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# Drug Titration Process Control and Identification System Using IoT-Based RGB Sensors

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**ABSTRACT** (10 PT)

The process of determining the levels of drug raw materials using the titration method in pharmaceutical laboratories is generally still carried out manually, potentially causing inaccuracy in determining the titration endpoint. This study aims to design and implement an automatic drug titration control and identification system using an Internet of Things (IoT)-based RGB color sensor. The system is controlled by a built-in ATmega 2560 WiFi microcontroller integrated with a dosing pump as an actuator for adding titrant and a DC motor as a solution stirrer. The RGB sensor is used to detect color changes in the solution until it reaches orange as an indicator of the titration endpoint. The results of the titration process, in the form of process time and titrant volume, are sent in real-time via WhatsApp notifications. Tests were conducted on several drug raw materials, namely stearic acid, boric acid, and citric acid. The test results showed that the system was able to work as designed with titration results close to the manual method, with the highest accuracy level reaching 98.7%. This system is expected to improve the efficiency and consistency of the titration process in pharmaceutical laboratories.

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## 1. INTRODUCTION

The development of automation technology and microcontroller-based control systems has significantly contributed to improving the efficiency and accuracy of various industrial processes, including in the pharmaceutical sector. One important process in testing the quality of pharmaceutical raw materials is titration, a chemical analysis method used to determine the concentration of a substance in a solution through a reaction with a specific standard solution. The titration method is widely used in chemical analysis due to its high level of accuracy in determining the concentration of substances in solution [1], [2]. However, titration processes in laboratories are still often performed manually, potentially leading to errors in determining the titration endpoint and requiring relatively longer testing times [3]. Therefore, the development of automated titration systems has become an important research topic in laboratory instrumentation.

With the development of electronics technology and the Internet of Things (IoT), various studies have developed automation systems to replace manual processes in laboratory activities. The IoT concept allows various electronic devices to be connected via an internet network so that data can be monitored and controlled in real time [4], [5]. The use of microcontrollers such as Arduino and ATmega2560 enables the integration of various sensors and actuators to automatically control processes and perform system monitoring more efficiently [6]. Furthermore, IoT technology also enables direct transmission of measurement data to users via communication networks, simplifying monitoring and decision-making [7], [8].

In modern chemical analysis processes, color sensor-based approaches are increasingly being used to automatically detect color changes in chemical reactions. RGB-based color sensors, such as the TCS3200, are capable of converting light intensity into frequency signals that can be processed by a microcontroller, allowing color changes to be quantitatively identified [9], [10]. Several studies have shown that microcontroller-based color sensors can be used for colorimetric chemical analysis with a fairly good level of accuracy. For example, research developing an Arduino-based TCS3200 color sensor system to detect Rhodamine B levels in syrup samples demonstrated measurement results comparable to UV-Vis spectrophotometry methods, with recovery rates reaching 96–110% [11]. Other research has also shown that color sensors can be used as portable chemical analyzers to measure the concentration of specific compounds through color changes in chemical reactions [12].

Although these studies demonstrate the potential of color sensors for chemical analysis, several limitations remain. First, most existing systems focus only on color detection or chemical concentration measurement, without integrating the system into a complete automated titration mechanism that includes reagent dispensing and endpoint detection. Second, many previously proposed systems rely on simple detection modules without integrating actuator control, such as dosing pumps, which are necessary to perform automated titration processes. Third, although some studies have implemented IoT-based monitoring systems for color detection applications [13], the integration of color-based endpoint detection, automated titrant control, and real-time IoT monitoring in a single titration system is still limited. In addition, other research on color sensor applications mainly focuses on object classification or industrial automation rather than chemical titration processes [14]. Furthermore, recent studies have demonstrated the potential of microcontroller-based sensing systems for automation and real-time monitoring applications. A TCS3200-based color detection system has been successfully applied for automated color classification with high accuracy [14]. In addition, IoT-based monitoring systems using microcontroller platforms have shown effective integration of sensors and communication networks for real-time data acquisition [15]. Similar work also developed a microcontroller-based color detection system capable of transmitting monitoring data in real time, indicating the feasibility of integrating color sensing with embedded control systems for automated measurement applications [16].

