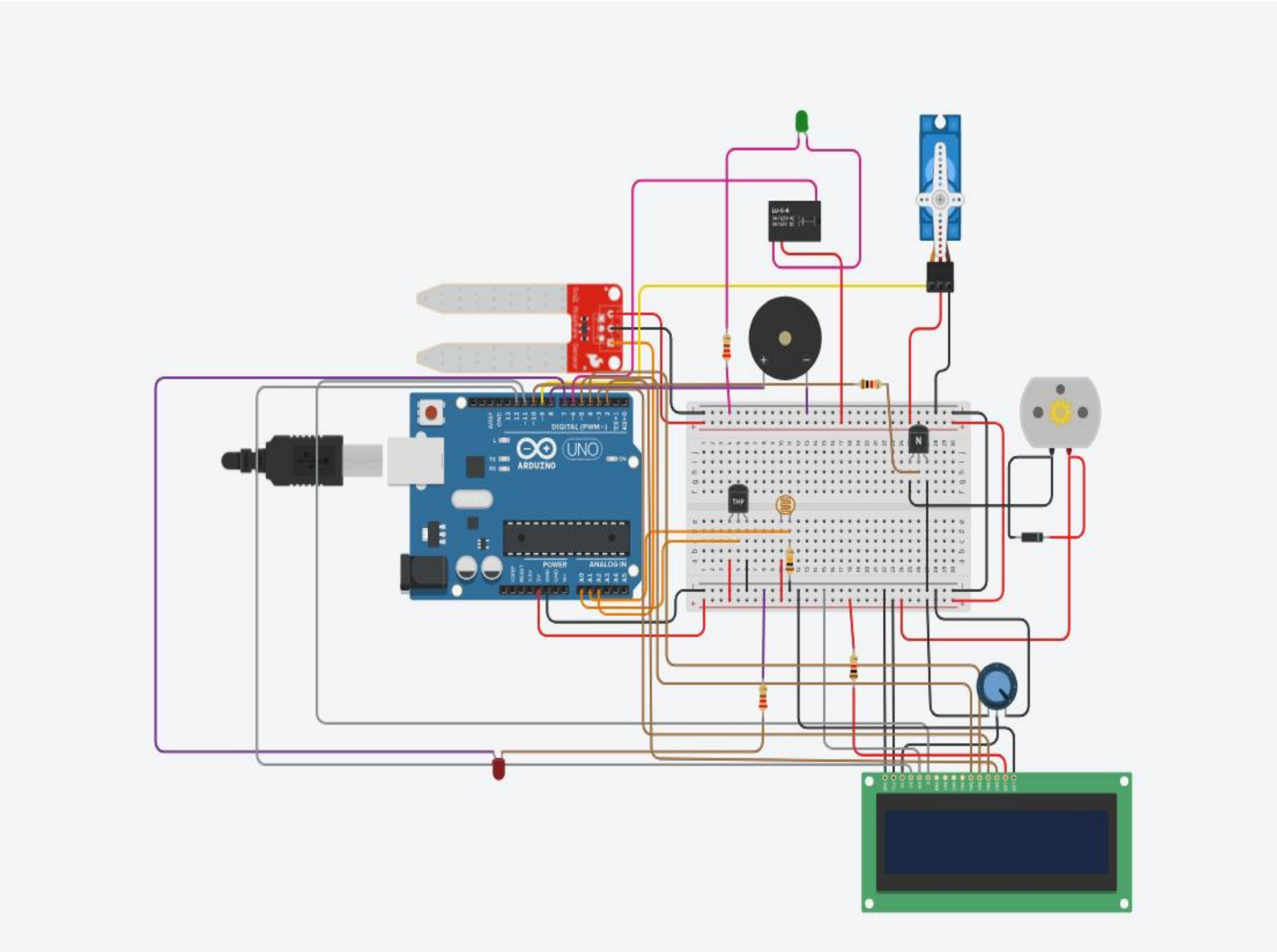


Figure 8:View of prototype

H. Schematic View Of the Prototype

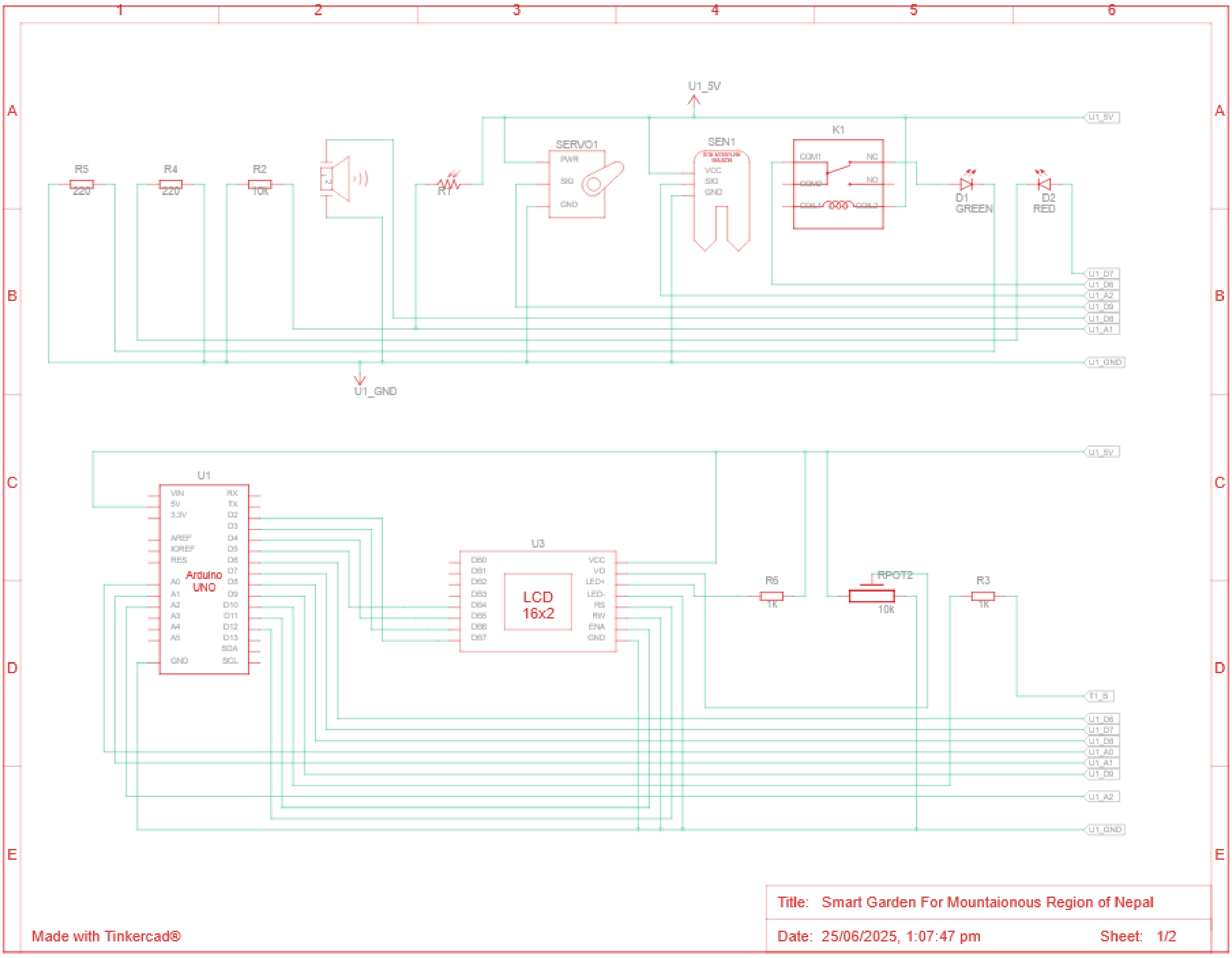


Figure 9:schematic view1

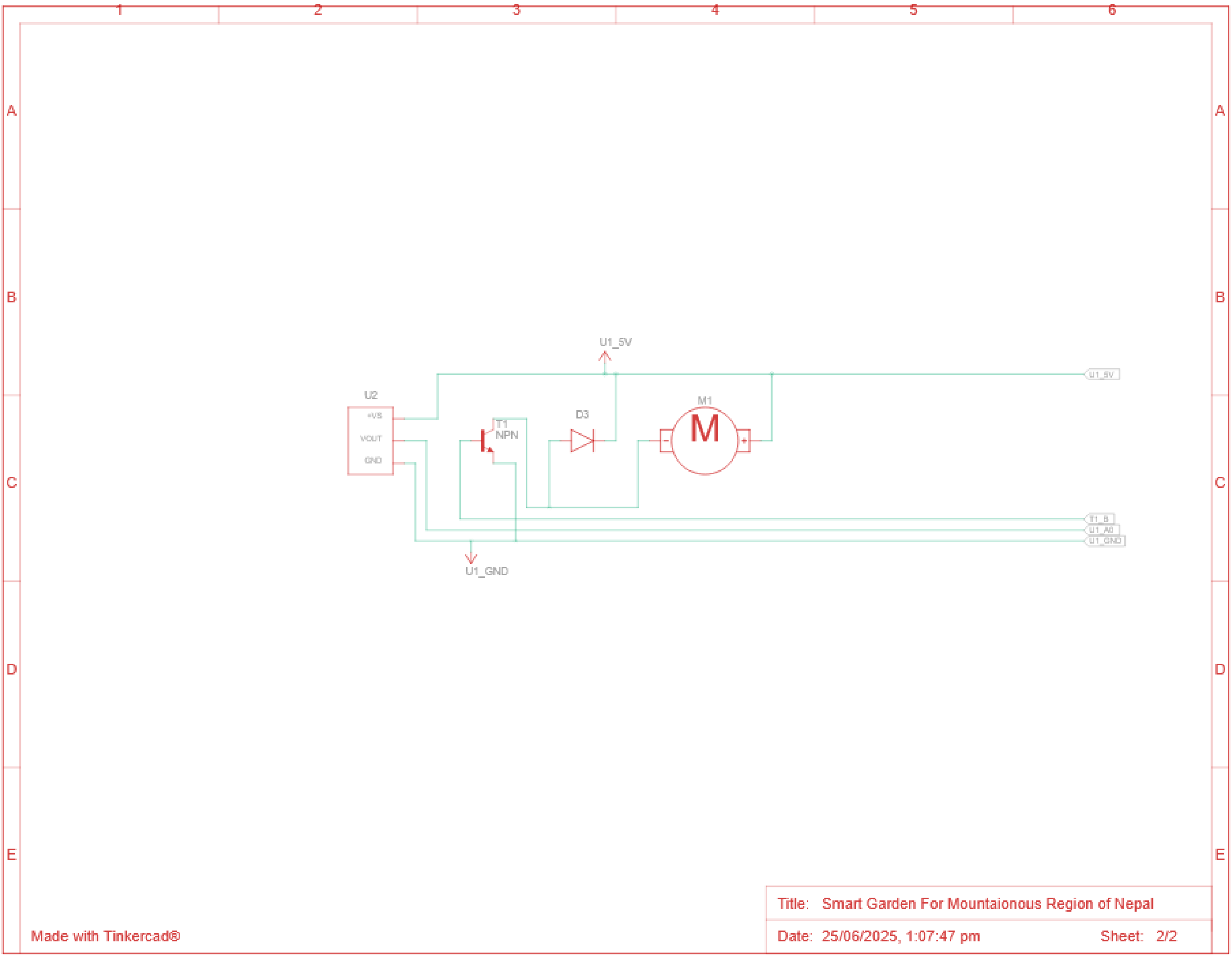


Figure 10:schematic view2

I. Componenets List

Name	Quantity	Component
U1	1	Arduino Uno R3
U2	1	Temperature Sensor [TMP36]
R1	1	Photoresistor
SEN1	1	Soil Moisture Sensor
SERVO1	1	Positional Micro Servo
M1	1	DC Motor
PIEZO1	1	Piezo
D1	1	Green LED
D2	1	Red LED
K1	1	Relay SPDT
R2	1	10 kΩ Resistor
R3 R6	2	1 kΩ Resistor
R4 R5	2	220 Ω Resistor
D3	1	Diode
T1	1	NPN Transistor (BJT)
U3	1	LCD 16 x 2
Rpot2	1	10 kΩ Potentiometer

