Greenhouse Soil and Irrigation Monitoring System

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Habiba Khaled- Hana Samir - Nada Reda

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Abstract

The major obstacle Egypt faces in becoming more efficient is managing and utilizing modern technologies to improve humans' life, specifically through the development of an intelligent greenhouse aimed at optimizing crop growth year-round. The project implements Multi-Sensor Integration, allowing for continuous monitoring of essential parameters such as soil moisture linked to a water pump for moisture regulation, light intensity which triggers a buzzer if light level exceeds requirements, temperature monitoring, and air quality sensors that detect CO_2 concentration variations between day and night. The system is designed to provide real-time data updates every 30 seconds to ensure optimal conditions for plants. A Bluetooth terminal interface provides a user-friendly digital platform for non-technical users, and the greenhouse stores data for up to a year through Tera-Term, transferring it to Excel sheets. Alerts notify users when environmental thresholds are breached, enhancing responsiveness. Additionally, the sensors are powered by a battery designed to last a minimum of six months without replacement, supporting sustainability. The battery is supported by renewable energy sources to extend its lifetime. In conclusion, the integration of a soil moisture sensor with a water pump addresses soil dryness and excessive water consumption, contributing to efficiency.

Introduction

Egypt faces major environmental challenges, including improving its scientific and technological environment, reducing climate change effects **(Lindwall, 2022)**, and enhancing its industrial and agricultural base while recycling waste for economic and environmental purposes. This challenge focuses on developing an integrated multi-sensor system for monitoring conditions, providing real-time feedback and alerts, and addressing accessibility concerns. One such project is the "Soil Moisture Monitoring System" which uses IoT and Raspberry Pi technology to automate irrigation processes **(Tan, Gebremariam, Rahman, Salman, & Xu, 2022)** by collecting data from humidity, temperature, and sound sensors. It offers cost reduction, water efficiency, and low maintenance but faces initial setup costs, technical complexity, internet connectivity dependence, sensor limitations, and scalability concerns. Another essential prior solution is "Towards Automated Greenhouse Monitoring" which offers benefits like improved crop growth, resource efficiency, and environmental control **(Li, Guo, Zhao, Wang, & Chow, 2021)**, but also faces challenges like implementation, initial costs, and limited practical application. Overall, Egypt's environmental challenges require a comprehensive approach to address these challenges and promote sustainable development. To avoid the previous disadvantages and provide easy readings to non-technical users, a safe remote monitoring system was developed using Arduino and sensors like soil moisture, light intensity, gas, and temperature. In order to achieve the desired results, certain design requirements were chosen. The first is using Multi-Sensor Integration: soil moisture (Controlling the water pump), light intensity, air quality (specific CO_2), and temperature. The second design requirement involves making the system provide real-time data updates every 30 seconds. The third involves using a Bluetooth terminal to design a user-friendly digital interface that visualizes data for non-technical users. The fourth involves storing the data for at least one year of continuous operation using Excel and Tera Term applications. The fifth involves using an alert mechanism to notify users when thresholds are reached, activated by a buzzer. The sixth involves running the sensors on a battery-powered by a renewable source, which is a solar panel, and operating continuously for at least six months without replacement. Finally, a technical report will explain sensor integration, signal interpretation techniques, and the system's performance in a test environment. The chosen solution addresses Egypt's environmental concerns by constructing a greenhouse for monitoring the soil and plant conditions using eco-friendly materials like palm fronds, which are highly resistant to high temperatures and direct sunlight, thereby regulating temperature. The greenhouse's dome-like form helps distribute heat evenly. The solution will be implemented in Al Minya, Upper Egypt, utilizing the region's fertile soil and favorable climate to enhance crop yields. Overall, the solution will address the selected design requirements and achieve the desired results.

Materials

Table (1): Materials

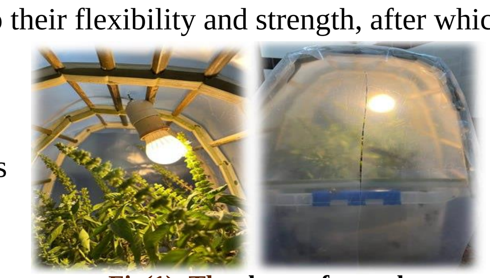
soil moisture	H-Bridge	Solar panel	solar charger	convertor	Arduino board
bread board	water pump	photoresistor	DHT-22	light bulb	lithium-ion battery
MQ-135	Buzzer	Bluetooth module	USB & Wires	Plastic sheet	palm fronds
Total : 1900 L.E.					