Therefore, there is still a research gap in the development of a fully integrated automated titration system that combines color-based endpoint detection, microcontroller-based control, automated titrant dispensing, and IoT-based monitoring for pharmaceutical laboratory applications. Addressing this gap is important in order to improve the efficiency, repeatability, and reliability of titration processes used in pharmaceutical raw material analysis.

Based on these considerations, this study proposes the design and implementation of an automated titration control and identification system for pharmaceutical raw materials using an RGB color sensor (TCS3200) based on an ATmega2560 microcontroller integrated with a dosing pump mechanism. The proposed system is also equipped with an IoT-based monitoring feature that enables real-time notification of titration results via a messaging application. The main contribution of this research is the integration of color-based endpoint detection, automated reagent control, and IoT monitoring into a single system to improve the efficiency and accuracy of titration processes in pharmaceutical laboratories.

## 2. METHODS

### A. System Design

This research uses an automated system design method for the titration of drug raw materials in a pharmaceutical laboratory. The developed system aims to identify color changes in the solution during the titration process and automatically control the amount of titrant added. This system consists of several main components: a built-in ATmega2560 WiFi microcontroller as the main controller, a TCS3200 RGB color sensor to detect solution color changes, a dosing pump as an actuator for dropping the titrant solution, a DC motor as a stirrer, and an Internet of Things (IoT)-based monitoring system. The block diagram is shown in Figure 1.

In this system, the color sensor detects changes in the color of the sample solution during the titration process. When the solution color has not reached the titration endpoint, the dosing pump will continue to gradually drip the titrant solution. Once the sensor detects a color change to orange, indicating the titration endpoint, the microcontroller will stop the dosing pump and display the resulting titrant volume. Information on titration results is then sent via the IoT system in the form of a WhatsApp message, allowing users to monitor the process in real time.

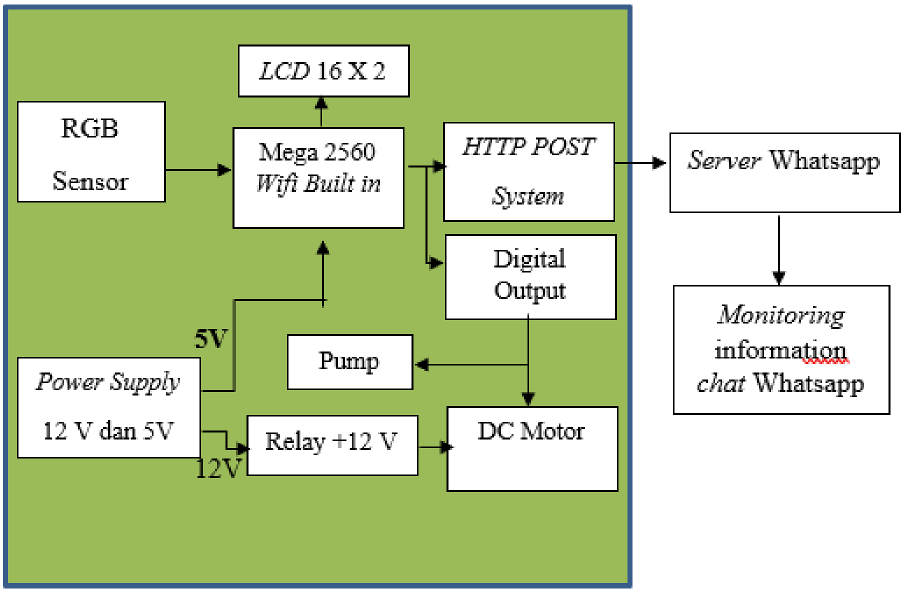

Figure 1. System Block Diagram

**B. System Architecture**

The developed system architecture consists of several subsystems: an input subsystem, a processing subsystem, an actuator subsystem, and a monitoring subsystem.