Figure 11: components

J. Code of prototype

```
#include <LiquidCrystal.h> // For the LCD screen
#include <Servo.h>         // For the Servo motor

// PIN DEFINITIONS
// Sensors
const int tempPin = A0;
const int ldrPin = A1;
const int soilPin = A2;

// Actuators
const int servoPin = 9;
const int buzzerPin = 8;
const int heaterLEDPin = 7;
const int pumpPin = 10;
const int growLightRelayPin = 6;

// LCD Pins
const int rs = 12, en = 11, d4 = 5, d5 = 4, d6 = 3, d7 = 2;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);
Servo ventServo;

// THRESHOLDS
const float frostThreshold = 4.0;     // (Celsius) Below this, turn on frost alarm/heater
const float highTempThreshold = 30.0; // (Celsius) Above this, open the vent
const int lowLightThreshold = 300;    // (Analog value) Below this, turn on grow lights
const int drySoilThreshold                    = 400;     // (Analog value) Below this, turn on the water pump

void setup() {
  // Initialize Serial Monitor for debugging
  Serial.begin(9600);

  // Initialize LCD
  lcd.begin(16, 2);
  lcd.print("Smart Greenhouse");
  lcd.setCursor(0, 1);
  lcd.print("Initializing...");

  // Initialize Servo
  ventServo.attach(servoPin);
  ventServo.write(0); // Start with the vent closed

  // Set pin modes for all output devices
  pinMode(buzzerPin, OUTPUT);
  pinMode(heaterLEDPin, OUTPUT);
  pinMode(pumpPin, OUTPUT);
  pinMode(growLightRelayPin, OUTPUT);

  // Set initial state of outputs to OFF
  digitalWrite(heaterLEDPin, LOW);
  digitalWrite(pumpPin, LOW);
  digitalWrite(growLightRelayPin, LOW); // LOW for relay might mean ON or OFF depending on wiring. Adjust if needed.

  delay(2000); // Wait for 2 seconds
```

```
  lcd.clear();
}

void loop() {
  //  1. READ SENSOR DATA

  // Read Temperature (TMP36) and convert to Celsius
  int tempReading = analogRead(tempPin);
  float voltage = tempReading * 5.0 / 1024.0;
  float temperatureC = (voltage - 0.5) * 100;

  // Read Light Level (LDR)
  int lightLevel = analogRead(ldrPin);

  // Read Soil Moisture
  int soilMoisture = analogRead(soilPin);

  // Print values to Serial Monitor for debugging
  Serial.print("Temp: "); Serial.print(temperatureC); Serial.print(" C, ");
  Serial.print("Light: "); Serial.print(lightLevel); Serial.print(", ");
  Serial.print("Soil: "); Serial.println(soilMoisture);

  //  2. IMPLEMENT CONTROL LOGIC

  // Frost Protection Logic
  if (temperatureC < frostThreshold) {
    digitalWrite(heaterLEDPin, HIGH); // Turn on heater indicator
    digitalWrite(buzzerPin, HIGH);    // Sound the alarm
  } else {
    digitalWrite(heaterLEDPin, LOW); // Turn off heater
    digitalWrite(buzzerPin, LOW);     // Turn off alarm
  }

  // Ventilation Logic
  if (temperatureC > highTempThreshold) {
    ventServo.write(90); // Open vent to 90 degrees
  } else {
    ventServo.write(0); // Close vent
  }

  // Grow Light Logic
  if (lightLevel < lowLightThreshold) {
    digitalWrite(growLightRelayPin, HIGH); // Turn on grow lights
  } else {
    digitalWrite(growLightRelayPin, LOW); // Turn them off
  }

  // Irrigation Logic
  if (soilMoisture < drySoilThreshold) {
    digitalWrite(pumpPin, HIGH); // Turn on water pump
  } else {
    digitalWrite(pumpPin, LOW); // Turn it off
  }

  // --- 3. UPDATE LCD DISPLAY ---
  lcd.clear();
  // Line 1: Temperature and Light
```

```
  lcd.setCursor(0, 0);
  lcd.print("T:");
  lcd.print(temperatureC, 1); // Print temp with 1 decimal place
  lcd.print("C L:");
  lcd.print(lightLevel);

  // Line 2: Soil Moisture and System Status
  lcd.setCursor(0, 1);
  lcd.print("Soil:");
  lcd.print(soilMoisture);
  lcd.setCursor(11, 1);

  // Display status of actuators
  if (digitalRead(pumpPin) == HIGH) lcd.print("PUMP");
  else if (digitalRead(growLightRelayPin) == HIGH) lcd.print("LITE");
  else if (ventServo.read() > 10) lcd.print("VENT");
  else if (digitalRead(heaterLEDPin) == HIGH) lcd.print("HEAT");
  else lcd.print("OK");


  // Wait for a second before the next loop
  delay(1000);
}
```

