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Design and development of automatic Droplet system for Core-Shell Quantum Dot Synthesis

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ABSTRACT

The gradual and precise addition of solution is a critical factor in the synthesis of core–shell quantum dots. Manual dripping poses a risk of inaccuracy in both volume and timing, thus an automated system capable of operating stably and programmatically is required. This research aims to design and develop an automatic solution dropping system based on an Arduino Uno microcontroller and a servo motor combined with gear and rack mechanisms. The system is designed to control both the volume and timing of the droplets, with selectable intervals tailored to the synthesis requirements. The main components used include a syringe, servo motor, gears and rack gear as mechanical actuators, along with an LCD and buzzer as user interface and status indicators. Test results show that the system operates automatically according to the set time and can deliver solution droplets with consistent volume. This device is expected to enhance the synthesis process of quantum dots by increasing efficiency, precision, and minimizing manual intervention.

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1. INTRODUCTION

The laboratory serves as the heart of science education activities, particularly in chemistry learning, as it provides a place to observe, experiment, test, and evaluate scientific concepts until students gain a deeper understanding of science [1]. One of the key activities in a chemistry laboratory is the synthesis of semiconductor nanoparticles, also known as quantum dots (QDs), as these materials are considered essential building blocks in the fabrication of advanced optical and photonic materials due to their size-dependent optical transitions [2]. Since QD applications are highly specific and require a high degree of precision, their synthesis methods and surface engineering must be tailored to the specific demands of each case [3].

Quantum dots are among the most extensively studied materials due to their ability to meet the demands of various modern applications, such as biological labeling, sensors, lasers, light-emitting diodes (LEDs), and medical diagnostics [4]. Additionally, QDs play a crucial role in charge carrier confinement, contributing to a wide range of optoelectronic applications, including solar cells, LEDs, and luminescent solar concentrators (LSCs) [5]. To obtain QDs with the desired size and optical properties, one of the most widely used synthesis methods is the Hot Injection method, first introduced by Bawendi and colleagues in 1993 for the synthesis of cadmium chalcogenide nanocrystals. This method is well-known for producing uniform particles with tunable optoelectronic characteristics [6]–[7]. Moreover, it is considered promising due to its speed, simplicity, and suitability for larger-scale synthesis. However, to this day, the Hot Injection method is still largely performed manually, particularly during the solution injection stage, which demands high precision and consistency [8].

Therefore, an automation approach is needed to replace the manual process in order to achieve more efficient and stable timing and outcomes. Automation refers to the substitution of some or all human functions with a programmed technological system [9]. One of the widely used technologies in modern automated systems is the microcontroller, which is capable of controlling various digital and mechanical functions. A microcontroller is a compact computer system on a single chip that integrates a processor, memory, and input–output interfaces to manage control processes in automated systems [10]–[11].

The Arduino Uno is one of the most popular microcontrollers in automation due to its combination of user-friendly hardware, programming language, and integrated development environment (IDE) [12]. To perform mechanical movements such as those in an automatic solution dropping system, the Arduino Uno can be combined with a servo motor—a high-precision actuator that operates using a closed-loop feedback system to accurately control position [13]. A servo motor is a motor equipped with a closed-loop system in which the motor's position is continuously fed back to its internal control circuitry. It is essentially a DC motor integrated with a control circuit [14]–[15].

2. METHOD

This study employs a research and development (R&D) approach aimed at producing an automatic solution dropping system to support the synthesis process of core–shell quantum dots. The initial stage begins with the overall system design, covering both mechanical and electronic aspects. Mechanically, the device utilizes a syringe driven by a combination of gears and a rack gear to generate linear motion for droplet dispensing. On the electronic side, the design involves an Arduino Uno microcontroller, a servo motor as the actuator, a proximity sensor to detect the position of the syringe piston, and an I2C LCD module to display time and system status information. Additionally, a buzzer is used as a process status indicator, and push buttons serve as control inputs to start, pause, and stop the system. The figure below illustrates the device design.

