Solar-Powered Peltier ThermoelectricWater Cooling and PH Monitoring

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Abstract – *This project focuses on the development of a solar-powered system for water cooling and pH monitoring using Peltier thermoelectric technology, specifically tailored for hydroponic applications. The system aims to maintain optimal water temperature and pH levels, which are critical for plant growth in hydroponics—ideally keeping water temperature below 29°C and pH levels between 5.5 and 6.5. The system design involves the integration of solar panels, Peltier modules, and sensors to achieve the desired cooling and monitoring functions. Simulation and hardware testing were conducted to validate the system's performance. Results showed that the system effectively maintained water temperature below 29°C and pH levels between 5.5 and 6.5, indicating its potential to support optimal conditions for hydroponic systems, which could contribute to improved crop management and resource efficiency. This research highlights the feasibility of using solar power as a renewable energy source for agricultural applications and demonstrates its potential as a sustainable approach to enhancing farming practices.*

Keywords: *Peltier Thermoelectric Cooling, pH Monitoring, Renewable Energy, Solar-Powered Systems, Water Cooling*

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I. Introduction

Urban agriculture is the cultivation of plants and animals in the urban environment for production of food crops. It encompasses several activities including neighborhood gardening, rooftop gardening, vertical farming, and other advancements for instance hydroponics. Some of the advantages of urban farming include the availability and consumption of fresh foods, enhanced food security alimentary, likelihood of interaction and development of communities as well as economic chances for growth. However, it also came with some issues like space and soil issues and some legislation issues that are fundamental. Nevertheless, urban agriculture, as an innovative and effective method to fight food deserts and improve stewardship in the city, is staking its place. [1].

Water management plays a strong role in urban agriculture, especially given the fact that most urban areas are facing water rationing. There are several ways of under-reducing water use in urban farming including the use of drip irrigation systems and rainwater harvesting. Further, instead of the nutrient-soil mix, hydroponics employ the use of nutrient-infused water to minimize water wastage. All these methods of fighting water usage, therefore, allow urban farmers to make necessary insights towards developing sustainable urban agriculture. [2].

Renewable energy can be considered essential in the context of future urban farming. The renewable energy generated from solar panels and wind turbines can be used to power grow lights, pumps, and other equipment used in urban farming operations. Aside from minimizing the contribution of urban agriculture as a source of carbon emissions, this approach also contributes to lowering the high energy costs incurred in controlled environment agriculture. Additionally, the employment of renewable resources can enhance the ability of urban farming to continue operating during energy crises or periods of high prices [3].

This project aims to design an effective approach for managing water tanks in plant cultivation through the integration of solar power generation, advanced sensor networks, and Peltier thermoelectric technology. In hydroponic systems, maintaining optimal water temperature and pH levels is critical for healthy plant growth. Proper control of these factors ensures efficient nutrient absorption, minimizes plant stress, and enhances crop productivity. Peltier technology, powered by solar energy, offers precise temperature regulation by stabilizing the water within the ideal range, thereby preventing issues like nutrient lockout caused by fluctuating conditions. By focusing on these key aspects, this project seeks to provide a sustainable solution for improving resource efficiency and crop yield in hydroponic farming [4].

II. Literature Review

This chapter reviews reports, papers, and research on solar-powered water quality monitoring in hydroponic systems. It covers the solar-powered system, water temperature management, Peltier cooling technology, and methods for developing the hydroponic monitoring and control system.

A. Theory of Photovoltaic System

A photovoltaic system is an electrical system that employs photovoltaic cells to generate electricity directly from sunlight for practical use. Direct current is converted to alternate current through such a solar inverter and then using various electrical devices including mounting, cabling, and such the system is assembled and made functional [5] – [6].

There are two types of photovoltaic systems: Grid-tied systems and stand alone installations, respectively. On-the-grid is tied to conventional domestic and business power and Off-the-grid is for distant places where there is no such power [8]. The photovoltaic system is based on the absorption of sun rays using panels comprised of photovoltaic cells. These cells convert sunlight into direct current DC electricity. DC electricity through an inversion and changes into AC is utilized at home and offices [6].

Installing solar energy depends on several factors, one of which is the size of the solar power system. The size of a solar power installation is calculated using the formula Equation (1) [7].

$$\text{Solar Power System Size (kW)}: = \frac{\text{Average Energy Usage (kWh/day)}}{\text{Peak Sun Hours}} \times 1.43 \quad (1)$$

This formula determines the optimal size of a solar power installation based on average daily energy consumption and peak sun hours in the solar panel's location. As a result, the size of the solar system required to meet the household's energy needs is estimated. The typical peak solar period in Malaysia lasts four hours, from 11 a.m. to 3 p.m. Using both sets of data, one can estimate the size of a solar power system. The formula for solar panel efficiency is using Equation (2) [7].

$$\text{Efficiency} = \frac{\text{Power Output From Solar Panel}}{\text{Power Input From Sun}} \times 100\% \quad (2)$$

The efficiency of a solar panel is calculated by dividing the maximum power output of the solar panel by the amount of sunlight that falls on the solar panel. The result is multiplied by 100 to obtain the solar panel efficiency percentage [8].

