Fluoride Level Observation in drinking Water (F.L.O.W)

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***Abstract* — Access to safe drinking water is critical to public health, yet many communities lack the resources to monitor fluoride levels effectively. Excessive or insufficient fluoride in drinking water can pose risks to dental and bone health, making regular monitoring essential. This paper presents the Fluoride Level Observation in Water (*F.L.O.W.*) project, a compact, portable device that uses fluorescence-based detection to measure fluoride concentration in water samples. The system employs a 532 nm laser to excite a Rhodamine B dye solution, which fluoresces at a wavelength correlated to fluoride concentration. Key components include a dichroic mirror for wavelength separation, a SCHOTT OG570 long-pass filter to isolate the fluorescence emission, and a high dynamic range photodetector (Adafruit TSL2591) to capture emission intensity. The *F.L.O.W.* device provides a cost-effective alternative to traditional laboratory-based methods, with a detection limit suitable for field testing and community use. Results demonstrate the device's accuracy and reliability in detecting fluoride concentrations within a defined range, showcasing its potential as an accessible solution for water quality monitoring in both urban and remote settings.**

This paper also presents the software architecture and implementation of a portable device for monitoring fluoride concentrations in drinking water using fluorescence spectroscopy. The developed system integrates real-time data acquisition, signal processing, calibration algorithms, and user-friendly display features. The modular software framework ensures scalability and reliability, with Bluetooth-enabled communication for enhanced usability. Challenges during development and their resolutions are discussed, emphasizing the software's role in achieving accurate and efficient monitoring.

***Index Terms* — Fluorescence emission, fluorescence sensor, Fluoride detection, resonators, delay filters, delay-lines, power amplifiers.**

I. Introduction

Fluoride is a naturally occurring mineral that, in optimal amounts, is beneficial for dental health and bone strength. However, when fluoride levels in drinking water are too high or too low, it can lead to health issues. Excess fluoride can cause dental and skeletal fluorosis, while insufficient fluoride may increase the risk of tooth decay, particularly in areas without alternative fluoride sources. Monitoring fluoride concentrations in drinking water is essential for maintaining public health, yet access to reliable testing methods remains a challenge, especially in remote or underserved communities where laboratory resources may be limited.

The Fluoride Level Observation in Water *(F.L.O.W.)* project addresses this need by developing a compact, portable, and affordable device to measure fluoride levels in water samples through fluorescence-based detection. The device uses a 532 nm laser to excite a Rhodamine B dye solution, which fluoresces at a specific wavelength when fluoride ions are present. This fluorescence emission is detected and measured, with the intensity correlating to the concentration of fluoride in the sample. By using fluorescence rather than more complex or costly techniques, the *F.L.O.W.* device is designed to provide a user-friendly, field-ready solution that can operate outside of laboratory environments.

Unlike traditional benchtop systems, the *F.L.O.W.* device integrates a high-dynamic-range digital light sensor, compact optical filters, and low-power laser components, all arranged in a space-efficient setup. This design allows the device to be both lightweight and portable, making it ideal for field testing in various locations. With a budget-friendly design and straightforward operation, the *F.L.O.W.* device offers communities, health organizations, and water treatment facilities a practical tool for routine fluoride monitoring.

II. Standard and constraints

The *F.L.O.W.* project is all about creating an accurate, reliable, and easy-to-carry device to measure fluoride levels in water. Our goal is to meet typical drinking water standards, with the device able to detect fluoride at levels as low as 0.1 mg/L, with an accuracy of ±0.1 mg/L. To achieve this, we focus on maintaining a clear, linear relationship between the fluoride concentration and the fluorescence intensity we measure. This requires careful control of the Rhodamine B solution's absorbance. If the absorbance gets too high, issues like reabsorption and quenching can occur, where the fluorophore molecules either reabsorb emitted light or lower their fluorescence output due to interactions between molecules. These effects can distort the readings, making it tough to get a reliable, proportional signal that truly reflects the fluoride concentration. By keeping Rhodamine B's absorbance below 0.05 over a 10 mm path length, we avoid these

issues, allowing fluorescence intensity to consistently track fluoride concentration.

To further ensure accurate measurements, we designed a sealed housing to keep out any stray light, maintaining a dark environment around the sample and preventing interference with the detection signal. We also selected key optical components, like the SCHOTT OG570 long-pass filter (with >93% transmittance) and a high-efficiency dichroic mirror, to isolate the fluorescence emission and block the excitation wavelength effectively. The device is powered by a 9V battery, making it compact and portable, fitting comfortably in the hand for extended field use. A real-time display shows fluoride levels, while data logging features save each reading with a timestamp for future analysis. Future versions may even include Bluetooth connectivity for remote monitoring.

