
Design and Modeling of an Automated Solar Powered Laboratory Incubator, with Time Regulation Unit

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Abstract

Epileptic electric power supply and laboratory monitoring are major experimental challenges, in most under-developed and developing Nations. This research was carried out to design and create a prototype of smart laboratory incubator, using real-time management and a solar power system. The computerized structure was produced with ESP32 controller, DS18B20 sensor, DS3231 module, heating element, buzzer, solar panel, and C++ language. MATLAB was used for the modeling and C++ was the programming language, employed for the model production. Remarkably, the microprocessor handled the raw data the sensor sent to it, and makes appropriate decisions, using the algorithms. Additionally, the real time unit (DS1307) helps to regulate the system, to prevent energy and time wastage. Interestingly, results achieved from the laboratory evaluation of the prototype, depicted that the prototype has overall efficiency of 88%. This research's findings revealed that this automated incubator produced, can be effectively used for scientific research organizations, as well as reducing dependence on fossil-fuel based energy.

Keywords: ESP32 controller, model, green energy, incubator, real time clock

1.0 Introduction

Heat treatment is one of the fundamental unit operations in laboratory settings, particularly during sterilization and microbiology. High dependence on public power system and monitoring approaches had often resulted in energy wastage, high labor cost and poor sterilization and microbial evaluation [1]. Recently, smart system and renewable energy have been developed to counter the challenges posed by traditional laboratory settings. Automated laboratory equipment and apparatus are substantial alternative to traditional settings, primarily because most of them use renewable energy; hence reducing reliance on public electric power and fossil fuels. This has increased efficiency, environmental friendliness and dependence on fossil fuels [2-4].

Most automated laboratory apparatus use photovoltaic units, microcontrollers and other electronic accessories, to sustainable power source and functionality [5,6]. Automation of scientific apparatus through real time systems substantially optimizes laboratory operations in various fields. Basically, this is achieved through utilization of modern technologies, such as timers and sensors, which help to reduce danger and errors associated with anthropogenic activities [7]. The quest for sustainable experimental practices, to meet up with human endeavors and environmental challenges, have necessitates the development of innovative solutions for laboratory activities [8].

Remarkably, within the past two decades, numerous advancements have been made in the development of smart and automated systems for laboratory and other research operations [8-11]. Though, a lot of automated laboratory equipment prototypes have been developed, there is no comprehensive reports specifically detailing, the development of laboratory incubator models. Incubator plays essential roles scientific investigations, such as: microbial analysis, cells culture, and other biological-based scientific explorations. Consequently, it is paramount to develop an automated incubator prototype for scientific purposes. Therefore, this study's was conducted to design and develop a model of a programmable solar-powered incubator system, with the capability of real-time monitoring and control units.

2.0 Materials and Methods

To realize the goal of this study, the model design mainly focused on harmonizing hardware components, software packages and programming language, to regulate the operation of a laboratory incubator. The schematic diagram of the system is displayed in Figure 1.

