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Designing a Green Laboratory: Automated Refrigeration System Powered by Renewable Energy

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Abstract
This study was embarked upon to develop an automated laboratory refrigeration system, which will be compactable with solar power. The model will utilize mechanical, electrical, and electronic components to achieve its goals. ESP32 microcontroller, sensors, and relay nodule were the major electronic components used for the prototype creation; while a combination of C++ language and MATLAB, were used the code acquisition and algorithms implementation, to achieve the main aims of this study. Similarly, the solar panel, charge controller and cooling unit, were the major hardware incorporated into the system. The created model was tested for real-time and cooling temperature monitoring. Remarkably, the experimental outcomes result revealed that the automated system had 91% efficiency. Interestingly, this study's results highlighted that this computerized refrigerator, can be utilized in the laboratories, leading to reduction on the dependence on fossil fuel-based energy.
Keywords: Cooling system, green energy, microprocessor, prototype, sensors.

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1.0 Introduction

Cooling system (refrigeration) is one of the major equipment required in the laboratory. It is an essential apparatus that helps in temperature monitoring and control; hence, facilitating the actualization of various laboratory research. Apart from specimens' preservation, refrigeration helps in sustaining the integrity and permanence of sensitive reagents and vaccines, thereby contributing immensely to the precision and competence of experimental operations [1]. Inadequate cooling unit operation has led to poor experimental findings, incomplete research, and significant loss of research materials and time. Nigeria is plagued by consistent electric power outages, created by poor electric power generation and distribution; and this has posed serious challenges to the nation's research performance [2, 3]. Therefore, this has resulted to the demand for defensible electrical power solutions, which is independent on the national electrical grid unit, mostly in the laboratories and research institutions.

Automated systems enhance scientific investigations and learning capability, as they intelligently control the laboratory equipment and guarantee the public health safety [4]. The incorporation of automaton and other smart technologies into laboratory operations, have help to improve research and learning, particularly quality control, precision and public safety. Standard laboratory apparatus/equipment and their optimal application are fundamental to industrialization, as well as rapid advancement of home-grown technology [5]. Automated system functionality is influenced by the compatibility between the hardware, software and the programming language used for the structure development. A computerized structure allows the apparatus/machine to be triggered and disengaged, based on the codes andalgorithms designed for the task's implementation [6].

Recently, there has been substantial improvement in the development of automated machines, equipment and apparatus had been developed for various laboratory activities [7 -9]. One of the major challenges associated with computerized systems in Nigeria, is poor electric power supply. It is now paramount to develop programmablelaboratory instruments, and other relevant facilities,which will operate on sustainable energy. This will lead to modernization of Nigeria research institutions. Therefore, the major objectives of this study are to design and developed a prototype of a sustainable laboratory refrigeration system, that will usedsolar (renewable) power, and automate the cooling conditions using pre-set time/temperature schedules. The automated refrigeration operation will be time controlled, thereby reducing the incidences of power waste, and enhanced specimens' preservation.

2.0 Materials and methods

To effectively develop a computerized solar powered refrigeration system, it requires the integration of various mechanical, electrical, and electronic components. This can be further broadly categorized into hardware, software and sensors.

The system hardware and electronic control units

The hardware and electronic components used for the model production, and their specifications are presented in Table 1. These include the photovoltaic (PV) cells commonly referred to as "solar panels", charge regulating device, refrigeration (cooling)unit, battery (energy storage), and relay modules. Likewise, the electronic system consists of: microprocessor, real-time clock (RTC), sensors (temperature-based), and the display unit.