1. Input Subsystem: The input subsystem uses a TCS3200 RGB color sensor to detect color changes in the solution during the titration process. This sensor reads the intensity of red, green, and blue colors, which are then converted into digital values by the microcontroller.
2. Processing Subsystem: The processing subsystem uses a built-in ATmega2560 WiFi microcontroller to serve as the system's control center. The microcontroller processes data from the color sensor to determine whether the solution has reached the titration endpoint.
3. Actuator Subsystem: The actuators used in this system consist of a dosing pump and a DC motor. The dosing pump delivers precise drops of titrant solution in milliliters, while the DC motor stirs the solution to ensure a homogeneous chemical reaction.
4. Monitoring Subsystem: The monitoring subsystem uses an Internet of Things (IoT) network to send titration results to users via WhatsApp messages. The information sent includes the volume of titrant used and the titration process time.

**C. Hardware Design**

The hardware used in this study consists of several main components, namely:

1. ATmega2560 Built-in WiFi microcontroller
2. TCS3200 RGB color sensor
3. Dosing pump (peristaltic pump)
4. DC motor for stirring the solution
5. 16x2 LCD as a local display
6. 5V and 12V power supplies

The TCS3200 color sensor detects color changes in the solution based on RGB color components. The sensor readings are then processed by the microcontroller to determine the condition of the solution during the titration process. The dosing pump is controlled by the microcontroller via a relay to regulate the amount of titrant solution dripped into the sample solution. The control system design is shown in Figure 2.

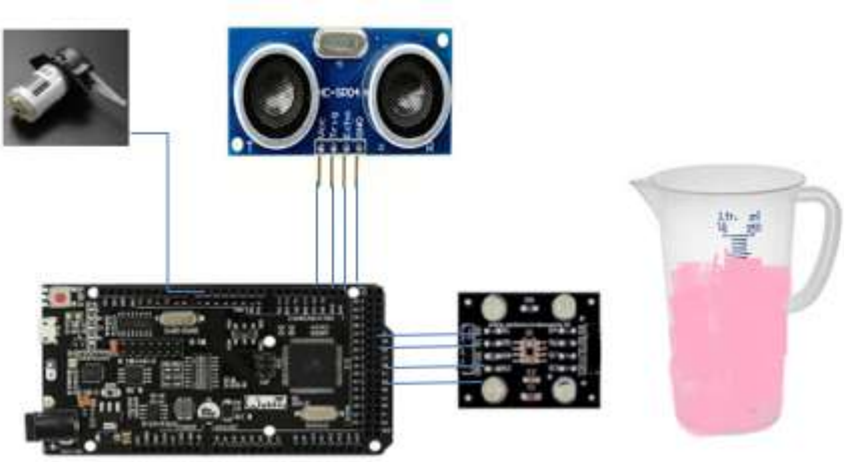

Figure 2. Titration Control System Design

### D. Software Design

The system software was developed using the C++ programming language on the Arduino IDE platform. The program is designed to periodically read color sensor values, process the data, and control actuators based on the detected conditions. The flowchart is shown in Figure 3. The system workflow begins with the RGB sensor reading the solution's color value. The color data is then processed by the microcontroller to determine whether the solution has reached the titration endpoint, which is indicated by a color change to orange. If the color has not changed, the dosing pump will continue to drip the titrant solution. Conversely, if the color has changed to orange, the system will stop the dosing pump and display the measurement results.