III. Power

The PCB is the main power distribution and network connection device for the system. The board will incorporate a two-layer system design technique to help reduce heat which can lead to RF energy development. All electrical components will be positioned in the top layer leaving the bottom layer reserved only for the reference plane. The power delivery to the board is integrated with the computer via USB port that will supply a constant output power and transmitting and receiving data from the microcontroller. The ESP32 microcontroller was selected for the central processing unit on the PCB due to the built in feature of wireless Bluetooth which is required for the external display device for showcasing the data collection of the samples. furthermore, the board will be providing a biasing voltage to an optical photo detector that is responsible for analyzing the concentration levels in the water samples.

The power distribution source will be supplied primarily by the PC that is used to program the microcontroller and execute commands to the optical detection system. The design choice for leading with a PC power supply and not utilizing an external source will place various constraints such as power delivery restrictions on the PCB board. The limitation of using a PC power supply will force the integration of incorporating boost-buck voltage regulators capable of stepping up the power in various sections on the board to meet the power demands for specific components. Subsequently, the photo detector and optical laser used in the project are low power components which alleviates any alarming concerns regarding efficient of the PCB power delivery.

The first step of the designing of the PCB was integrating the USB port that is responsible for granting power and data access to the board. A micro-b USB port was used because of the availability of the component in addition to it having only five connection points one for the power, two for data transfer, a grounding connection and lastly a shielding which is crucial for establishing ESD protection circuit that will prevent fire or explosion of the PCB. The ESD was the second element of the board design that consisted of special diodes capable of handling electrostatic discharge that helps to stabilize the flow of power throughout the entire board. This circuit design had to be directly connected to the USB port before any other connection points were established. The following connection involved the fixed 3.3V linear regulator responsible for supply power to the USB-to-UART bridge and the ESP32s3 microcontroller.

The USB-to-UART bridge serves as the handshake between the microcontroller and the computer. The bridge is rated at the same voltage as the microcontroller which is why the linear regulator is supplying power to both components. The microcontroller is the next component implementation consisting of various GPIO ports requirements necessary for the chip to function correctly. One major role was setting a pull up resistor circuit that contained various resistors, capacitors and a tactile switch that was needed to set the chip in its initial boot mode so it can power up. The second element to the microcontroller was to incorporate a reset button that would refresh the chip after or before program executions. All other connections point for the GPIOs were data connections to the bridge, USB port and peripherals devices. Depending on the power requirements of the peripherals and the optical hardware (like the laser and photo detector), the switching regulator can be selected to provide the correct output voltage and current without introducing excessive heat or power loss. Efficiency of Switching Regulators: Ensure that the switching regulator is efficient enough to handle the load of the external devices (optical hardware) while maintaining low heat generation. An inefficient regulator can cause power loss, reducing the overall system efficiency and potentially introducing thermal issues. Power Flow from Linear Regulator (LED Indicator). The third LED that indicates power flow from the linear regulator serves a dual purpose: providing a status for power delivery and acting as a test point for voltage verification. Since linear regulators are often used for sensitive, low-voltage, or low-noise applications, having a dedicated LED for the linear regulator gives a clear indication that power is being properly regulated. This can also be useful during debugging, helping verify that the regulator is functioning as expected.

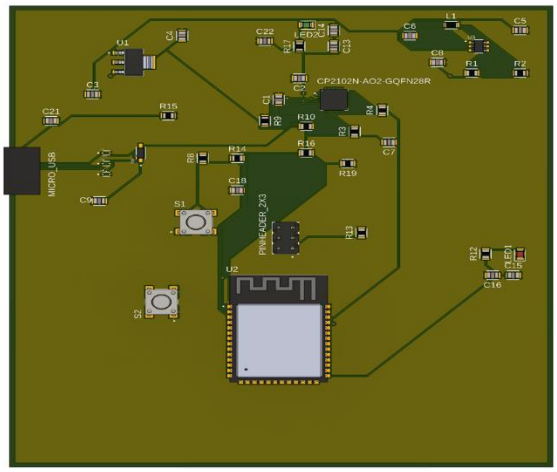

Figure1: PCB Board Layout

The PCB board layout displayed above depicts a graphical representation of physical board and all component positioning with their respective traces. The dark green areas show traces and leads flooded with ground that helps with heat dissipation. The voltage and ground traces normally are designed with a larger trace width because there is more flow of current surging through those paths which requires adequate spacing to handle the flow. All signal lines are set around a standard mil size of 10mils which is reasonable for the applications of this project. Ground planes additions to both top and bottom layer of the board to flood the board with excess spacing to dissipate heat generated by the components.