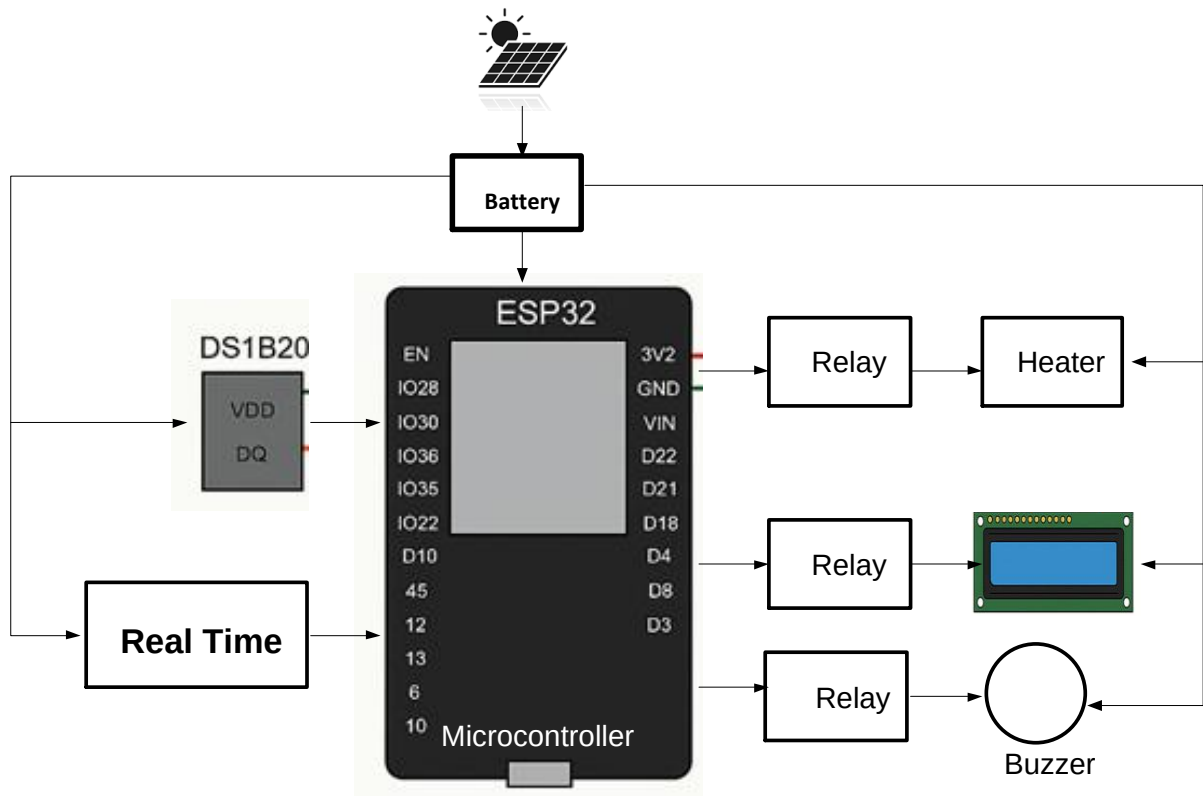


Figure 1: The model schematic diagram

The system software

The Arduino IDE (compiler) version 2.x and MATLAB were the software used for model production. Additionally, the C++ was chosen as the programming language for the automated structure.

The system hardware

The hardware used and their specifications are presented in Table 1.

Table 1: hardware components List

Component	Specification
ESP32 Microcontroller	Clock Speed ~ 240 MHz Dual Core, 2.2V operating voltage, 520 KB SRAM, 16 MB flash memory, 32-bit microcontroller.
DS18B20 Digital Temp Sensor	Operating temperature ~ -55 to 125°C, water resistance, operating voltage ~ 5 V, compatible with ESP32,
DS3231 RTC Module	Voltage range ~ 2.3 to 5.5V, 400Khz I2C interface, compatible with IoT device, CR2032 backup battery
Relay Module (1-channel)	Voltage ~ 5V, peak current ~10A, low-level trigger, trigger voltage ~ 3.3V to 5V DC.
Heating element - Positive Temperature Coefficient (PTC) thermistor	12V, 40–60W, operating temperature range ~ -60 to 180°C
LCD Display (16x2 I2C)	For display
Buzzer	Max. sound ~88 decibel, operating voltage ~3 to 24 V
Solar Panel	180W
Charge Controller	Maximum Power Point Tracking
12V Battery	50Ah

System architecture

The photovoltaic panel supplies the required voltage (power) to the system, with the aids of the Maximum Power Point Tracking (MPPT) acting as a charge controller, which regulates the amount of current leaving the photovoltaic unit. The battery (lithium-ion) was charged by the solar energy, and preserves the stored energy till when it is required for utilization (mostly during non-availability of direct sunlight). Furthermore, the ESP32 microprocessor is the control unit of the automated structure, as it has the potential of monitoring all the accessories connected to it. It mainly used sensors and systematic programming to achieve the controlling tasks. The DS18B20 sensor was programmed to regulate the system's temperature; while the Real Time Clock (RTC) helps to control the timing of the incubator, triggering the alarm system and turning off the heating unit, after the expiration of the pre-set incubation duration. Also, the LCD provides the updated information, about the system's functionality.