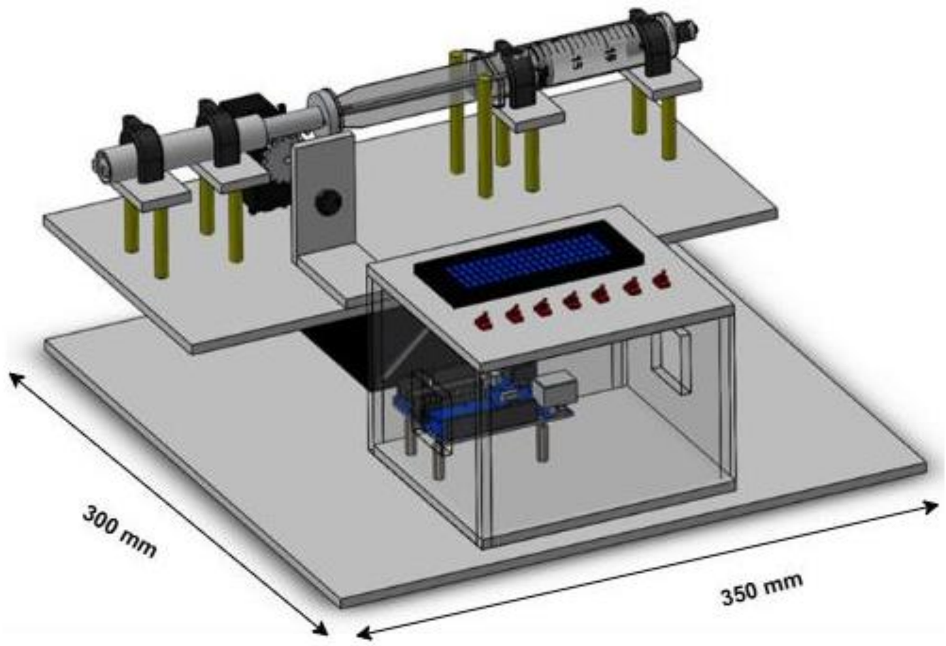


Figure 1. Design of the Automatic Solution Dropping System

The first step in operating this device is initializing the components to prepare them for operation, which is indicated by a "Standby" display on the LCD. The user can then select a time interval using the available switches. Once a switch is selected, the system begins operating: the servo motor activates according to the time interval shown on the LCD, moving to push the gear and rack mechanism. This motion drives the syringe plunger, resulting in solution droplets being dispensed. If the servo encounters a failure, the buzzer will sound as an alert. If no failure occurs, the servo continues to operate according to the selected duration. When the solution in the syringe is depleted, the servo returns to its initial position, completing the dispensing cycle. However, if the solution is not fully depleted due to an error, the buzzer will sound to indicate a failure. A detailed overview of this process is illustrated in the flowchart below.