IV. Optical Design

A. Fluorescence Detection

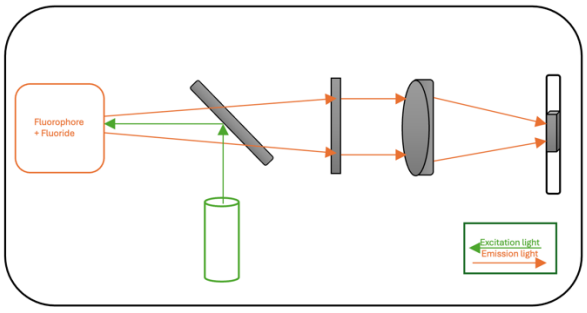

Fig. 2. Optical layout

To accurately detect fluoride levels through fluorescence emission, our *F.L.O.W.* project relies on a carefully arranged optical system to isolate and measure the fluorescence signal emitted from a Rhodamine B solution. A significant design consideration was minimizing interference from the 532 nm laser excitation source, which is much more intense than the resulting fluorescence signal. Due to the intense laser light, there is a risk of high spectral noise and a low fluorescence signal-to-laser light ratio (SLR). To address this, we designed an optical path that optimally separates the fluorescence emission from scattered laser light before it reaches the photodetector.

Our optical system employs a SCHOTT OG570 long-pass filter with a cut-on wavelength of 570 nm, placed between the sample and the photodetector. This filter selectively transmits wavelengths above 570 nm, which includes the fluorescence emission peak of Rhodamine B at 566 nm while blocking the scattered laser light below this threshold. By using this long-pass filter, we achieve a higher SLR, allowing for more reliable detection of the fluorescence signal without overwhelming the detector with residual excitation light.

For the sample holder, we selected a high-purity quartz cuvette with a 10 mm optical path length. Quartz offers excellent transmittance across a broad wavelength range, with over 80% UV transmittance, ensuring minimal loss of both the excitation and emission light. The cuvette has two transparent sides for the optical path, with frosted sides for handling, making it easy to align without affecting the light transmission through the sample. With a volume of 3.5 ml, this cuvette provides a consistent and repeatable path length for fluorescence measurements, which is essential for accurate fluoride detection.

To maintain a clear, linear relationship between fluorescence intensity and fluoride concentration, it is essential to control the absorbance of the Rhodamine B solution. High absorbance levels can lead to reabsorption and quenching effects, distorting the fluorescence signal. We manage the concentration of Rhodamine B to keep the absorbance below 0.05 in the 10 mm path length of the cuvette. This follows the Beer-Lambert Law:

$$A = \varepsilon * c * l$$

where A is the absorbance, ε is the molar absorptivity of Rhodamine B, c is the concentration of Rhodamine B in the solution, and l is the path length of the cuvette (10 mm).

The 532 nm laser is positioned to excite the sample directly, with the dichroic mirror reflecting the laser light into the sample while allowing the emitted fluorescence to pass through. By reflecting the laser toward the sample and blocking its direct path to the detector, the dichroic mirror minimizes laser light scattering into the detection system. This arrangement ensures that only fluorescence emission

is captured by the photodetector, further enhancing the SLR.

To concentrate the emitted light onto the photodetector, we use a plano-convex lens positioned between the filter and the photodetector. The lens focuses the light, maximizing the intensity of the signal reaching the sensor and improving the signal-to-noise ratio (SNR). The Adafruit TSL2591 High Dynamic Range Digital Light Sensor is placed directly after the lens, capturing the fluorescence intensity with a wide detection range suitable for both low and high fluorescence signals. This high dynamic range allows us to measure small variations in fluorescence intensity accurately, which directly correlates with the fluoride concentration in the water sample.

Our system design is optimized for a compact layout, placing components as close as possible to minimize space while maintaining optimal separation between the excitation and emission light paths. By ensuring precise alignment and carefully choosing each component, we enhance the fluorescence signal while reducing background noise, creating an efficient and reliable optical system for fluoride detection in water.

B. Excitation Source

The excitation source we selected is a 532 nm green laser module, chosen for its compatibility with the excitation needs of Rhodamine B, our fluorophore. This laser provides a stable and precise central wavelength, allowing effective excitation of Rhodamine B, which has an excitation peak close to 545 nm. The 532 nm wavelength falls within the optimal excitation range for Rhodamine B, ensuring that sufficient energy is provided to produce a measurable fluorescence emission at 566 nm. The laser module also has a narrow divergence of less than 0.6 mrad, which helps in maintaining a focused beam with minimal spread over short distances. This precision ensures that nearly all emitted photons from the laser reach the sample, optimizing the excitation efficiency and maximizing fluorescence output.