B. Solar Energy in Agriculture

There has been a growing trend in the adoption of solar energy in the agricultural sector, especially in hydroponic farming. Since nutrient-rich solutions instead of soil are used for raising plants in a hydroponics setup, power can be advantageous for solar solutions. As for the motive force, the nutrient solutions can be pumped by solar power connected to the pumps for the circulation of the nutrient solutions while as for the heat and light for the plants, they can also be supplied by solar power. Besides, it helps to decrease the use of fossil fuels in agriculture, as well as increasing crop productivity and quality. For example, solar green houses enable controlled temperatures and humidities in order to-grow plants for most of the year when they would otherwise be seasonal [9].

Another area that has chances for a more efficient and green method of irrigation is related to the combination of solar energy in hydroponic farming. These nutrient solutions can further be distributed by solar-powered pumps so that water wastage is eliminated and a higher yield is achieved. Furthermore, the light can be used to power up sensors and controllers which help the farmers to monitor the soil moisture level, crop growth regulation, and expression of the climatic conditions prevailing for enriched farming. In conclusion, the use of solar energy as the main source of powering hydroponics will go a long way toward changing the traditional way of practicing agriculture by adopting new technologies that will foster the sustainable feeding of the ever growing population in the world. [10].

C. Water Temperature System

Another area of interest in hydroponic vegetable production is controlling the temperatures of the water to enable plant growth and development. These are primarily the temperature of water used in irrigation, which affects the efficiency by which nutrients and water are taken up by plant tissues, and other physiological changes that occur in plants. When water temperatures reach either low levels or high levels, they influence plant stress, rate of growth, and early signs of pests and diseases [11].

There are many methods and procedures practiced in controlling the temperature of water in hydroponic systems. The requirement can be fulfilled both by water heaters and chillers, where the temperature of the irrigation water is regulated before use. If this is required, these systems can be fixed at certain temperature range and they will pump water to the plants during the day and at night. Another approach involves using insulated pipes or tubing to maintain stable water temperatures during the transfer process. This method ensures that temperature fluctuations are minimized, providing consistent water temperature as it moves through the system. [11].

The impact of fluctuating temperatures in the water on the crops cannot be completed without mentioning the productivity and well-being of the plants. Variation in water temperature is also a threat because when it changes it will stress plants and consequently kill them through wilting, stunted growth or when the change is too much the plants become too exposed to the changes. Also using water at a temperature that is below the usual one slows down photosynthesis in plants, hinders nutrient assimilation, and also makes the plants more vulnerable to diseases. Gardeners can therefore supply their plants with the right temperatures depending on the check herein of temperatures, which is very important when it comes to the yields and quality of the crops [12].

D.Peltier Cooling Technology

Peltier cooling technique is named after the principle known as the Peltier Effect, which was first discovered by a French physicist by the name of Jean Peltier in the year 1834. Peltier effect is the process by which a temperature difference is created between two junctions of two dissimilar electrical conductors or semiconductors by passing an electric current through the pair. This means that one junction starts to cool down while the other heats up; the colder one will be known as the cold side and the warmer one as the hot side. Currently, if the direction of the current changes, the positions of the hot and cold sides can also be exchanged [13].

Thermoelectric coolers (TECs), commonly referred to as Peltier coolers, apply this phenomenon for cooling with no regard to standard refrigerator style compressor cooling systems. Peltier coolers consist of no moving parts and are almost completely wear-free, therefore, great for applications where vibrations and noise should be avoided. It can be developed of any size and is used to cool parts as small as sensors up to large enclosures. The advantages of Peltier coolers include fine temperature regulation, heat/cold generation, and the possibility of making relatively small and portable coolers [13].

In agriculture, Peltier cooling has been used for example in cooling the electrical boxes to protect the circuits from heat, cooling foodstuffs while in transit, and regulating the temperature of laboratory and medical equipment being used in agriculture research and food processing. Moreover, Peltier coolers offer a compact and vibration-free design for mounting applications, especially in mobile systems like tractors and other farm vehicles' interiors. It is true that Peltier coolers typically have a lower Cooling capacity per a unit of power as compared to compressor used in refrigeration technique but using Peltier coolers has almost no cons at all as they are small in size, do not make much noise and requires minimal maintenance in comparison to compressor coolers and hence can be used in many of the agricultural applications [14].

E. PH Monitoring and Management

The pH of the water being used in irrigation is an important component to consider in fertigation schemes since it influences the solubility and utilization of the nutrients in the water by the plants. Some of the key factors that should be considered while preparing for zymotechnics experiments include: An ideal pH for zymotechnics experiments should range between 5.5 and 6.5. It enhances soil fertility in that nutrients are always available to support plant growth and development, leading to each plant yielding its best [15].