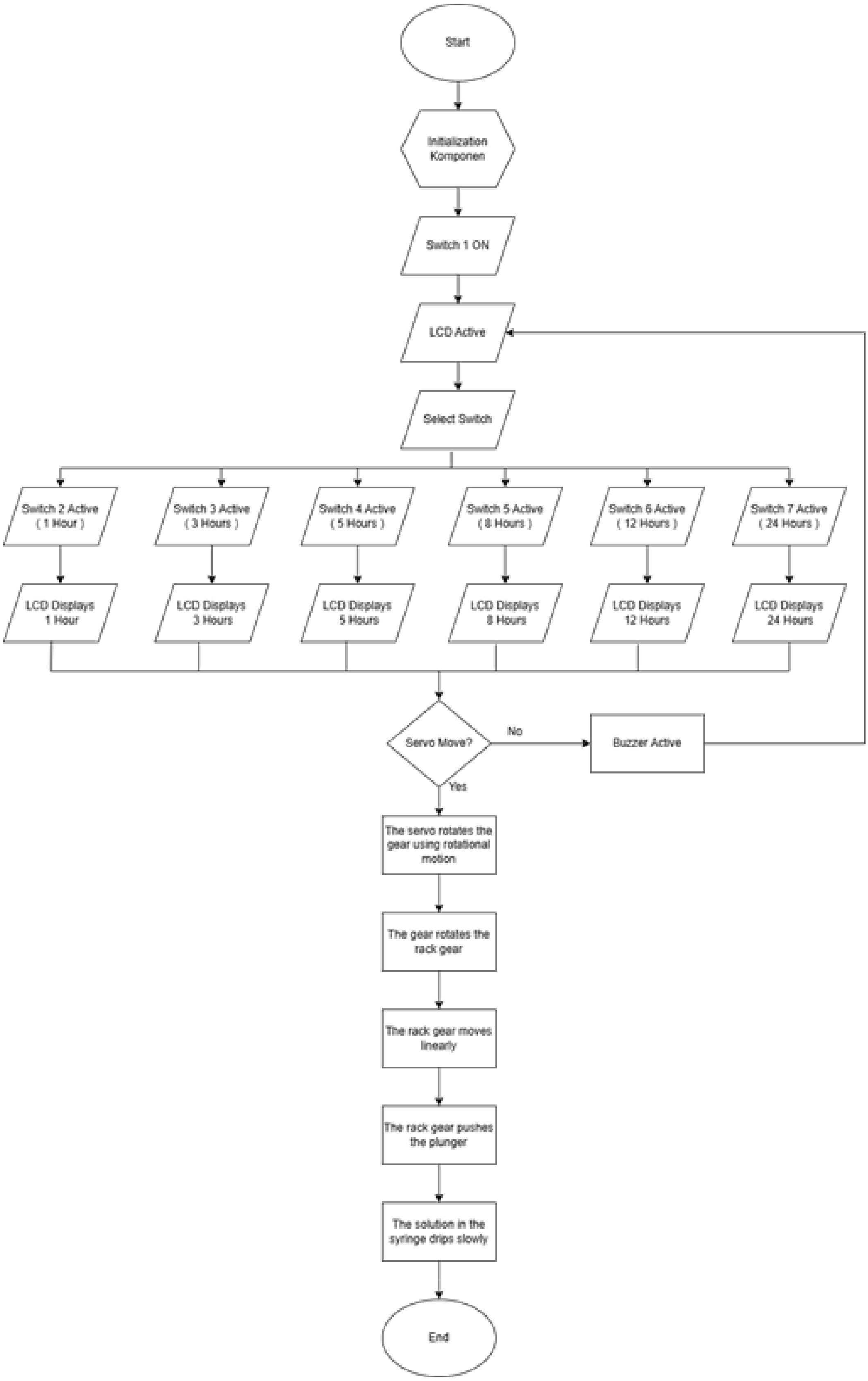
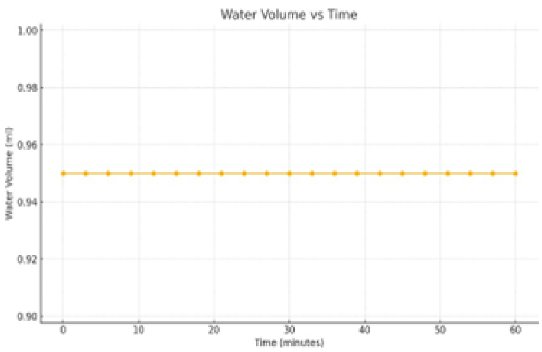


Figure 2. Flowchart of the Automatic Solution Dropping System

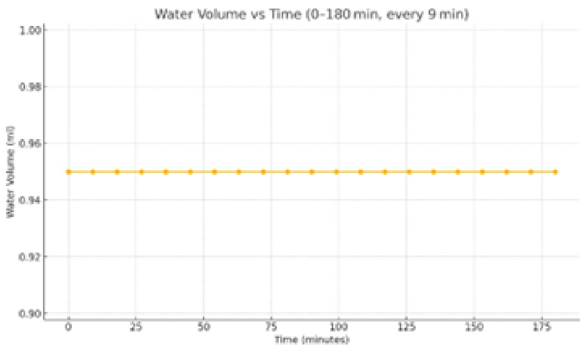
3. RESULTS AND DISCUSSION

The proposed tool was tested with various time variations ranging from 1 hour to 24 hours. Figure 3 shows the tool testing process. Figure 3 shows that the LCD screen displays a test time of 1 hour. Figure 4 shows a graph of the test results with time variations.