V. Simulation With Results and discussion

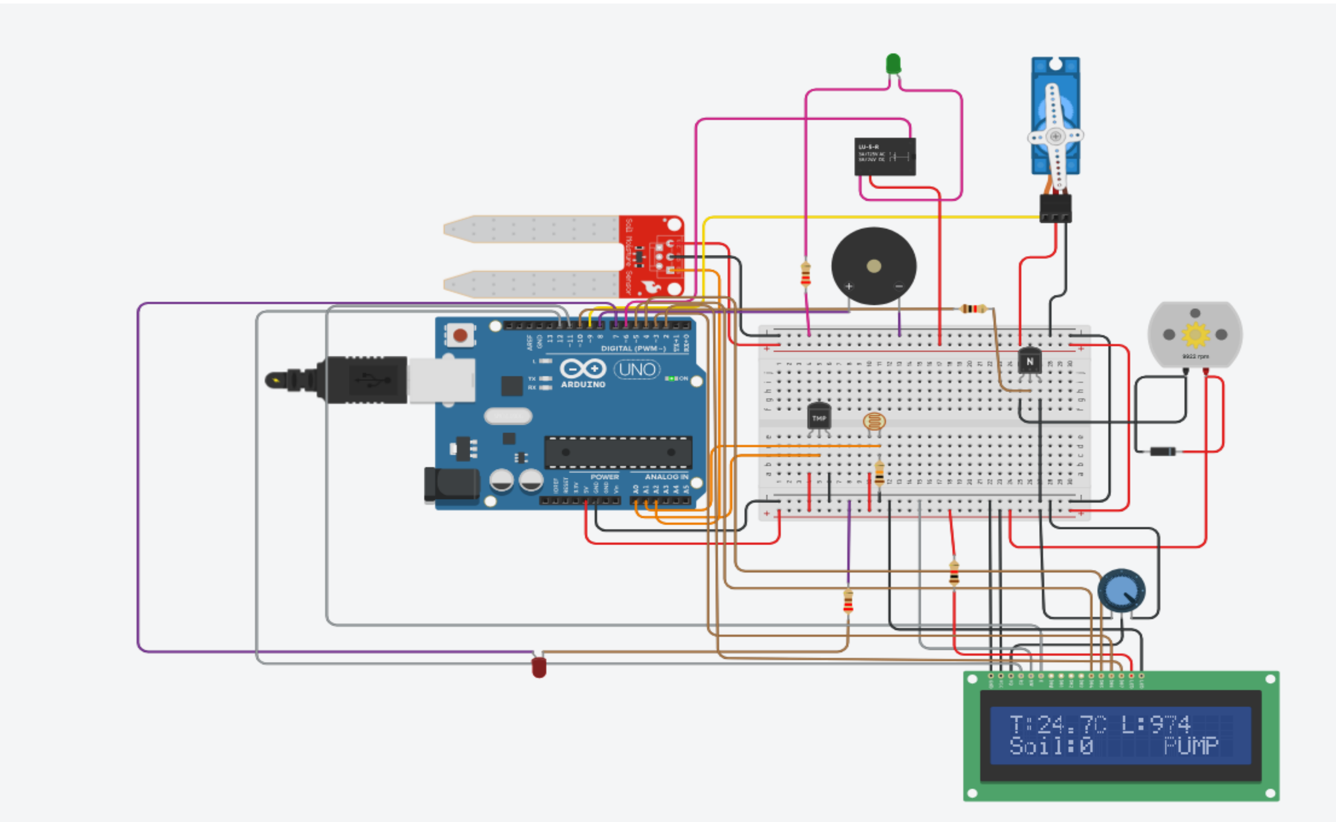


Figure 12:Moisture low

A. Simulation 1:Soil Moisture Low

- The soil moisture sensor outputs a low analog value to Arduino pin A2.
- The Arduino compares the reading to a predefined dryness threshold in the code.
- If the soil is too dry, the Arduino activates the DC motor (simulating a water pump) via digital pin 10.
- The signal from the Arduino turns on the NPN transistor, allowing current to flow through the DC motor.
- The DC motor runs, watering the plants automatically.
- A message like "PUMP" may appear on the LCD.