Supervising the levels of pH in fertigation systems; is the right frequency of nutrient delivery to our crops. This can be done by having the pH sensors placed directly in the irrigation line, which is frequently used to determine the level of acidity or basicity of the water-fertilizer solution. This type of sensor offers information on the current pH level at a given period, enabling growers to set the best pH levels for their crops [16].

In organizing the pH levels in the fertigation systems, it is done by injecting carefully either the acidic or basic solutions into the water used in the irrigation processes. This can be done with the help of certain chemicals; for example, with the use of acids like phosphoric or nitric acid, one can lower the pH, while with the help of bases like potassium or calcium hydroxide, one can increase the pH level. The amount of acid or base used also depends on properties such as starting or current pH, water acidity, and the desired pH level. With regard to the efficiency of nutrient delivery, automated pH control systems can be set to enable a certain range of pHs, which is good enough to allow the nutrients to be delivered when they are required all year round [17].

Failure in pH control in fertigation systems causes light greening or yellowing of the plants, toxic buildup or accumulation of nutrients, and slow plant growth. Both high and low pH levels are detrimental to plant growth because a high level will lead to the precipitation of certain nutrients, while a low level will lead to the fixation of several nutrients. For instance, at high pH levels, elements like iron and manganese settle, which may be detrimental to the body. On the other hand, it is revealed that low pH levels can enhance the solubility of heavy metals and may lead to toxicity levels. Therefore, controlling the pH, which refers to the acidity of the solution, allows growers to effectively feel that all nutrients are available to be absorbed by plant roots within the extension of the fertigation system [18].

F. Previous Research

In the paper by Rahul Nimbore et al.[19], the project involves setting up a solar-powered water quality monitor based on sensors. This is aimed at consistently gauging and surveying the pH and turbidity levels of water to ascertain its suitability for different uses like drinking, agricultural, and industrial among others. Some developing countries do not have data on water quality and yet they use it as drinking water which results in severe diseases. This system comprises solar-powered nodes that take readings of temperature, pH, oxygen density, and turbidity. It also sends this information to the Thingspeak cloud platform via the MQTT protocol where it can be analyzed remotely. This system involves monitoring water quality and making sure there is enough information that allows for preventive action to conserve water quality and safeguard public health.

The research by Ayomide et al.[20], to lower postharvest losses, researchers looked into improvements in tomato postharvest storage systems. The research most likely entailed investigating novel technologies, storage strategies, or treatments to improve tomatoes' quality and shelf life after harvest. According to the study's findings, the goal was to optimize tomato postharvest handling by introducing innovative technologies or storage strategies that would reduce losses, improve tomato quality, and boost supply chains' overall effectiveness. This research is pertinent to the current project because it emphasizes how crucial efficient postharvest management is to preserving agricultural produce's quality and minimizing losses. This knowledge may be used to design solar-powered fertigation systems that will maximize crop growth.

The paper by Gamutin et al. [21] describes a new air purifier system which employs Thermoelectric cooling and smart air quality detection sensors. The methodology involves coming up with an air purifier device whose working form is powered by thermoelectric cooling, which would effectively remove all contaminants from the air; the device is designed with sophisticated sensor systems to update the status of the air quality continuously. The thermoelectric cooling technology, ensures the efficiency of the purification of the air from various pollutants and contaminants such as suspended particles, VOS and other, dangerous substances. The advanced sensors on the other hand make it possible to monitor air quality in real-time and thus be in a position to take timely action whenever there is a pollution event and this in essence improves the quality of air. The outcomes highlight the effectiveness of the system in improving air purification efficiency, the decrease in the amount of particulate matter, and the reduction in the emission of volatile organic compounds. Further, the advanced sensing systems offer real-time feasibility to detect the quality of air in a region and respond to it before pollution takes place and the overall air quality also gets affected. This system can be applied in many sectors, both inside and outside the house, in commercial spaces, industrial settings, healthcare services, and spaces where people’s health and therefore quality of air are important.

According to Muhammad Fairuz Remeli et al.[22], an experimental study on the operation of a small cooler using a Peltier thermoelectric cell is presented in the research paper. To test the small cooler's cooling potential, the researchers created a prototype that ran on a Peltier thermoelectric cell. The study probably reports on the tiny cooler's overall performance, temperature decrease, and cooling efficiency. It was published in the IOP Conference Series: Materials Science and Engineering. The results indicate how well the Peltier thermoelectric cell works in a small cooler setting and highlight its potential for use in real-world small-scale cooling systems.

According to Abirami et al.[23], the authors propose a water condensation system based on a thermoelectric cooler using solar energy. This methodology involves the use of a Peltier device, which is a semiconductor that can cool air hence condensing water vapor. The product is self-reliant in terms of power supply, which makes the device comply with environmental conservation. This work proves that clean drinking water can be extracted from atmospheric moisture, and there is a high potential for the expansion of system through the usage of reverse osmosis (RO) and UV water filters to supply water that meets WHO and BIS recommendations respectively.