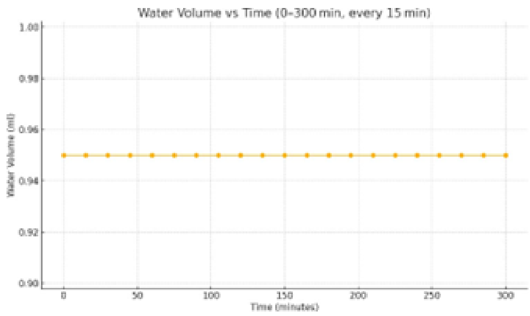
Figure 3. Hardware display for 1-hour duration



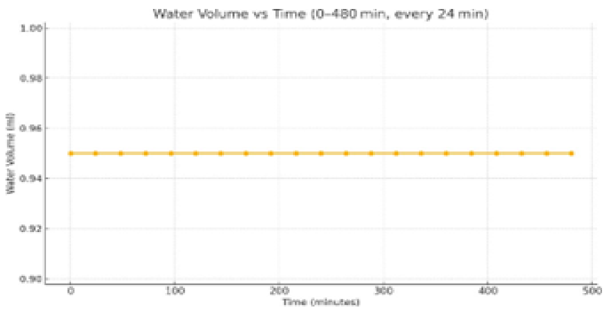
(a)



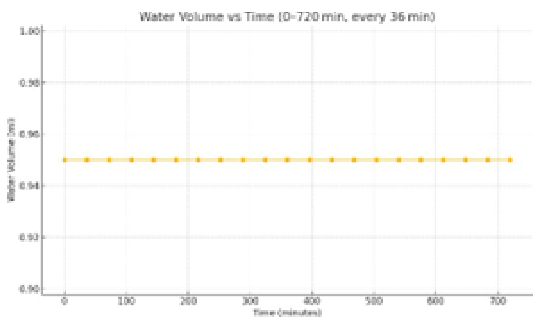
(b)



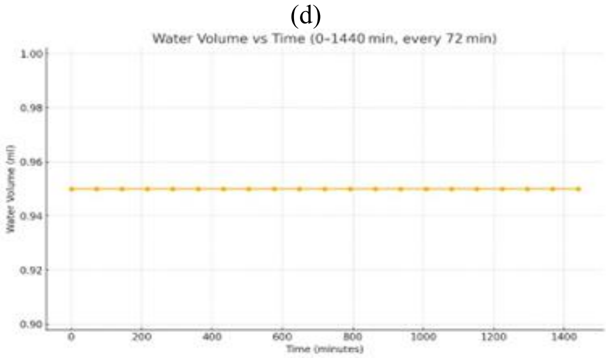
(c)



(d)



(e)



(f)

Figure 4. Experimental result with time variations
a) 1-hour, b) 3-hour, c) 5-hour, d) 8-hour, e) 12-hour, f) 24-hour

The 1-hour duration test includes the droplet timing and the volume of solution per droplet. The image below shows the LCD display for the 1-hour duration. The 3-hour duration test includes the droplet timing and the volume of solution per droplet. The graph below shows the display for a 3-hour duration. The 5-hour duration test includes the droplet timing and the volume of solution per droplet. The graph below shows the display for a 5-hour duration. The 8-hour duration test includes the droplet timing and the volume of solution per droplet. The graph below shows the display for a 8-hour duration. The 12-hour duration test includes the droplet timing and the volume of solution per droplet. The graph below shows the display for a 12-hour duration. The 24-hour duration test includes the droplet timing and the volume of solution per droplet. The graph below shows the display for a 24-hour duration

4. CONCLUSION

Based on the design and testing results of the automatic solution dropping system used in the synthesis process of core–shell quantum dots, several conclusions can be written that The system was successfully designed and developed using a combination of mechanical and electronic components, such as a servo motor, gears and rack gear, as well as an Arduino Uno as the main controller, which is capable of driving the syringe plunger to dispense the solution. The system is capable of regulating the droplets to fully dispense the solution within the predetermined time, making the device effective for synthesis processes that require gradual solution addition

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