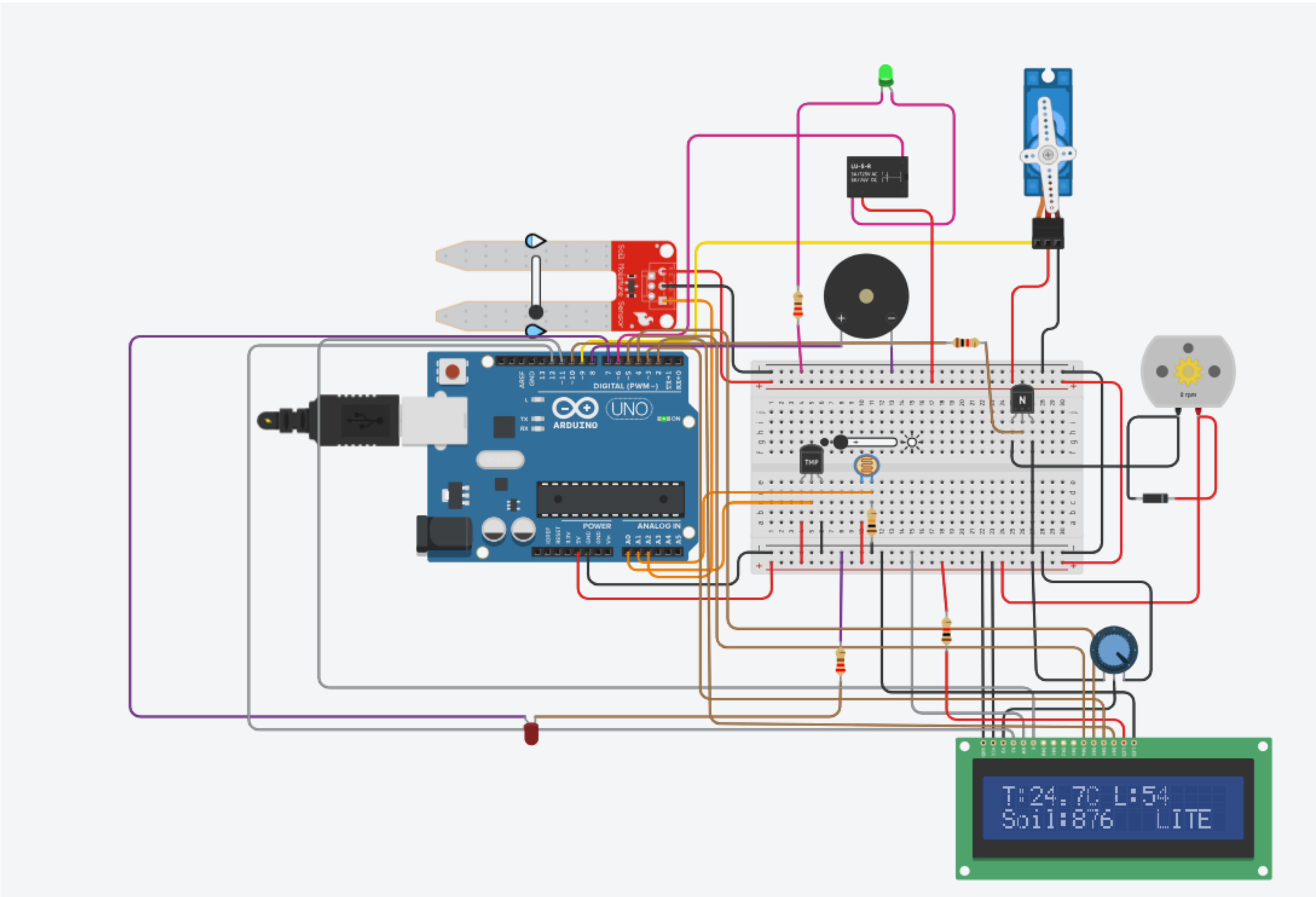


Figure 13:Light Low

B. Simulation 2: When the Light is too low

- The LDR (photoresistor) senses a drop in light intensity and sends a higher analog voltage (due to the voltage divider) to Arduino pin A1.

- The Arduino compares the light value to a minimum **light threshold** set in the code.
- If the light level is below the threshold, the Arduino **activates the** grow lights via digital pin 6.
- The Arduino energizes the relay coil, which simulates switching on an external light source (represented by the green LED).
- The green LED turns ON, showing that the grow lights are active.
- A message like "LITE" may appear on the LCD display.