The paper by Octarina Nur Samijayani et al [24], presents a study on the development and implementation of a solar-powered Wireless Sensor Network (WSN) for monitoring and classifying water quality. The study focuses on measuring and categorizing elements of water quality, including turbidity, pH, and total dissolved solids (TDS). A coordinator node gathers and sends data to a monitoring system while sensor nodes are designed and placed along a river to check water quality. The WSN effectively identifies and categorizes different types of water quality, showing the outcomes to users or a monitoring center. The integration of renewable energy sources and precise sensor readings in environmental monitoring are also emphasized in the study.

In a paper by Nohay et al [25], the authors have presented the details of the development of a portable solar energy powered thermoelectric refrigerator to store insulin. This paper focuses on the use of heating technique that involves use of a Peltier device, solar panel and battery to sustain the specific insulin temperature range. Thus, the experimental results illuminate that the proposed system can store insulin at proper temperature over 12 hours relying on solar energy, which ensures the insulin requirements of the villagers without depending on the utility electricity in rural areas.

The paper by Quintans et al [26], describes a system for thermoelectric energy harvesting where an energy storage system in the form of water and daily average temperature fluctuations are used to generate the power. The technique requires a thermoelectric module, a water storage tank, and a temperature sensor to capture the heat from the variation of the temperature in a spatial context with a cyclic temperature variation process. The outcome reveals that the system well capable of delivering large amount of power with an average of 1 power. 45 mW, thus making it applicable for usage in devices and sensors where the application of conventional methods of power provision is practically unachievable, particularly in regions where access to electric power is inaccessible due to different.

The paper by Salman et al [27], provides an optimization study on a solar powered air conditioning system employing an AC Peltier power source. This involves the design and simulation of a solar driven air conditioning system that employs the use of a Peltier module as the cold source, an AC Peltier power supply to enhance the system efficiency. The adopted Peltier power supply is in a pulsating manner to provide more efficient and stable supply power to affect the Peltier module in the best method favorable for the component. From figures derived, it is clear that the optimized system can therefore providing more reliable and energy saving solution to air conditioning by reducing the amount of energy consumed per unit of chilled water as well as the carbon emission. Furthermore, the results of the research also indicate the benefits of the optimized system for practical applications in different settings such as residential and commercial facilities, as well as in hot and humid climate zones.

III. Methodology

This chapter focuses on the project's methodology and flow mechanism. The goal is to develop software and hardware for a solar-powered water quality monitoring and control system for agricultural use. Fig. 1 illustrates a monitoring and control system using the Arduino Mega board for controlling the pH level and temperature of the water being treated.

The system starts by typing the code on Arduino IDE and uploading it to the Arduino Mega. If issues arise, the code is reviewed and addressed before a new upload is made. Real-time sensors and loads are integrated to monitor and control the system, with another communication port created to receive data and display it on an LCD. If readings are not visible, problems are identified and rectified. The system then measures pH and water temperatures, with a relay on when the water temperature exceeds 29°C, allowing the Peltier cooler and water pump to function. When the temperature drops to 29°C or below, the relay switches off, halting the cooler and water pump operations. The process continues until all measures are successfully applied.

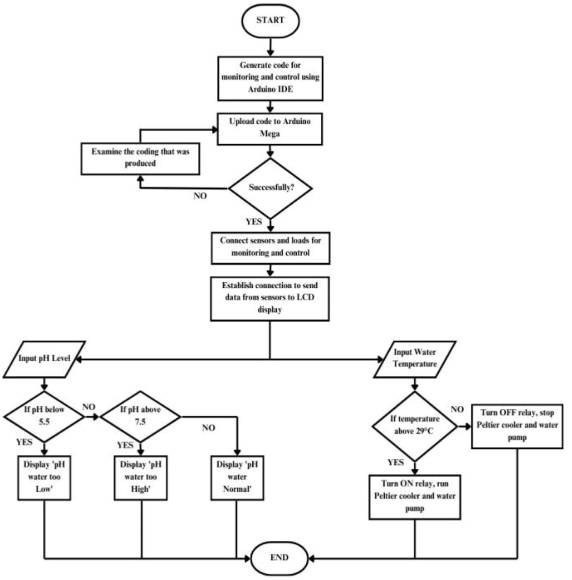

Fig. 1. System Flowchart.

A. Development of Hardware

The system in Fig. 2 is a water cooling and pH monitor hardware development. It uses a solar panel to convert light into energy, a micro-controller Arduino Mega to control its functioning, and a temperature and pH sensor to measure water temperature and acidity. The readings are displayed on an I2C LCD screen for monitoring and user information. The system also includes a relay module with a Peltier module and a water pump, which cools the water and monitors pH levels.

