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Development of Fluoride Detection and Alert System for Drinking Water

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Abstract: Excess fluoride concentration in drinking water is a major public health concern in many regions. While fluoride in small amounts is beneficial, prolonged exposure to high concentrations can cause dental and skeletal fluorosis. This is the development of a low-cost reagent-based fluoride detection and alert system using a colourmetric analysis approach. The system utilizes a fluoride-specific chemical reagent that produces a measurable color change proportional to fluoride concentration. A TCS34725 RGB color sensor captures the intensity variation under controlled white LED illumination. The ESP32 microcontroller processes the RGB values, estimates fluoride concentration through calibration mapping, and compares it with permissible limits. Real-time monitoring and alert notifications are implemented through IoT cloud integration.

Keywords: Fluoride Detection, Colourmetric Analysis, TCS34725, ESP32, IoT Monitoring, Water Quality, Reagent-Based Detection

I. INTRODUCTION

Groundwater contamination due to excessive fluoride is a widespread issue in many developing regions. According to World Health Organization guidelines, fluoride concentration above 1.5 ppm in drinking water can cause adverse health effects. Traditional detection methods rely on laboratory spectrophotometers or ion-selective electrodes, which are expensive and unsuitable for real-time domestic monitoring.

To overcome these limitations, this project proposes a reagent-based colourmetric fluoride detection system[3]. integrated with cloud monitoring. Instead of using an ion-selective electrode, the system uses a chemical reagent that reacts with fluoride ions and produces a color variation proportional to fluoride concentration. The intensity of the color is captured using a TCS34725 RGB sensor, enabling low-cost semi-quantitative estimation.

II. WORKING PRINCIPLE

A. Colourmetric Detection Mechanism

When fluoride ions react with a specific reagent solution (such as SPADNS or equivalent zirconium-dye complex)[6]., a measurable color change occurs. The intensity of the resulting color depends on fluoride concentration.

Higher fluoride concentration → Stronger color change
Lower fluoride concentration → Lighter color intensity

This color variation forms the basis of optical detection.

B. Optical Sensing Principle

The System Uses:

High brightness white LED (constant illumination)

Transparent sample cuvette

TCS34725 RGB color sensor

C. Literature Review

Fluoride detection in drinking water has been an important area of research due to its direct impact on human health. The World Health Organization (WHO) has established guidelines indicating that excessive fluoride concentration can lead to serious health issues such as dental and skeletal fluorosis [1]. Traditional methods for fluoride detection, such as ion-selective electrodes and spectrophotometric techniques, are widely used in laboratories due to their accuracy; however, these methods are often expensive, time-consuming, and require skilled personnel [2]. Researchers have explored various chemical and adsorption-based techniques for fluoride removal and monitoring, highlighting the need for efficient and low-cost detection systems [3]. Studies conducted in India have also shown significant fluoride contamination in

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groundwater, emphasizing the importance of continuous monitoring in rural areas [4],[5].Colorimetric analysis using chemical reagents has emerged as a simple and cost-effective approach for fluoride detection. The SPADNS method is one of the widely used techniques, where fluoride reacts with a zirconium-dye complex, resulting in a measurable color change proportional to fluoride concentration [6]. Comparative studies between SPADNS and ion-selective electrode methods have demonstrated that the colorimetric approach is suitable for practical and field-level applications [7]. With advancements in embedded systems, researchers have started integrating sensors and micro-controllers to automate detection processes. The use of RGB color sensors, such as TCS34725, enables digital conversion of color intensity values, which can be further processed for analysis.In recent years, the integration of Internet of Things (IoT) technology has enhanced water quality monitoring systems by enabling real-time data acquisition and remote access. Microcontrollers like ESP32 provide built-in Wi-Fi capability, allowing sensor data to be transmitted to cloud platforms such as ThingSpeak for visualization and analysis [8].