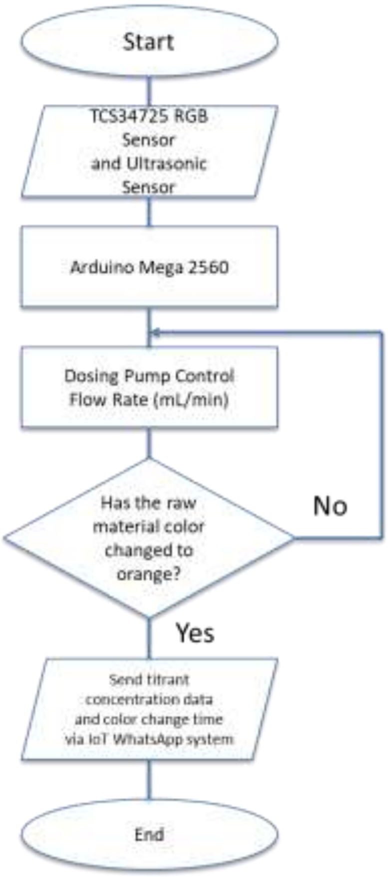

Figure 3. System Flow Diagram

### E. System Testing Methods

System testing was conducted by comparing titration results obtained from the developed instrument with manual titration methods in the laboratory. Tests were conducted on several pharmaceutical raw materials, including citric acid, stearic acid, and boric acid. Each test was performed by gradually adding the titrant solution until the solution changed color to orange, indicating the titration endpoint. The volume of titrant solution produced by the system was then compared with the manual measurements to determine the ratio measurement.
The ratio measurement was calculated using the following equation:

$$Ratio\ Measurement = \frac{Device\ Volume}{Manual\ Volume} x100\% \quad (1)$$

The test results are used to evaluate the system's performance in detecting the titration end point and the accuracy of titrant solution dispensing by the dosing pump.

## 3. RESULTS AND DISCUSSIONS

### A. Color Sensor Calibration

Before the system was used for automated titration, the TCS3200 color sensor was calibrated to ensure it could accurately detect color changes in the solution. The calibration process was performed using three primary colors: red, green, and blue. The color calibration process is shown in Figure 4.

Test results showed that the TCS3200 sensor was capable of reading color intensity values with a digital range of 0–255. Based on the calibration process, an average reading of 250 bits for red, 200 bits for green, and 150 bits for blue was obtained. These results indicate that the sensor is able to distinguish each color component well, making it suitable for detecting color changes in the solution during the titration process.

The success of this calibration process is crucial because the automated titration system uses the color change of the solution as an indicator of the titration endpoint. With proper calibration, the system can identify the color change of the solution to orange more consistently than visual observation by the operator.

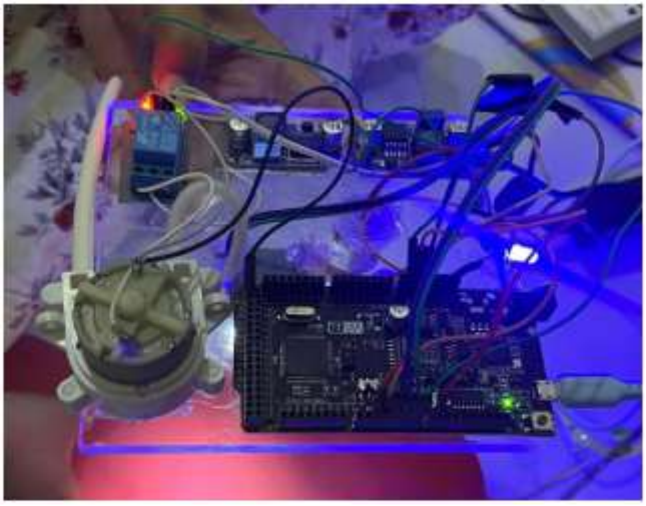

Figure 4. Color Sensor Calibration

### B. Dosing Pump Calibration

Dosing pump calibration was performed to determine the titrant solution discharge rate released by the pump. Testing was performed by turning on the pump for one minute and measuring the volume of the resulting solution using a measuring cylinder. The test results showed that the dosing pump was capable of dispensing 100 ml of titrant solution in 60 seconds. Based on these results, the pump output discharge rate was 1.67 ml/second. This value was then used as a parameter in the microcontroller program to regulate the number of titrant drops during the titration process. With this calibration process, the system can calculate the volume of titrant solution discharged more accurately based on the active time of the dosing pump. The pump calibration process is shown in Figure 5.