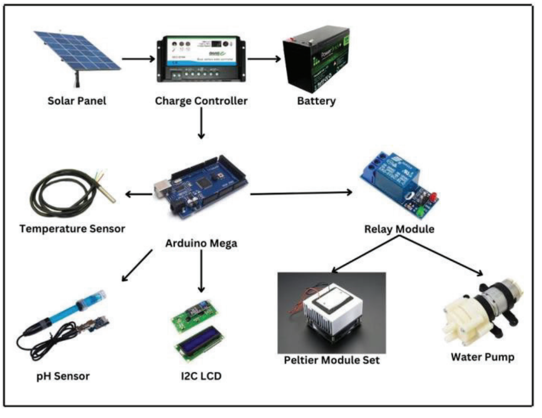

Fig. 2. Hardware Development

Table 1 tabulated Calculation of Load.

TABLE I
FORMULA OF CALCULATION LOAD

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FORMULA OF CALCULATION LOAD

Load Specifications	Power (P) = V x I
Total Power Consumption	Total Sum of Power Cosumption
Daily Energy Production	Power x Peak Sunlight Hours
Running Time Calculation	Total Energy Needed = Total Power x Running Time
Battery Charge	**Energy Capacity:** Voltage x Capacity **Charging Time (day):** $\frac{\textit{Energy Capacity}}{\textit{Daily Energy Production}}$

IV. Results

The results and discussions of the simulation and hardware development are presented in this chapter. The simulation focuses on monitoring and adjusting water temperature and pH levels.

A. Project Design

The project to provide an overview of the Solar-Powered Peltier Thermoelectric Water Cooling And Ph Monitoring is designed using Tinkercad. The 3D model is displayed in Fig. 3. It displays a basic concept for the system projects' design.

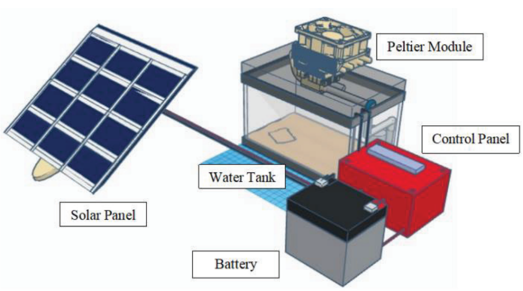

Fig. 3. 3D Project Design

B. Circuit Design Simulation

The Arduino UNO will be simulated using Proteus software and selected sensors like pH and water temperature. Fig. 4 and 5 show the simulation without integrating every sensor with the microcontroller to ensure the microcontroller can operate correctly with the pinouts used for each sensor.

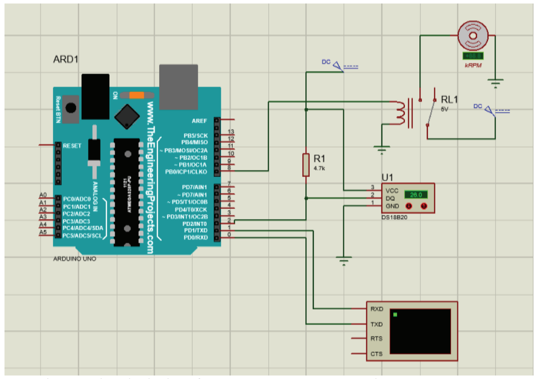

Fig. 4. Circuit design for a temperature sensor in Proteus

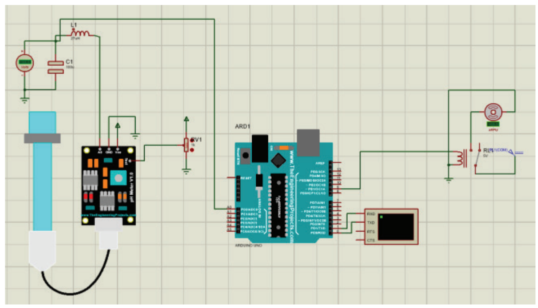

Fig. 5. Circuit design for a pH sensor in Proteus

C. Prototype Testing

The monitoring system uses an Arduino Mega board with sensors attached to its analog and digital ports. Temperature and pH sensors collect data, while a relay module controls a Peltier module and water pump. The pump circulates water through the Peltier module, cooling the 3-liter water tank. Fig. 6 and 7 show the prototype and testing at the UTHM Greenhouse Site.