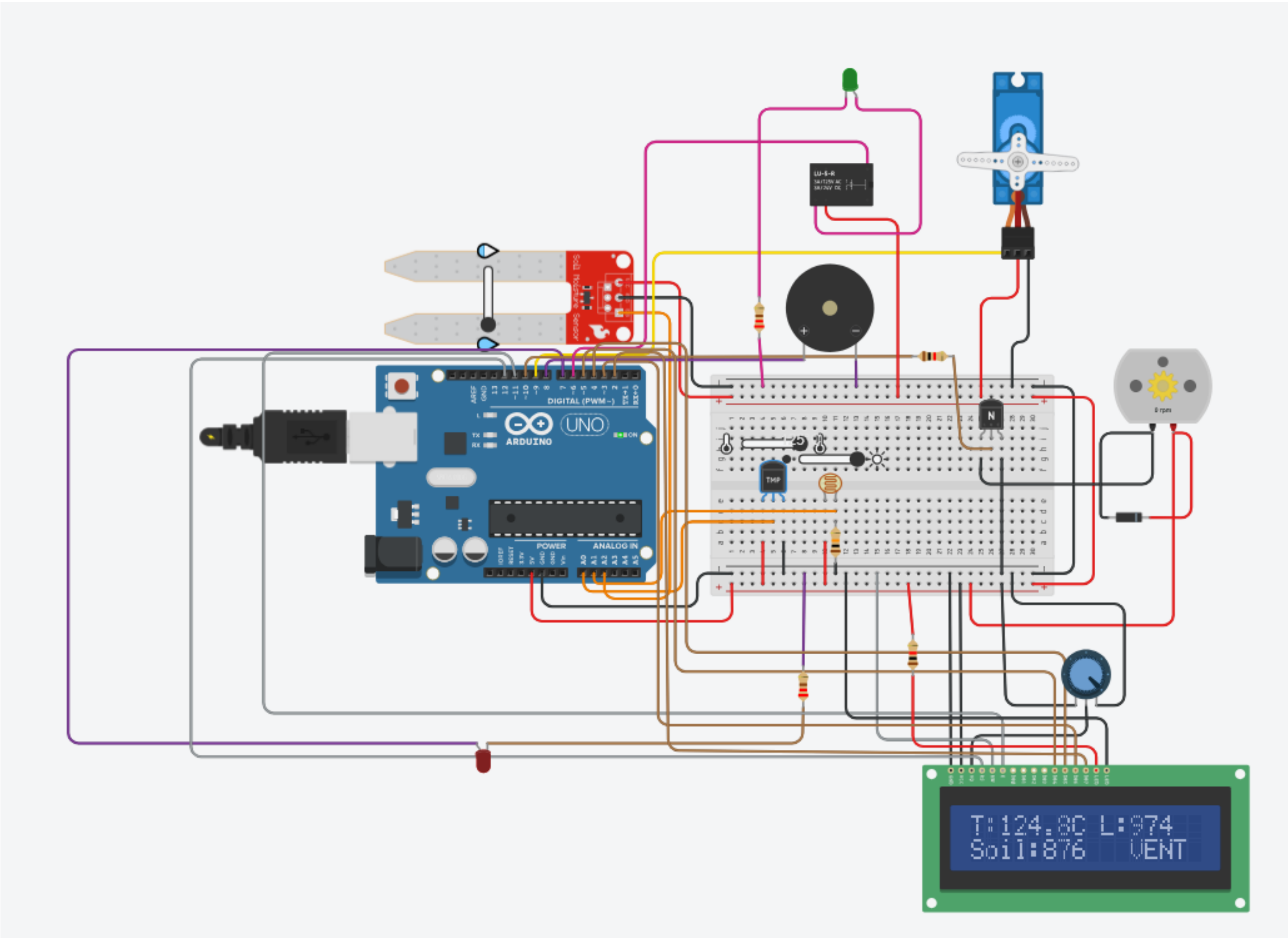


Figure 14:temperature High

C. Simulation 3: When Temperature is High

- The temperature sensor (TMP36) outputs a higher analog voltage to Arduino pin A0 as the temperature rises.
- The Arduino converts the analog reading into a temperature value in °C and compares it to a set upper threshold (e.g., 30°C).

- If the temperature exceeds the threshold, the Arduino activates the servo motor (connected to pin ~9) to open the greenhouse vents.
- The servo motor adjusts to a set angle (e.g., 90°) to simulate vent opening, allowing heat to escape and fresh air to circulate.
- A message like “Vent ” may appear on the LCD.