Methods

The project methodology consisted of several steps, including the construction of the greenhouse, the installation of sensors, and the implementation of a feedback control system.

- As shown in **Fig (1)**, the base consists of a plastic box used to hold the soil and basil.
- The design of the dome was selected to optimize the distribution of heat within the greenhouse
- Palm fronds were selected as the base of the dome due to their flexibility and strength, after which the dome was covered with plastic sheets, as them.

These material selections were made based on scientific considerations of their specific advantages and properties. Overall, the methodology aimed to create optimal conditions for any plants within the greenhouse, in order to achieve the design requirements successfully.

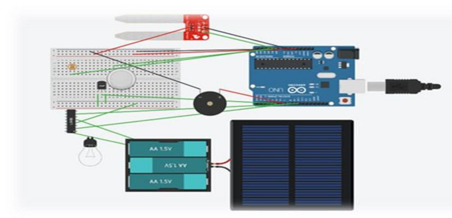


Fig(1): The shape of greenhouse

Feedback control system:

First, the solar panel was connected to its charger then connected to the battery and the converter to elevate the output voltages of the solar panels to 12 volts which will feed the system.

In the feedback control system, multiple sensors were utilized as shown in **Fig (2)**, including a temperature sensor (DHT22), light intensity sensor (photoresistor sensor), soil moisture, air quality sensor (MQ-135), connected to specific pins on the Arduino UNO and breadboard. When the measured intensity reached the specified threshold, the buzzer activated to provide an alert. An H-bridge was utilized to interface with the water pump, which controls the irrigation of the soil when the moisture increases. The whole system was linked to the smartphone through a serial Bluetooth terminal mobile application for the continuous monitoring of the recordings. To save these historical data there was a connection between the system and tera term application to represent these data in simple form via Excel Sheet.



Fig(2): sensors connections

Test plan:

The performance and effectiveness of the prototype, that's includes the Soil Moisture sensor with water pump action, MQ-135 gas sensor, light intensity sensor and its action buzzer, and DHT 22, are all tested under conditions and are clearly displayed in the **Table (2)**.

Table (2): sensors and way of testing them

Type of sensor	Way of testing
MQ-135	▪ To assess the sensor by concentrating on the variations in the CO_2 concentration readings between day and night.
Light intensity	▪ Link the light intensity sensor to a buzzer and switch it on or off according to the threshold to evaluate its functionality.
Soil moisture	▪ By placing the soil moisture sensor in the soil, to verify its performance. The water pump will then operate automatically based on the threshold.
DHT22	▪ To test DHT 22's accuracy, turn on and off the lightbulb that controls the greenhouse's temperature.

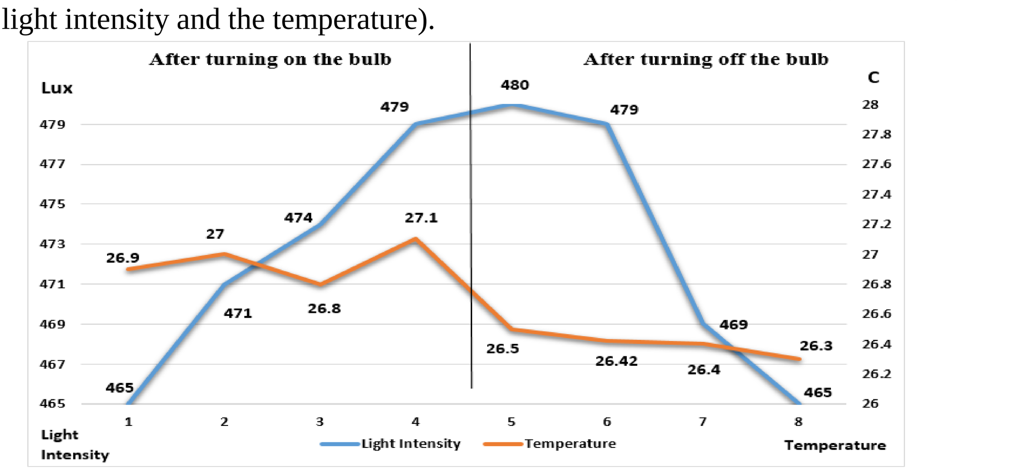
Results

By finishing the construction of the greenhouse, testing the connections of the sensors and the overall software, and hardware circuits through a series of organized steps; successful results were obtained as shown in **Table (3)**.