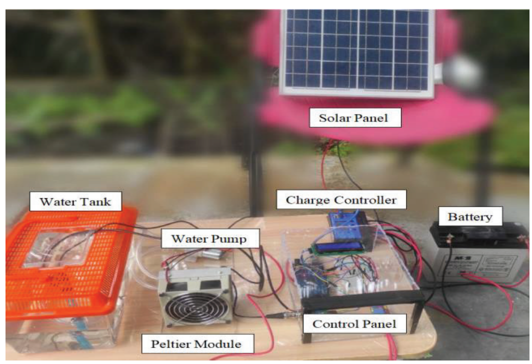

Fig. 6. Prototype Project

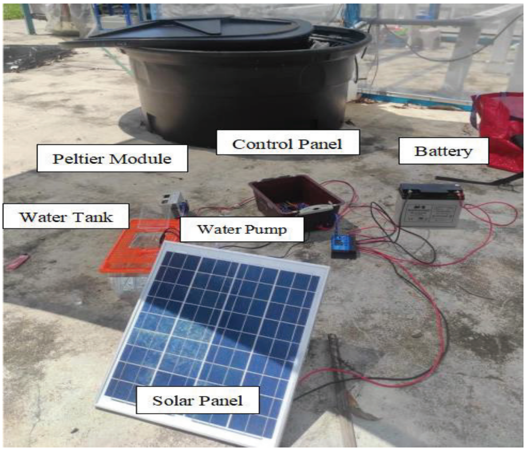

Fig. 7.Greenhouse Site at University Tun Hussien Onn Malaysia

Fig. 8 depicts prototype testing with a three-liter sample water tank. The LCD in Fig. 9 shows that the temperature in the water tank is 30.19°C, which is higher than 29.0°C. The water pump and Peltier module run as shown in Fig. 10. Fig. 11 depicts the LCD, which shows that the pH parameter is 6.13, which is within the range of 5.5-7.5, and informs the user that the pH parameter is normal.

Fig. 8.prototype testing with a three-liter sample water tank.

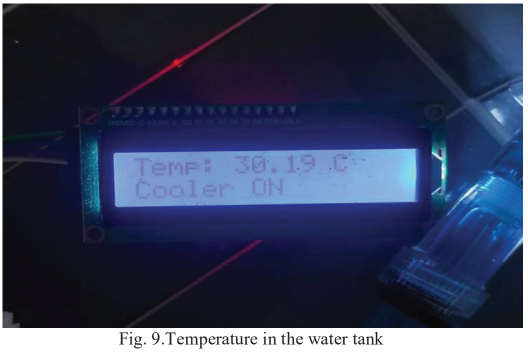

Fig. 9.Temperature in the water tank

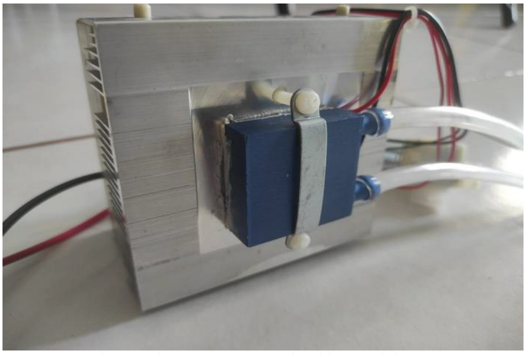

Fig. 10.The water pump and Peltier module start run

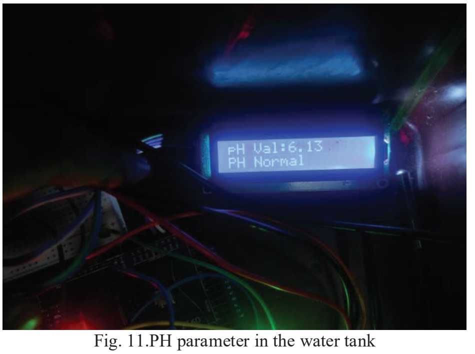

Fig. 11.PH parameter in the water tank

D.Data Collection Of Battery Charging Without Load for 3 Days

Table II demonstrates that on May 30, the voltage gradually rose during the day. The first time range (8:00 AM to 10:00 AM) revealed a modest rise of 0.2 volts. This further increase remained in the next time period, with the voltage rising by 0.3 volts between 10:00 AM and 12:00 PM, followed by a somewhat larger rise of 0.26 volts in the afternoon (12:00 PM to 2:00 PM). The rate of rise decreased in the later half of the day, with the voltage increasing by 0.17 volts between 2:00 PM and 4:00 PM before peaking at 0.07 volts at 6:00 PM.

TABLE II
DATA VOLTAGE INCREMENT AND DURATION TIME WITHOUT LOAD FOR DAY 1, 30 MAY 2024

30 May 2024	Voltage Range	Voltage Increment
8.00 am-10.00 am	12.0 V to 12.2 V	0.2 V
10.00 am-12.00 pm	12.2 V to 12.5 V	0.3 V
12.00 pm-2.00 pm	12.5 V to 12.76 V	0.26 V
2.00 pm-4.00 pm	12.76 V to 12.93 V	0.17 V
4.00 pm-6.00 pm	12.93 V to 13.0 V	0.07 V

Table III demonstrates that May 31 follows a similar voltage rise pattern as May 30. The early time range (8:00 AM to 10:00 AM) shows a smaller rise of 0.11 volts. The voltage increases by 0.2 volts between 10:00 AM and

12:00 PM. The noon hour (12:00 PM to 2:00 PM and 2:00 PM to 4:00 PM) had larger voltage spikes of 0.5 and 0.3 volts. The day ended with a last 0.16 volt boost between 4:00 and 6:00 p.m.