Modeling

The MATLAB was used to simulate the power consumption, time management, and thermal fluctuations of the system. This enhances the operation efficiency of the incubator system.

Wiring

The relay module's Voltage Common Collector (VCC) pin was linked to the 5V terminal of the ESP32 board; while the module's ground (GND) pin was connected to the ESP32 GND pin. Also the temperature sensor VCC and GND pins were connected to the ESP32 board via the 5V and GND ports, respectively.

Testing

The system was tested five times, using incubation parameters of 1 h (34°C), 2 h (27°C), 4 h (31°C), 5 h (28°C) and 8 h (37°C), respectively. The incubator internal temperature was 22°C, and each experimental (testing) option was repeated 15 times. The incubator performance was computed using Equations 1 (Odoh *et al.*, 2023).

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

Where: T_o and F_o are true and false outcomes, respectively.

3.0 Results and Discussion

This study's results are presented in Figures 2 to 6. The results highlighted that the automated system exhibited commendable performance of 80, 93, 87, 100 and 80% for experiments 1, 2, 3, 4 and 5, respectively. This depicted that the developed model had an average performance efficiency of $88 \pm 8.63\%$. Similar findings were reported for automated structures developed by Arka *et al.* (2025) and (Odoh *et al.*, 2023). The positive outcomes observed from this research, can be associated with the functionality and collaboration the hardware, software and algorithm, employed for the overall incubator prototype production [11]. Likewise, the few false positive recorded during the testing procedure, can be linked anthropogenic actions and sensors failure, probably caused calibration errors and wears of the hardware (Odoh *et al.*, 2023). Interestingly, the findings documented for this study, portrayed that the computerized incubator, can be used for academic research institutions, and for on-site microbial investigation.