III. MATHEMATICAL MODELING AND CALIBRATION

To estimate fluoride concentration, calibration is performed using standard fluoride samples of known ppm values.
A linear regression model is used:

$$ppm = mI + c \text{ [6].}$$

Where:
ppm = Fluoride concentration
I = Selected intensity parameter (e.g., Clear value or Blue channel)
m = Calibration slope
c = Calibration constant

During Calibration:
1 ppm → Record RGB values
2 ppm → Record RGB values
3 ppm → Record RGB values

Architecture

Sensing Unit :

The sensing unit includes:

White LED illumination system,

Reagent-treated water sample,

TCS34725 RGB sensor.

The LED ensures consistent lighting conditions, minimizing external light interference.

Processing Unit:

The ESP32 micro-controller:

Reads RGB values via I2C,

Applies calibration equation,

Calculates fluoride concentration,

Compares with threshold (1.5 ppm),

Triggers alert if exceeded.

Alert Mechanism:

If :

ppm > 1.5 → Red LED + Buzzer ON

Block Diagram:

The block diagram of the fluoride detection system illustrates the overall flow of the system from input to output. The process starts with the water sample mixed with SPADNS dye solution, which is placed in a glass cuvette. The cuvette is positioned in front of the TCS34725 color sensor, which detects the color characteristics and generates RGB and clear values. These values are sent to the ESP32 micro-controller, which processes the data and applies threshold-based logic

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to determine whether the water is safe or unsafe. Based on this decision, the LED and buzzer are activated to provide immediate alerts. At the same time, the ESP32 transmits the data to the ThingSpeak cloud using Wi-Fi, where it is stored and displayed in graphical form. The user can monitor the results through a mobile phone or laptop. Thus, the block diagram represents the interaction between sensing, processing, alert, and communication units of the system.

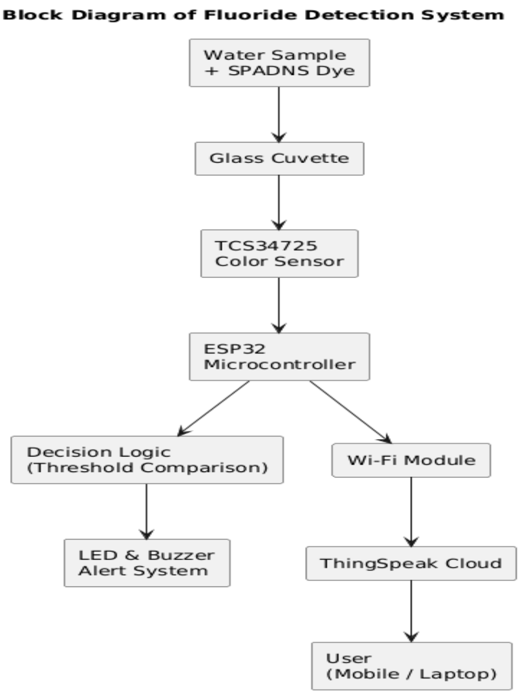

Fig 1 : Block Diagram

A. Prototype Design

Sensing Chamber (Black Box):

The sensing chamber is designed using a closed black box structure to block external light and create a controlled environment for accurate color detection. It helps in maintaining consistency in readings by preventing interference from ambient light. The chamber also ensures proper alignment of the glass cuvette and the color sensor, which improves the reliability of the measurements.

Glass Cuvette :

The glass cuvette is used to hold the water sample mixed with the SPADNS reagent. It is transparent, allowing proper transmission and reflection of light for accurate sensing.

TCS34725 Color Sensor :

The TCS34725 color sensor is responsible for detecting the color of the treated water sample.

ESP32 Microcontroller :

The ESP32 micro-controller acts as the main processing unit of the system. It receives the color data from the sensor and processes it using predefined threshold logic to determine whether the water is safe or unsafe. It also controls the LED and buzzer for alert generation and transmits the data to the Thing-Speak cloud platform using its built-in Wi-Fi capability[9].