TABLE III
DATA VOLTAGE INCREMENT AND DURATION TIME WITHOUT LOAD FOR DAY 2, 31 MAY 2024

31 May 2024	Voltage Range	Voltage Increment
8.00 am-10.00 am	11.50 V to 11.61V	0.11 V
10.00 am-12.00 pm	11.61 V to 11.81 V	0.2 V
12.00 pm-2.00 pm	11.81 V to 12.31 V	0.5 V
2.00 pm-4.00 pm	12.31 V to 12.61 V	0.3 V
4.00 pm-6.00 pm	12.61 V to 12.77V	0.16 V

Table IV illustrates that the pattern of voltage increases on June 1 mirrored the trend of the previous two days. The early time period (8:00 AM to 10:00 AM) had a 0.15-volt boost. The voltage growth was minor in the subsequent phases (10:00 AM to 12:00 PM), totaling 0.23 volts. The afternoon brings a larger voltage spike of 0.45 volts between 12:00 and 2:00 pm, followed by a more modest increase of 0.25 volts between 2:00 and 4:00 pm. The last time period (4:00 PM to 6:00 PM) produced a gain of 0.2 volts.

TABLE IV
DATA VOLTAGE INCREMENT AND DURATION TIME WITHOUT LOAD FOR DAY 3, 1 JUNE 2024

1 June 2024	Voltage Range	Voltage Increment
8.00 am-10.00 am	11.80 V to 11.95 V	0.15 V
10.00 am-12.00 pm	11.95 V to 12.18 V	0.23 V
12.00 pm-2.00 pm	12.18 V to 12.63 V	0.45 V
2.00 pm-4.00 pm	12.63 V to 12.88 V	0.25 V
4.00 pm-6.00 pm	12.88 V to 13.08V	0.2 V

The table provide a detailed analysis of the battery charging process, highlighting the system's ability to capture and store solar energy. The consistent voltage increments demonstrate the battery's efficient energy accumulation, a crucial insight for understanding the dynamics of solar-powered battery charging systems and their performance over time.

E. Data Collection Of Battery Charging With Load for 3 Days

Table V shows that on May 24, the voltage gradually rose during the day. The first time range (10:00 AM to 11:00 AM) indicated a little rise of 0.1 volt. This further rise remained for the next time period, with the voltage rising by 0.15 volts between 11:00 AM and 12:00 PM, followed by a 0.13 volt increase in the afternoon (12:00 PM to 1:00 PM). The rate of growth decreased in the later half of the day, with the voltage climbing by 0.0.9 volts between 1:00 PM and 2:00 PM until peaking at 0.08 volts at 3:00 PM.

TABLE V
DATA VOLTAGE INCREMENT AND DURATION TIME WITH LOAD FOR DAY 1, 24 MAY 2024

24 May 2024	Voltage Range	Voltage Increment
10.00 am-11.00 am	11.5 V to 11.6 V	0.1 V
11.00 am-12.00 pm	11.6 V to 11.75 V	0.15 V
12.00 pm-1.00 pm	11.75 V to 11.88 V	0.13 V
1.00 pm-2.00 pm	11.88 V to 11.97 V	0.09 V
2.00 pm-3.00 pm	11.97 V to 12.05 V	0.08 V

Table VI indicates that May 25 follows a similar voltage rise trend as May 24. The early time range (10:00 AM to 11:00 AM) shows a smaller rise of 0.07 volts. The voltage increases by 0.12 volts in the following intervals (11:00 AM to 12:00 PM). The noon hour (12:00 PM to 1:00 PM and 1:00 PM to 2:00 PM) had greater voltage spikes of 0.23 and 0.1 volt, respectively. The day ended with a last 0.13 volt boost between 2:00 and 3:00 PM.

TABLE VI
DATA VOLTAGE INCREMENT AND DURATION TIME WITH LOAD FOR DAY 2, 25 MAY 2024

25 May 2024	Voltage Range	Voltage Increment
10.00 am-11.00 am	11.45 V to 11.52 V	0.07 V
11.00 am-12.00 pm	11.52 V to 11.64 V	0.12 V
12.00 pm-1.00 pm	11.64 V to 11.87 V	0.23 V
1.00 pm-2.00 pm	11.87 V to 11.97 V	0.1 V
2.00 pm-3.00 pm	11.97 V to 12.1 V	0.13 V

Table VII shows the pattern of voltage increases on May 27 continued the trend of the previous two days. The early time range (10:00 AM to 11:00 AM) had a 0.09 volt rise. The voltage gain was minor in the subsequent stages (11:00 AM to 12:00 PM), totaling 0.13 volts. The afternoon brings a larger voltage spike of 0.21 volts between 12:00 and 1:00 pm, followed by a more modest increase of 0.15 volts between 1:00 and 2:00 pm. The last time period (2:00 PM to 3:00 PM) produced a gain of 0.08 volts.

