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Design and Implementation of a Low-Cost Arduino-Based Incubator for Preserving Biological Samples

Sajjad Majid Jabbar [1*], Alaa Majeed Raheem [2], Ali Reza Muhammad [3], Ahmed Hamid [4], Sajjad Fahd [5], Fakher Sami [6], Abdul Aziz Kazem [7]

[1-7] Department of Medical Physics and Radiotherapy, Technical Engineering College, Sawa University, Almuthanna, Iraq

* Corresponding Author: **Sajjad Majid Jabbar**

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Abstract

This project was the design of a simple biological incubator based on an Arduino microcontroller, a temperature sensor, and a heating element. The purpose of the incubator is to have constant and proper temperature that would support the preservation of biological samples. The system was coded to automatically control heat and maintain the temperature at the range of desired temperatures.

Performance test was done to determine the capacity of the incubator to attain target temperature and its stability within a specific duration. The outcomes revealed that the system was able to maintain the necessary temperature with the slightest variation. The overall mean temperature measured and the values of the deviation show that the incubator is a stable and controlled system to be used in basic biological applications.

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Keywords: Biological Incubator, Arduino, Temperature Control, Heating System, Biological Samples

1. Introduction

A biological incubator is a very crucial and critical instrument in the disciplines of molecular biology, microbiology as well as cell culture [1]. It is characterized as a thermal device with insulation to establish a tightly regulated artificial environment and the primary role of which is to provide optimum growth or preservation conditions to microorganisms, cells, or tissues [2]. The purpose of the incubator is determined by the need to have a more accurate and constant control of various environmental conditions, most notably temperature, which is regulated with heating systems that are usually driven by a PID controller and temperature sensors [3–4]. As an illustration, the majority of mammalian cells need a steady temperature of 37 o C to replicate physiological conditions [5].

Cell culture incubators also require humidity control since the level of humidity is important in preventing the evaporation of the growth media, thus preserving the concentration of nutrients and integrity of the sample [4]. Special incubators such as CO 2 incubators may also be provided to have carbon dioxide regulation facilities, normally with 5% CO 2 set-point, to stabilize the pH necessary to achieve optimal cell proliferation [4]. To put it in brief, biological incubators are the beating heart of numerous laboratories, which make biological experiments reliable and reproducible and allow scientists to investigate biological processes in a controlled environment.

Designs of incubators are different based on the research and clinical requirements. Shaking incubators, such as, are used to provide aeration to bacterial and yeast cultures to allow oxygen to be easily transferred and increase growth and efficiency of microorganisms and protein synthesis [6]. In the meantime, long-term preservation of samples or study of low temperature tolerant organisms, e.g. in the environmental test or in hydroponic cultures, is performed in refrigerated incubators [7]. To reduce risk of contamination and ensure high standards of hygiene, modern incubators tend to include automated processes of sterilization (decontamination) using dry heat or ultraviolet radiation with sensitive biological samples [8].

2. Problem Statement

In microbiology, cell culture and biomedical research, biological incubators are important as the environmental conditions are critical to the integrity of samples and the reproducibility of experiments. Nonetheless, a few studies have reported that many of the commercially available incubators have severe performance constraints. The problem of a low temperature uniformity is one of the most widespread in which variations and spatial gradients within the chamber have an adverse impact on cell viability and experimental accuracy. It is reported in [9] that any slight deviation of the optimal temperature may result in unstable cell behavior and inaccurate results**.**

The other significant hurdle is that it is not possible to ensure humidity control devoid of contamination. Studies have shown that traditional humidity systems tend to support the growth of microbes and lack sterility, especially in incubation conditions that are long-term. In the preservation of humidity but excluding cross-contamination is a continual engineering and biological issue**.**

Also, commercial incubators are often afflicted with slow restoration of environmental conditions following door openings, which cause a temporary break in temperature, CO 2 concentration, and humidity. According to, these variations may have a considerable effect on the physiological reaction of cultured cells particularly those that need a tight regulation of CO 2 and temperature**.**

Lastly, large energy usage is also still a significant disadvantage of conventional incubator designs. Poorly insulated materials and mechanisms to seal lead to higher heat loss and longer operation of the heater, which, in addition to increasing costs of operation, increases the speed of component degradation.

Thus, the primary issue that has been solved within the framework of the present project is the necessity to create a cost-effective, efficient biological incubator that would be able to ensure the stable temperature distribution, the humidity control resistant to contamination, the fast recovery of the environment, and the decreased energy consumption, which would eventually lead to the enhancement of the overall system performance in comparison with the currently available commercial solutions.