Table 1: Components used for the model design and their specification

Component	Specification
Microprocessor (ESP32-D2WD)	240 MHz clock speed, operating voltage of 3.0V, ROM ~ 448 KB, 32-bit, 16 MB flash memory, operatingtemperature ~ -40°C to 85°C.
Temperature sensor (DS18B20)	Accuracy ~±0.5^{o}C, operating temperature ~ -55 to 125^{o}C, 12 bits, operating voltage ~ 5.5V DC (direct current'), Built-in EEPROM, Data transfer speed ~ 16.3 kbps.
RTC Module (DS3231)	Accuracy ~ ±2 min per annual, operating voltage~ 5.5V DC, Power usage ~1.5 mA, backup battery ~ coin cell, Integrated temperature sensor ~ between -40°C and 85°C.
Relay Module (1-channel)	Input voltage ~ 5V DC, current rating ~10A, operating temperature ~ -40 to 85^{o}C.
Cooling unit	Temp range 0 to 10°C
LCD Display (16x2)	5 by 10 dot matrix/character, voltage ~ 5V DC, 8-bit, operation temp ~ 0 - 50°C
Buzzer	Frequency ~ 4kHz, voltage ~ 12 V, SPL ~ 80dB
Solar Panel	300W
MPPT Charge Controller	Battery voltage range ~ 24V, max PV input current ~ 40A, operating temperature ~ -25 to 60^{o}C, max PV Power ~500W
Battery	12V/200Ah

System architecture

The prototype block diagram is presented in Figure 1. The PV cell captures solar energy from the sun to create a direct current (DC) power, with the charge controller helping to prevent the occurrence of overcharging situation. Typically, the battery is the power bank, which stores the energy acquired and releases it when it is needed. The microcontroller is the brain of the automated cooling system; principally, it harmonizes the input commands from the sensor, and implementing the control commands, utilizing already programmed logic. Additionally, the DS18B20 sensor monitors the cooling chamber temperature, maintaining the cooling operation at a projected temperature range; while the relay module preforms the switching (ON/OFF) operation via the instructions provided by the microcontroller[12]. Specifically, the RTC module (DS3231) plays the functions of a time keeper, as facilitates scheduled refrigeration maneuver; whereas, the LCD unit was programmed to display the major functionalities of the refrigeration system on a screen.

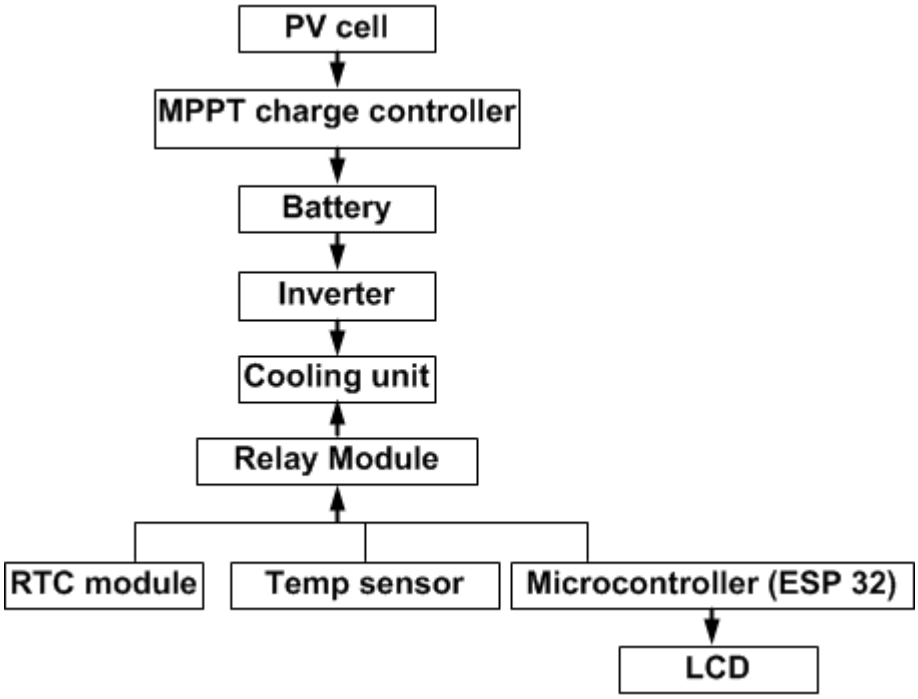


Figure 1: The prototype block diagram

Programming language

A combination of MATLAB and C++ programming languages were used for the modeling, code generation andalgorithmsimplementation, during the production of automated system.The MATLAB will be typically used for algorithm simulation, and the C++ will be employed basically for hardware actions execution. The application of MATLAB in prototype modeling and algorithm replication greatly helps timing control, temperature regulation, and other relevant algorithms implementations [10].