Table (3): conditions and actions of the sensor

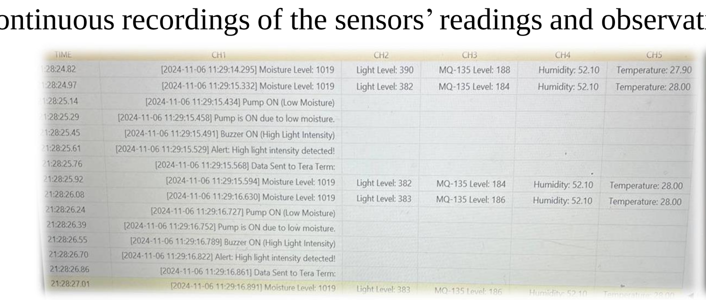
The condition	Action
Soil moisture value > 200	▪ Water pump will be turned on.
Soil moisture value < 200	▪ Water pump will be turned off **(No action will be taken).**
light intensity value > 250	▪ Buzzer will be turned on as an alert (which is considered one of the design requirements).
light intensity < 250	▪ Buzzer will be turned off **(No action will be taken).**

As shown in **Fig (3)** these are several readings of the light intensity and temperature sensors after and before turning on the bulb (the x-axis represents the definite number of readings and the y-axis represents the light intensity and the temperature).

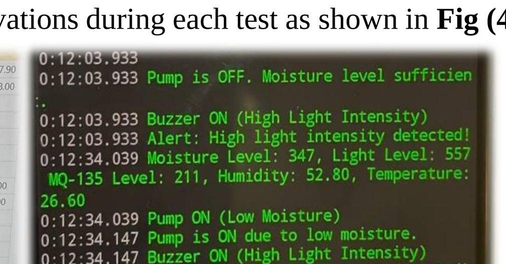


Fig(3): readings of temperature and light sensors before and after turning on the bulb

For easy, simple access and monitoring of the greenhouse and the soil, the system was connected to a smartphone mobile application which is: **Serial Bluetooth Terminal** using Bluetooth module for continuous recordings of the sensors' readings and observations during each test as shown in **Fig (4)**.



Fig(5): saved data and readings



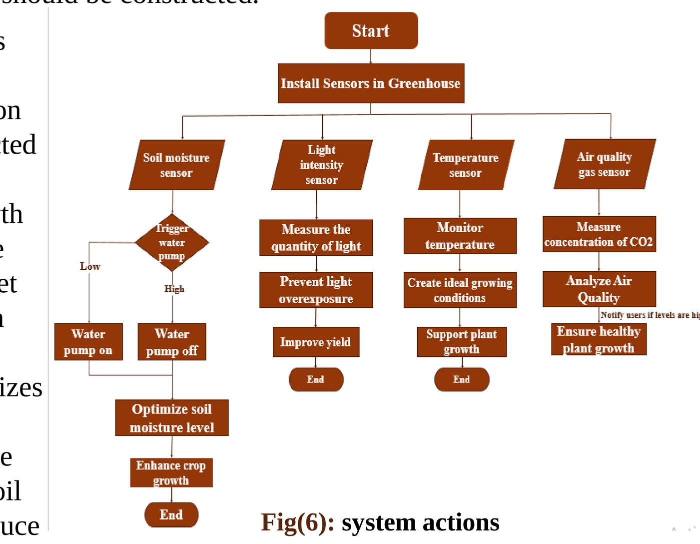
Fig(4): data in serial Bluetooth terminal

The data is supposed to be shown continuously every 30 seconds and is saved automatically in **Tera-Term application**, achieved one of the desired design requirements which is storing the data of the system for at least one year of continuous operation. The data was presented in an Excel sheet as shown in **Fig (5)** to facilitate the readings for the non-technical users.