TABLE VII
DATA VOLTAGE INCREMENT AND DURATION TIME WITH LOAD FOR DAY 3, 27 MAY 2024

27 May 2024	Voltage Range	Voltage Increment
10.00 am-11.00 am	11.11 V to 11.2 V	0.09 V
11.00 am-12.00 pm	11.2 V to 11.33 V	0.13 V
12.00 pm-1.00 pm	11.33 V to 11.54 V	0.21 V
1.00 pm-2.00 pm	11.54 V to 11.69 V	0.15 V
2.00 pm-3.00 pm	11.69 V to 11.77 V	0.08 V

The voltage drop may be due to the load of Peltier modules and the water pump for cooling the tank, causing a lower voltage rise. However, the overall rising trend suggests that solar panels will provide enough electricity to maintain a net positive charge in the battery throughout the day. The table provide a comprehensive overview of the battery charging process, with a growing voltage trend over three days demonstrating the system's capacity to efficiently gather and store solar energy. This knowledge is crucial for understanding the dynamics of solar-powered battery charging devices over time.

F. Data Collection of Water Temperature

Table VIII shows the Peltier module's effectiveness in maintaining the water tank temperature below 29°C. We can see that for five days (May 23–May 27), the cooling system successfully dropped the water temperature from its starting point to below the threshold. The starting temperature ranged from 30°C to 33.21°C, and the Peltier module consistently met the objective. This proves that the system can keep the temperature of the water tank within the prescribed limits.

TABLE VIII
DATA STARTING & ENVIROMENT TEMPERATURE AND COOLING TIME

Date/Time	Starting Temperature (°C)	Cooling Time (Minutes)	Enviroment Temperature (°C)
23 May/ 10.00am	30.00	14	31.00
24 May/ 11.00am	31.40	15	30.50
25 May/ 11.30am	32.00	16	31.00
30 May/10.30am	33.00	19	30.00
31 May/ 12.00pm	33.21	60	34.00

The Peltier module's cooling time is influenced by both the starting water temperature and the ambient temperature. On days with lower starting temperatures, the cooling period is shorter, requiring 14-16 minutes. On days with higher starting temperatures, it takes longer, ranging from 15 to 60 minutes, to achieve the target temperature. This indicates that the system requires longer time to overcome the temperature difference between the initial water temperature and the intended cold condition. The table also shows the potential impact of external temperature on the cooling process, with higher ambient temperatures during the day potentially offseting the cooling effect of the Peltier module. Overall, the Peltier module effectively controls the temperature of the water tank, with colder starting temperatures and lower ambient temperatures resulting in shorter cooling durations.

G.Data collection of pH parameter

Fig. 12 show pH values taken at different times during a five-day period. This information is particularly valuable for tracking plant health in hydroponic systems, where the ideal pH range is 5.5 to 7.5. The table lets you track pH changes over time. This data allows you to spot trends or patterns in pH behavior by comparing readings at different times throughout the day or across days. For example, the table indicates whether the pH varies substantially during the day or remains relatively constant.

The pH value indicates the acidity or alkalinity of the water in the hydroponic system. A pH of 7 is neutral; less than 7 is acidic, while more than 7 is alkaline. Understanding the context of the monitoring process is crucial for obtaining accurate results. However, the table can help determine whether the water is typically within the recommended range for optimal plant development (5.5-7.5) and whether there have been any significant swings in acidity or alkalinity during a 5-day period. It is critical to remember that the table only displays the pH reading at a certain time.

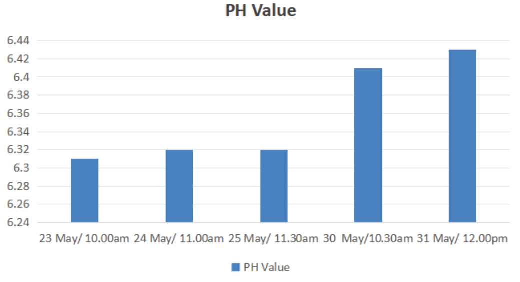

Fig. 12. Graph of pH value levels measured vs period of 5 days

V. Conclusion

The project successfully achieved three goals, resulting in the creation of a Solar-Powered Peltier Thermoelectric Water Cooling And Ph Monitoring system. The first objective involved designing an integrated system using peltier cooling, sensor networks, and solar panels to regulate hydroponic water temperature and monitor pH. The second objective involved performing simulation analysis using Proteus Software to monitor and control water temperature and pH levels. The final objective was to verify the hardware system in a real hydroponic environment to ensure optimal conditions and energy efficiency

VI. Recommendation

The project's current state requires continuous improvement to maintain quality and ensure long-term viability. Suggestions include optimizing Peltier modules for better cooling, upgrading to larger solar panels for adequate power supply, and conducting long-term testing to assess the durability and dependability of the water tank system components under various environmental conditions. Continuous improvements are crucial for maintaining the project's quality and longevity.

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Conflict of Interest

The authors declare no conflict of interest in the publication of this research article.

Author Contributions

K.I. Jasmee: Research conceptualization, conducted simulation tests, analyzed data, prepared the original draft, and managed manuscript editing; S.A. Jumaat: Supervised the research, guided the analysis and interpretation of results, and reviewed and refined the manuscript draft.

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