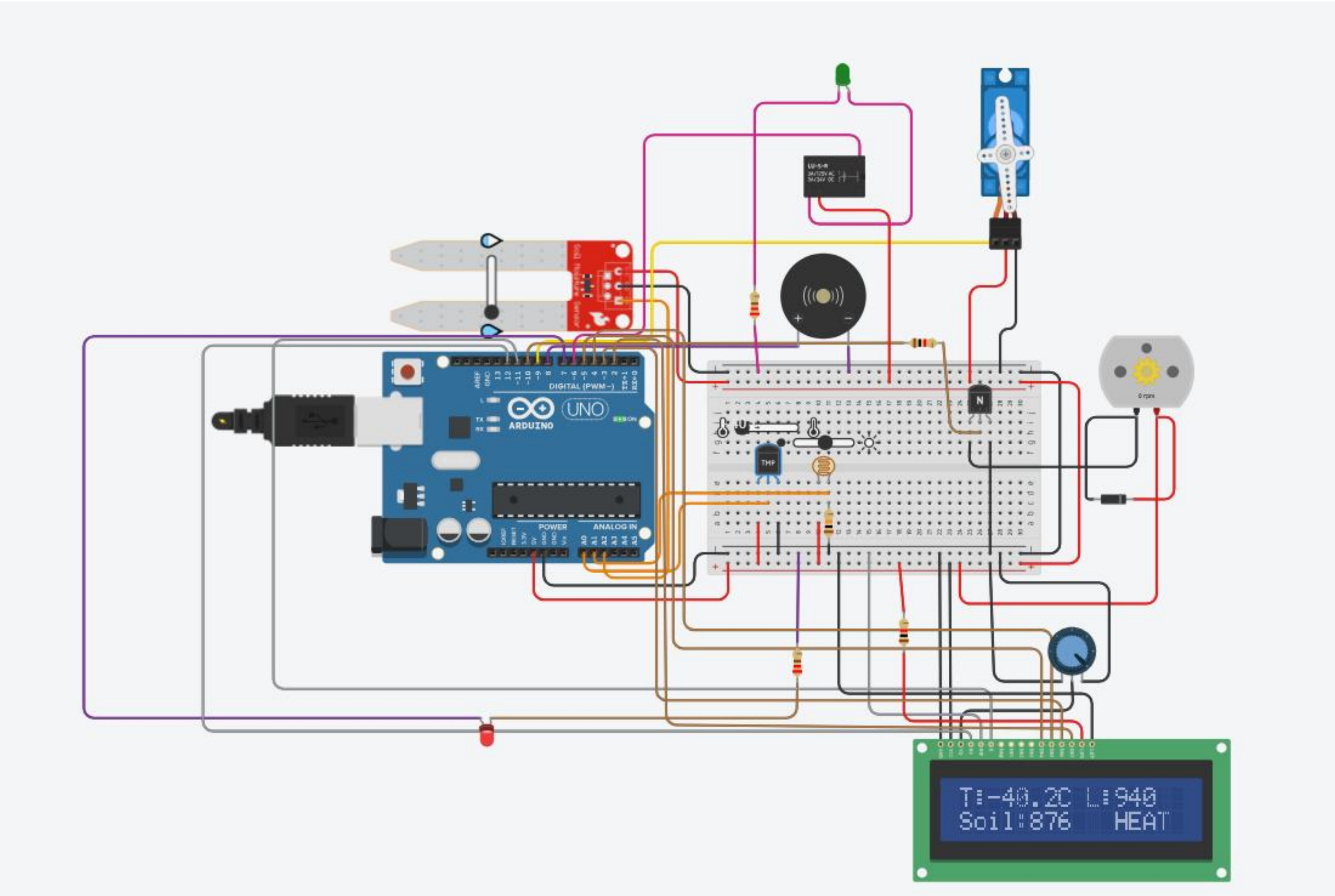


Figure 15:Temperature low

D. Simulation4: When Temperature is Low

- The TMP36 outputs a lower analog voltage to Arduino pin A0 as the temperature drops.
- The Arduino converts the analog signal into a °C value and compares it to a low-temperature threshold (e.g., below 5°C or a frost warning level).
- The red LED (connected to pin 7) activates to indicate the heating element is ON.
- The piezo buzzer (connected to pin 8)activates to sound a frost alert.
- A message like “HEAT” may be shown on the LCDx

VI. Conclusion

The "High-Altitude Hero" Smart Greenhouse prototype demonstrates the foundational principles of agricultural automation while highlighting the immense potential for technological advancement in this field. This comprehensive analysis of the Arduino-based system has revealed the transformative potential of smart greenhouse technology while highlighting critical considerations for future implementation. This prototype is effective in proving the major concepts of autonomous environmental regulation by means of its outline of sensing temperature, brightness of light as well as the degree of soil moisture. The implementation of Boolean logic offers a sound basis of making decisions, where actuator-to-sensor interrelationships are direct thus guaranteeing the sound implementation of the system. A combination of various sensors with a number of different actuators produces a unified ecosystem that covers the main prerequisites of controlling a greenhouse: climatic regulation, automation of irrigations, and environmental condition monitoring.

The future of smart greenhouse systems lies in the integration of cutting-edge technologies that extend far beyond the scope of this prototype. Future research needs to be directed toward the development of integrated security frameworks designed specifically for agricultural IoT systems, the advancement of predictive machine learning algorithms for greenhouse management, and the exploration of sustainable energy integration, including renewables and energy storage(Maraveas et al., 2023). Special consideration should be paid to Network Security because greenhouse networks are distributed. Steadfast frameworks should identify and avert several forms of attack such as taping, tampering, replay and denial of service attacks

With the rise of greenhouse systems to use artificial intelligence, edge computing, computer vision, blockchain, they can be more sophisticated and be able to solve complex farming issues. The effective implementation of these advanced systems however should look at cybersecurity issues and implement extensive security structures that will override the existing threats. The future is in the smooth combination of new solutions and complete protection of smart greenhouse technology so that we can be able to create sustainable and resilient farming systems in creating food production systems needed to satisfy the world food demands but at the same time being environmental stewards and ensuring the security of the operations.

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