LED Indicator :

The LED indicator provides a visual output for the system. It turns ON when an unsafe water condition is detected, allowing the user to quickly identify the status of the water sample without checking the display or cloud platform.

Buzzer :

The buzzer is used to provide an audible alert when unsafe water is detected. It helps in giving immediate warning to the user, especially in situations where visual monitoring is not possible.

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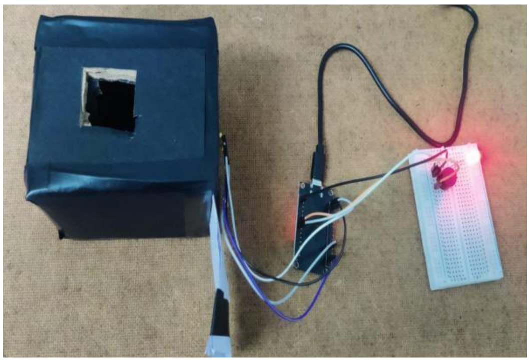

Fig 2 : Prototype

IV. RESULTS

```
WiFi Connected
Red Value = 179
Clear Value = 274
Calculated Formula: (Red / Clear) x 10 = (179 / 274) x 10 = 6.53
Status: Water is NOT Safe to Drink
Data sent to ThingSpeak
----------------------
Red Value = 37
Clear Value = 84
Calculated Formula: (Red / Clear) x 10 = (37 / 84) x 10 = 4.40
Status: Water is Safe to Drink
Data sent to ThingSpeak
```

Fig 3 : Fluoride Detected result

In the figure 3 , it is the output shown in the serial monitor , when the fluoride is detected , it shows the intensity of the red color and the clear value to calculate the PPM(Parts Per Million) in the water

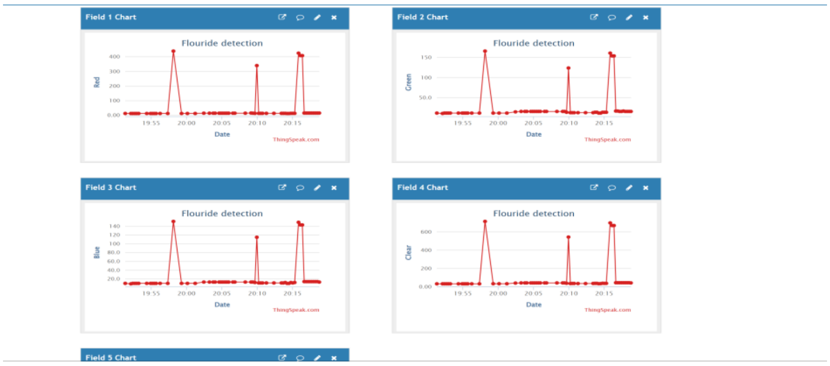

Fig 4: Graphs In the ThingSpeak cloud

In the figure 4 , it is shown the outputs in the cloud platform called ThingSpeak , it shows the intensity of the red color in the red field , when fluoride is detected. And the other fileds for the RGB detection , first is for the red field , second is Green field for green color and blue is for Blue color and the Clear field is for showing the clear value graph , it means how much intensity of light is coming to the RGB sensor.

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Fig 5: status graph in the ThingSpeak cloud

In the figure 5, it shows the status of the fluoride detected , when the PPM is above 1 then the graph reaches its peak value in the status field