Analysis

Egypt is currently facing an extremely difficult mission, figuring out how to use new technology and modern development methods that can both help in our daily lives, this semester's main concerns are reducing pollution, combating climate change, strengthening Egypt's economic and agricultural bases, and enhancing the environment for everyone who uses science and technology. To deal with these major issues, an autonomously intelligent building should be constructed.

The solution involves a greenhouse, which is divided into two main components: the feedback system and the building construction method. Extensive research has been conducted greenhouse that supports the cultivation of various annual crops requiring specific growth climates. The prototype features a base made from a plastic box connected to a plastic sheet with a palm leaves dome, chosen to maintain internal temperatures unaffected by external weather conditions, the feedback system utilizes multiple sensors to meet the initial design requirements. The first sensor, a soil moisture sensor to regulate moisture and dryness of soil with a connected water pump, helping to reduce water consumption. The second sensor, a light intensity sensor regulates the level of light that plants need with the alert buzzer if the intensity is higher than the threshold. The third sensor, a temperature sensor, measures the internal temperature generated by the light bulb, while the fourth, an air quality gas sensor, monitors carbon dioxide emissions from plants day and night, tracking concentration changes as shown in **Fig (6)**. To satisfy the second design requirement, the system's batteries must last at least six months without replacement. This project is powered by renewable energy to extend battery life through silicon solar panels, which absorb sunlight and convert it to energy, in accordance with the law of conservation of energy **(CH.3.01)**: "Energy can neither be created nor destroyed but only converted from one form to another." The efficiency of solar panels varies throughout the day, being lower in the morning, peaking at midday, and decreasing in the afternoon due to factors like the sun's angle and position. These variations must be considered in the efficiency of the design of solar energy systems for optimal performance. Lithium-ion batteries typically offer around 6000 cycles, meaning they can be discharged and recharged 6000 times before experiencing significant degradation. A "cycle" refers to discharging the battery and recharging it. The remaining capacity of a battery, often referred to as the "aging index," indicates how much usable power is left. For calculating the life of the battery for this system the battery will have 2 cycles per day so dividing the whole cycles over the cycle per day $\frac{6000\ cycles\ for\ battery}{2\ cycles\ per\ day}$ = **3000 cycles (means 3000 days)**, then to know the time it will stay before damaging or replacing $\frac{3000}{365\ days/year} = \mathbf{8.21}$ **years**, so achieving the design requirement of using the same battery for at least 6 months due to the cycles consumed on the 6 months which calculated using this rule: $\mathbf{2\ (cycles\ per\ day) \times (6\ months\ \times 30\ days\ in\ month)}$ = **360 cycles per 6 months**, which indicate that the lithium-ion battery was the better type for this project. Battery efficiency is a crucial factor in supplying power to the system. Most lithium-ion batteries have an efficiency rate of 95% or higher. Once the prototype is completed, data will be collected continuously for at least a year, with updates every 30 seconds to meet additional design requirements. This data will be transmitted via the Tera-Term application, which automatically saves it in an Excel sheet and generates graphs to create a user-friendly digital interface for non-technical users.



Fig(6): system actions

After implementing the feedback system, the following results were observed:

Positive Results:

- Both the hardware and software of the greenhouse project were tested and successfully met design requirements, with all components, including sensors and actions, functioning as expected.
- The water pump activates to reduce soil moisture when necessary.
- The light bulb provides heat and light to support greenhouse conditions.
- Heat is efficiently preserved inside the building by plastic sheets.
- Data is organized in an Excel sheet with graphs, creating an accessible digital interface.

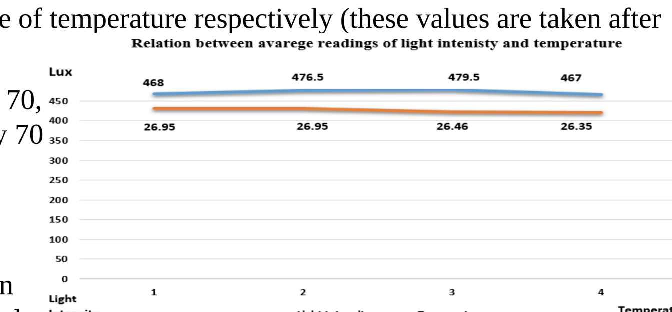
Negative Results:

- The efficiency of solar PV decreases with temperature increases, dropping by 0.4% to 0.5% for each degree Celsius above 25 °C.
- The Bluetooth module has limited range, only transmitting notifications within the building, and is not suitable for sensor readings over distances of 10 meters.
- To overcome the difficulty of solar panels which operate on 5 volts, that are able to recharge only one 4-volt lithium-ion battery at a time, a converter was connected to the solar panel in order to increase the voltages that the panel emits to the batteries.