The system was programmed to monitor the refrigeration time through the RTC module, and determined the temperature condition through the DS18B20. Primarily, model was developed to transits electrical energy (power) to the cooling unit using already pre-set temperature thresholds and time interims. Additionally, the display unit (LED) showed the model operating temperature, cooling duration, battery status and other related programmed responses/factors. Specifically, the prototype was imputed with numerous automation logics, which were time regulation and temperature control based.

Testing and Evaluation

The model was tested with laboratory based pilots, to evaluate the refrigeration system's response to temperature and time factors. The prototype's performance was calculated by applying Equations 1 [4].

$$P = \frac{T_0}{T_o + F_o} \times 100 \qquad 1$$

Where: T_o ~ true reading, and F_o ~ false reading.

Results and Discussion

The results obtained from the prototype evaluation are presented in Table 2 and Figure 2. Based on the cooling temperature, it was seen that when the model was tested as 4, 5, 6 and 7^{o}C, the automated system performance was 93.3, 86.7, 86.7 and 93.3%, respectively. Regarding the real time management, the evaluation outcomes depicted that the system has

95% efficiency (Figure 2). The high efficiency recorded in this study can be linked to collaborations between the hardware and software used for the model production, as well as compatibility of the programme used for the prototype design [4,10]. Remarkably, the false positive outcomes recorded in this research, can be linked to program errors, algorithmic inadequacies and other mechanical failure[11].

Table 2: The readings from cooling evaluation

Time (hour)	Temp ≤4°C	Temp ≤5°C	Temp ≤6°C	Temp ≤7°C
1	T	T	T	T
2	T	T	T	T
3	T	T	F	T
4	T	T	F	T
5	T	T	T	T
6	T	T	T	T
7	T	F	T	F
8	F	T	T	T
9	T	T	T	T
10	T	T	T	T
11	T	T	T	T
12	T	T	T	T
13	T	T	T	T
14	T	F	T	T
15	T	T	T	T

T = True positive, F = False positive

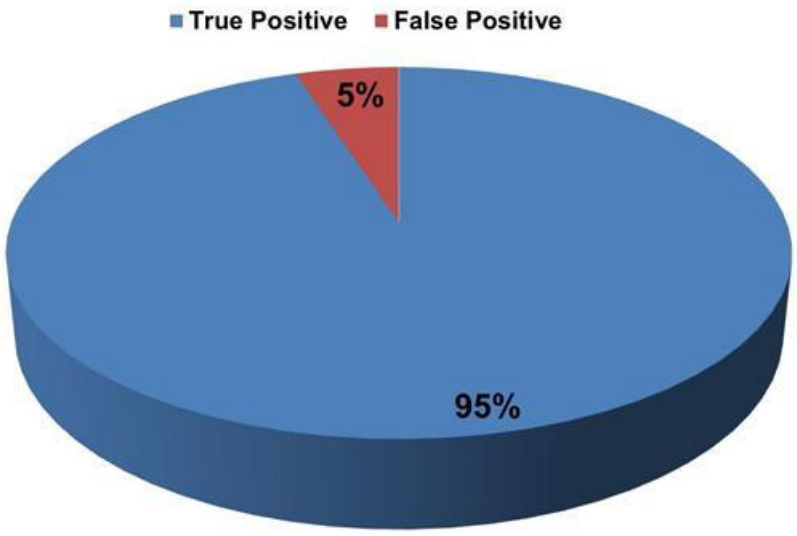


Figure 2: The outcome of the real time evaluation

4.0 Conclusion

The research was initiated to look into the possibilities of using renewable energy to power automated refrigeration system. This automated cooling structure employed microcontroller, sensors, relay modules, C++, MATLAB, as well as hardware to realize the cooling operation. Performance evaluation of the system was done through, timing and cooling temperature monitoring. Results obtained from the system efficiency evaluation, depicted that the model produced hadnet (overall) efficiency of 91%. The 9% false positive (failure rate) documented for the automated apparatus, can be linked to mechanical (hardware) failure and program

errors. Remarkably, the findings of this study demonstrated that the use of this computerized refrigerator in lab settings can lessen reliance on energy derived from fossil fuels.

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