3. Objectives

1. Developing a biological incubator capable of providing a precise environment that mimics natural growth and preservation conditions, ensuring the reliability of laboratory results and enhancing sample integrity by minimizing contamination and protecting samples from external influences.
2. Designing and implementing a practical, efficient, and cost-effective incubator system that is user-friendly, operationally efficient, and maintains appropriate thermal stability to improve daily performance in research and educational laboratories.

4. Methodology

Methodology Steps Based on the Diagram

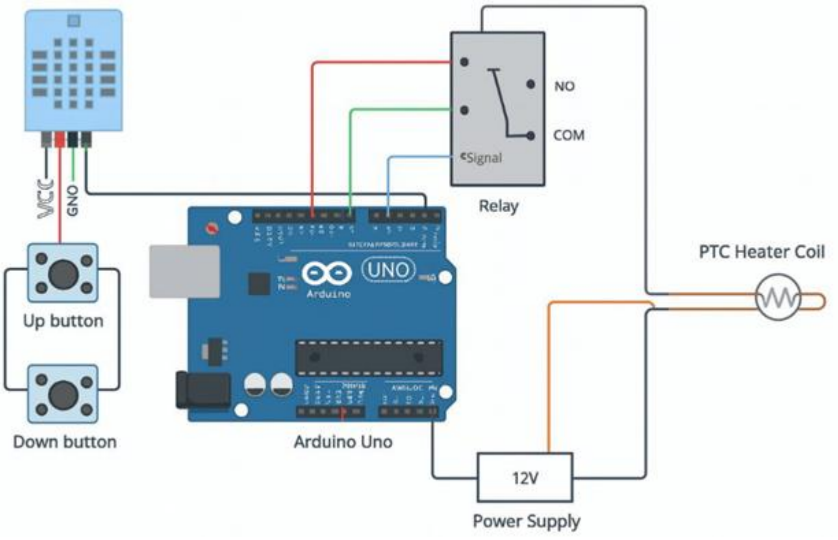

Fig 1: Device diagram

Testing and Operation

Practical Procedure and Experimental Results

1. Turn on the system.

Switch on the incubator and all parts should be functioning.

2. Measuring the temperature on the screen.

Take the baseline temperature and ensure that the display is working properly.

3. Verify relay operation.

Test that the relay can open and close in relation to the increase and decrease of the temperature, which means that the heating element is controlled.

4. Temperature can be adjusted using the buttons.

Enter the desired temperature and ensure that the system reacts to the adjustment directions correctly.

5. Stabilization experiment (Practical Experiment).

An experimental test was established to check the stability in temperature:

The incubator was set to 37°C.

The temperature was measured after every 1-2 minutes and extends to 30-60 minutes.

The measurements have been tabulated and put in a table with Time and Temperature, and a plot of Time Vs Temperature has been drawn.

5. Results and Discussion

5.1. Results These are the results that appeared after examining the device.

Time (min)	Temperature (°C)
0	30.2
2	32.8
4	34.9
6	36.1
8	36.8
10	37.2
12	37.4
14	37.3

5.2. Discussion

Experimental outcomes of the thermal stability test of the incubator indicate that the system is able to attain and sustain the desired temperature within a small range of variations. When the device was turned on and the temperature was set to 37 o C, the temperature was rising steadily between 30.2 o C and 36.8 o C between the first eight minutes and then rose to the target value within the next 10 to 12 minutes. This response time is deemable acceptable to a small heating system in relation to a heating element with a control system operated by a thermal sensor and an ON/ OFF relay or other control device**.**

Once the stabilization was attained, long-term measurements between 30 and 60 minutes indicated that the temperature was maintained between 36.5 o C and 37.5 o C. This minor change in temperature (±0.5 o C) is a positive indication of good control system operation, particularly that the control can be in a hysteresis control mode thus some deviation is tolerated before the system rectifies itself.

All these results suggest that the incubator can offer an appropriate thermal setting in which to store biological samples without advancing sudden changes that would alter the stability of the samples and the accuracy of the experiment. Besides, the fact that the device can achieve thermal stability quickly is its indication of the suitability in laboratory tasks that demand readiness and speed. All in all, the data indicate that the thermal control system is very reliable and its work corresponds to the standard requirements of the use of educational and research laboratory incubators.

6. Conclusion and Recommendation

6.1. Conclusion

In this project, we developed and built a simple low-cost biological incubator based on an Arduino-controlled system to hold the temperature in a suitable range to allow growth of samples. Though the system is thought to offer a rather stable thermal environment, the existing prototype has a few limitations such as the lack of humidity or gaseous control and inbuilt self-sterilization mechanism. Moreover, the system is not packed with an inbuilt data-logging system.

6.2. Recommendation

To enhance it further, we suggest that in future development we should add specific humidity-control modules, which should include an automatic sterilization system, data-logging by USB / SD, and a better control algorithm to increase accuracy and environmental stability.

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