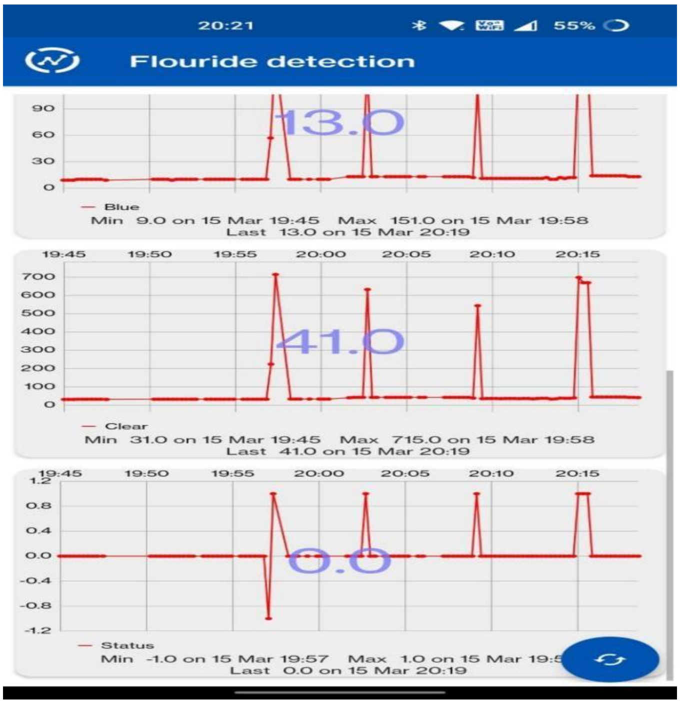

Fig 6: Graph on mobile before detection

In this figure 6 shows the ThingSpeak cloud interface accessed on a mobile device. The system is connected to the same Wi-Fi network, allowing real-time monitoring of the sensor data through the ThingSpeak application. The displayed graphs represent the transmitted values from the system before fluoride detection.

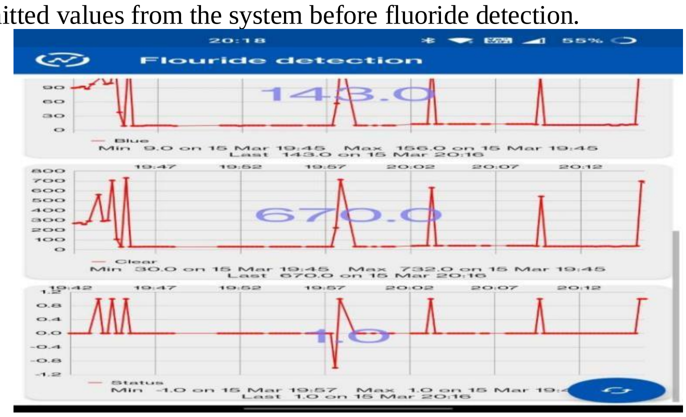

Fig 7: Graph on mobile after flouride detected

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In this figure 7 shows the ThingSpeak cloud interface accessed on a mobile device. The system is connected to the same Wi-Fi network, allowing real-time monitoring of the sensor data through the ThingSpeak application. The displayed graphs represent the transmitted values from the system after fluoride detection. As observed in the status field, the value is recorded as "1," indicating that the water is classified as unsafe.

Fig 8: LED and BUZZER alert

In the figure 8, it shows the alert system of the fluoride system , when the sensor detects the PPM is above 1 , then via Esp 32 the signal is transmitted and the RED led is shown and buzzer starts to make noise to alert the people near them.

V. CONCLUSION

The developed fluoride detection system provides a simple, low-cost, and effective approach for basic water quality monitoring using a reagent-based colorimetric method. By combining SPADNS dye solution, a TCS34725 color sensor, and an ESP32 microcontroller, the system is able to detect the color response of the treated water sample and classify it as safe or unsafe based on predefined threshold conditions. The inclusion of LED and buzzer alerts enables immediate local indication, while the integration of the ThingSpeak cloud platform allows real-time remote monitoring and graphical visualization of sensor readings and water status. The project successfully demonstrates how embedded systems, color sensing, and IoT communication can be combined to create a practical fluoride detection and monitoring model. Although the system is mainly intended for academic demonstration and basic analysis rather than precise laboratory-grade measurement, it offers a useful foundation for future enhancements such as improved calibration, more accurate fluoride concentration estimation, advanced mobile alert systems, and deployment in larger real-time water monitoring applications.

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