While working on the system and testing it, the precision **(Zumdahl, S. S., & Zumdahl, S. A., 2014, p. 12-13)** and the rate of change were put into consideration to achieve and reach an efficient result. Accordingly, three trials were conducted to compare the readings of the temperature sensor and the light intensity sensor and calculate the difference between their readings.

Using **(MA.2.07)**, the average rate of change was calculated using this formula: $y4 - y1\ / x4 - x1$ = 479-465 / 27.1-26.9 = 70, as $y4$ and $y1$ represent the final and initial value of light intensity respectively and $x4$ and $x1$ represent the final and initial value of temperature respectively (these values are taken after turning on the bulb).

The value of the rate of change obtained was 70, meaning that as the light intensity changes by 70 lux, the temperature changes by 1 degree Celsius, as shown in **Fig (7)**.



Fig(7): relation between average readings of light and temperature sensors

Applying **(CH.3.01)**, several readings of the sensors show that the precision value between 472 and 473, is calculated by using this formula: (the total of the measured values / the number of these values). It indicates that the reading values are close to each other. **(MA.1.02)** was used in calculating the average "mean" of a group of values using this formula: $\mathbf{sum\ of\ values\ /their\ number}$ = 479+474+471+465 / 4 = 472.25, it used also while calculating the precision.

Table (4): Learning outcomes

(MA .2.07)	Calculating the average rate of change.
(CH.3.01)	Know the precision value in the system, which indicates that the readings values are close to each other.
(MA.1.02)	Used in calculating the average "mean" of a group of values using this formula: $sum\ of\ values\ /their\ number$.
(PH.3.02)	There are various types of waves, including light, which is classified as a transverse wave. This type of wave does not require a medium for propagation, allowing it to travel through the vacuum of space at high velocities. The light emitted from a bulb serves as an example of such a wave.
(BI.3.03)	Thermoreceptors which are specialized sensory receptors that detect variations in temperature, both heat and cold. Similarly, in our project, a temperature sensor functions analogously to a thermoreceptor, effectively detecting and measuring heat.

Conclusion

After testing the prototype, we concluded that employing the soil moisture sensor in conjunction with the water pump is crucial for addressing the challenges of excessive water consumption and dry soil conditions. We also observed a direct relationship between the temperature and light intensity sensors, which is vital for optimizing plant growth. The system is designed to provide real-time data updates every 30 seconds, allowing for timely adjustments to maintain optimal growing conditions. A Bluetooth terminal creates an intuitive digital interface that visually presents data, making it accessible for non-technical users and enhancing user experience. Additionally, the system can store data for a minimum of one year of continuous operation, utilizing the Tera-Term application for efficient data transfer to Excel sheets. Sustainability is further promoted by the battery, which is engineered to operate for at least six months without replacement and is supplemented by renewable energy sources to extend its lifetime.

Recommendations

1. Use electric conductivity sensors to accurately measure soil nutrient levels, enhancing understanding of nutrient availability for optimal plant growth.
2. Incorporate pesticide sensors to determine the suitable soil concentration for effective pest control while minimizing environmental impact.
3. Integrate movable solar panels to maximize sunlight collection, improving energy efficiency and output in solar systems.
4. Adopt Bi-Directional Logic Converters for large-scale applications to facilitate communication between different logic levels in complex systems.
5. Utilize pH meters to assess soil acidity, aiding in the selection of appropriate plants for better growth and yield.

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Further Information

Habiba Khaled
habiba.2222545@stemsharkya.moe.edu.eg
Hana Samir
hana.2222539@stemsharkya.moe.edu.eg
Nada Reda
nada.2222516@stemsharkya.moe.edu.eg