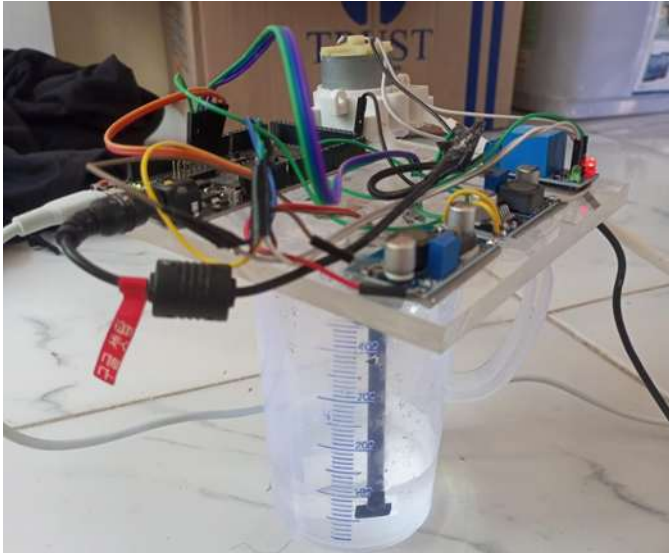

Figure 5. Dosing Pump Calibration

### C. Automated Titration System Testing

The system was tested using three types of pharmaceutical raw materials: citric acid, stearic acid, and boric acid. Each material was tested using a manual titration method and compared with the titration results using the developed automated system. The test results showed that the system was able to automatically control the addition of the titrant solution until the solution turned orange, indicating the titration endpoint. Furthermore, the system successfully sent information about the titrant volume used via WhatsApp messages, allowing users to monitor the test results in real time. The citric acid weighing process is shown in Figure 6.

Figure 6. Weighing Citric Acid

A comparison of manual and automatic titration results is shown in Table 1. From the test results, it can be seen that most of the automatic system measurement results have values that are very close to the manual titration results.

Table 1. Tool Test Results

| No | Test Materials | Sample Mass (mg) | Manual Volume (ml) | Tool Volume (ml) |
|---|---|---|---|---|
| 1 | Citric Acid | 500 | 8.2 | 8.1 |
| 2 | Citric Acid | 650 | 10.2 | 10.2 |
| 3 | Citric Acid | 800 | 12.6 | 12.6 |
| 4 | Stearic Acid | 500 | 8,2 | 8.2 |
| 5 | Stearic Acid | 600 | 22.7 | 22.7 |
| 6 | Stearic Acid | 650 | 24.6 | 24.6 |
| 7 | Boric Acid | 500 | 31.7 | 31.7 |
| 8 | Boric Acid | 900 | 14.7 | 14.7 |
| 9 | Boric Acid | 1.5 | 24.5 | 31.7 |

### D. System Accuracy Analysis

Based on the test results, the automated titration system demonstrated a high level of accuracy in determining the volume of titrant solution required to reach the titration endpoint. In tests using citric acid, the measurement results showed very little difference between the manual and automated methods, with an accuracy level of approximately 98.7%. In tests using stearic acid, the manual and automated methods yielded identical results, indicating excellent accuracy.

However, in one test using boric acid, there was a difference in results between the manual and automated methods. This difference was likely caused by several factors, such as lighting conditions affecting the color sensor readings, solution inhomogeneity during the stirring process, and the chemical reaction characteristics of the tested materials. Overall, the test results demonstrated that the developed system is capable of performing the automated titration process with a level of accuracy approaching that of the manual method. Furthermore, this system offers the added advantage of real-time process monitoring via Internet of Things technology.

## 4. CONCLUSIONS

This study presented the design and implementation of an automated titration system for pharmaceutical raw material analysis using a TCS3200 RGB color sensor integrated with an ATmega2560 microcontroller. Experimental results demonstrate that the proposed system is capable of automatically detecting color changes during the titration process and determining the titration endpoint with a high level of accuracy. The system achieved an accuracy of up to 98.7% in the citric acid test and produced titrant volume measurements for stearic acid and boric acid that were comparable to those obtained using conventional manual titration methods.

The main contribution of this research lies in the integration of color-based endpoint detection, automated titrant control using a dosing pump, and IoT-based monitoring within a single system. This integration enables automated titration operation while providing real-time notification of measurement results via a messaging application, thereby reducing human intervention in the titration process.

The proposed system has important implications for pharmaceutical laboratory practices, as it can improve the efficiency, repeatability, and reliability of titration analysis while also supporting the development of digital laboratory environments through real-time monitoring capabilities. Future work may focus on improving sensor calibration techniques, enhancing titrant dispensing precision, and integrating cloud-based data management systems to support more advanced smart laboratory applications.

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