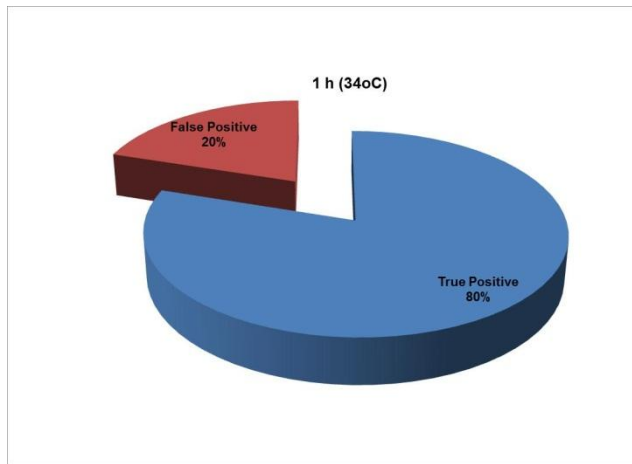


Figure 2: The result of the first testing

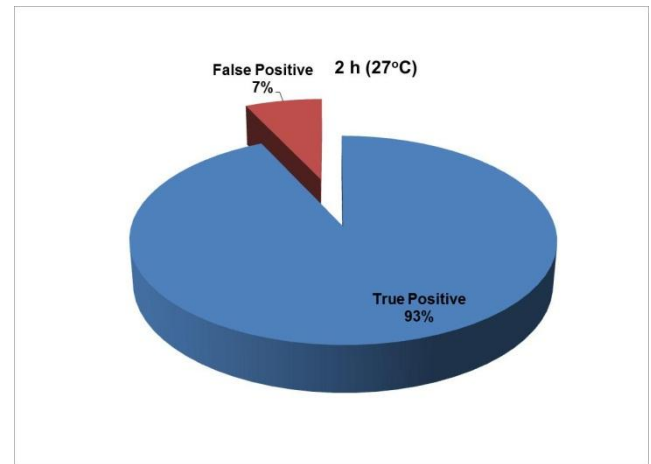


Figure 3: Second testing outcome

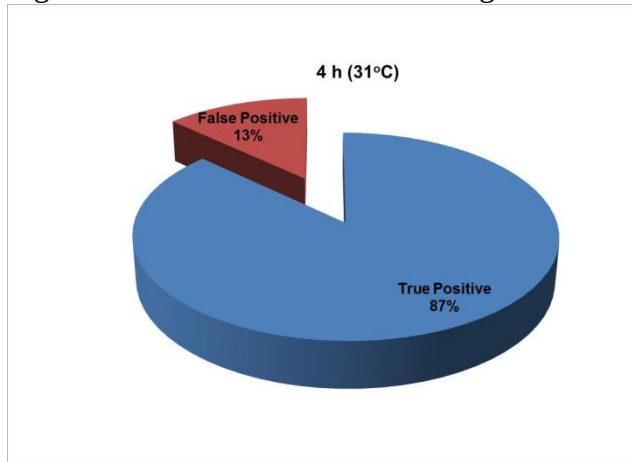


Figure 4: The result of the 3rd evaluation

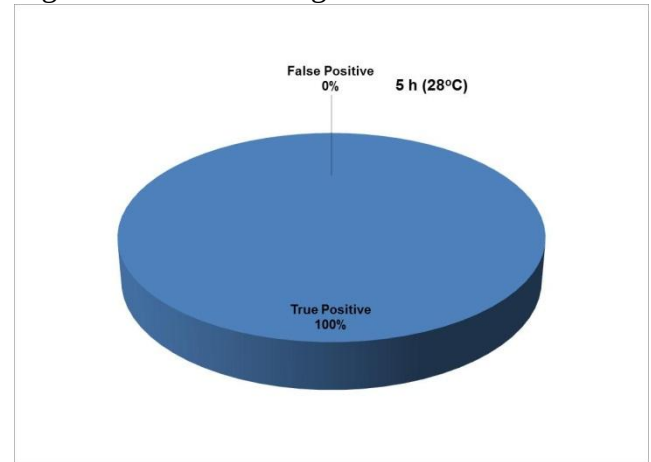


Figure 5: The 4th evaluation outcome

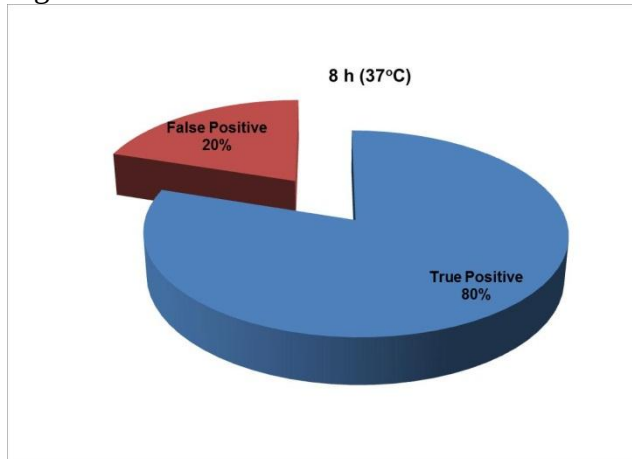


Figure 6: The outcome of the sixth testing

4.0 Conclusion

The study was undertaken to create a programmed laboratory incubation system, which is solar with real time management. The computerized system utilized ESP32 microcontroller, sensors, relay modules, software and hardware to actualize its goals. Notably, the created model was tested under different temperatures and incubation durations, and results obtained revealed that the incubator prototype has performance efficiency of 88%. This performance outcome can be primarily considered to be above average performance rating. The few shortcomings noted during the prototype's evaluation, can be corrected through the use of

more compatible units (sensors and hardware) for the model production, and also by integrating modern technologies into the automated system.

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