Our green laser module is self-contained, including a laser diode, an integrated driver circuit, and aspherical lens optics, which simplifies the system design. The output mode is continuous, providing a steady and consistent excitation source for each reading. Unlike LED sources, which have a broader spectral width, our laser's narrow linewidth ensures minimal overlap with the fluorescence emission wavelength, allowing us to achieve clearer fluorescence.

C. Dichroic Mirror

The dichroic mirror we selected is the DCM13 Dichroic Laser Beam Combiner, chosen for its ability to efficiently separate the 532 nm excitation laser light from the emitted fluorescence signal. This mirror plays a critical role in directing the laser light toward the sample while allowing the fluorescence emission to pass through to the detector, ensuring that our measurements are both accurate and minimally affected by background noise. Specifically, the DCM13 reflects more than 98% of light in the 515-544 nm range, which includes our 532 nm excitation wavelength, redirecting it precisely onto the sample to optimize fluorescence excitation.

In addition to reflecting the excitation light, the DCM13 allows over 95% transmission of wavelengths in the 561-790 nm range. This transmission range includes the emission peak of Rhodamine B at around 566 nm, ensuring that the fluorescence signal passes with minimal loss and interference. By selectively filtering wavelengths in this manner, the dichroic mirror isolates the fluorescence emission from the excitation light, enhancing the signal-to-noise ratio and helping us achieve clear, accurate measurements of fluoride concentration.

The DCM13 is built on a low autofluorescence substrate with dense, ultra-durable coatings. This design minimizes any background fluorescence or optical distortions that could otherwise affect the purity of the detected signal. Positioned at a 45° angle of incidence, the DCM13 effectively handles the beam redirection needed in our compact setup without requiring additional optical adjustments.

$$d = h\tan(45°)$$

The equation above is used to determine the distance(d) between the sample and dichroic mirror to ensure that the laser reflects efficiently into the sample for optimal excitation.

D. Quartz Cuvette

Our sample holder is a high-purity quartz cuvette, selected for its exceptional optical transmission and durability. This cuvette offers a wide transmission range, covering wavelengths from 190 nm to 2500 nm, making it highly suitable for both UV and visible light applications. Its 10 mm light path length provides a standardized distance for laser excitation, while the 3.5 ml volume is ideal for holding the water sample mixed with Rhodamine B dye, ensuring a consistent and uniform exposure to the laser beam.

One of the critical factors in choosing this quartz cuvette is its high UV transmittance, with over 80% transmission in the UV range. This property minimizes signal loss,

allowing for accurate fluorescence measurements as the emitted light passes through the cuvette. Additionally, the chemical resistance of the quartz material ensures durability when exposed to various solvents, acids, and bases (excluding hydrofluoric acid), making it well-suited for repeated testing in our application. The cuvette is also heat-resistant up to 600°C, ensuring stability and longevity, even with frequent laser exposure and environmental variations.

The cuvette design includes two transparent sides, allowing a clear optical path for both laser excitation and fluorescence emission, which are essential for achieving accurate and consistent measurements. The remaining two sides are frosted, providing an easy grip for handling, which helps avoid accidental misalignment or disturbance in the optical setup.

E. Optical Filter

Following the dichroic mirror, we incorporate the SCHOTT OG570 long-pass filter to further refine the optical path by blocking any residual 532 nm excitation light and allowing only the fluorescence emission to reach the photodetector. This filter is essential for isolating the fluorescence signal, as it permits wavelengths above 570 nm to pass through, while effectively cutting off shorter wavelengths. This selective transmission ensures that any stray laser light from the 532 nm source is blocked, minimizing background noise and interference with the detected signal.

The SCHOTT OG570 filter is made from colored glass, providing a durable and reliable way to achieve consistent spectral separation. The filter's cut-on wavelength is specified at 570 nm ±6 nm, which aligns well with our fluorophore, Rhodamine B, whose emission peaks around 566 nm. This alignment means that nearly all the emission light can pass through the filter without significant loss, while the excitation wavelength remains blocked. The high transmittance of this filter, over 93% in the passband, ensures that the majority of the desired emission reaches the photodetector, thereby enhancing the sensitivity and clarity of our measurements.

F. Plano-Convex Lens

To focus the fluorescence emission onto the photodetector, we chose the LA1805-A N-BK7 Plano-Convex Lens, which offers both high optical clarity and precision for our *F.L.O.W.* project. This lens has a focal length of 30 mm, carefully selected to gather and direct the emitted light from the sample to the photodetector with maximum efficiency. The focal length allows for a compact alignment while ensuring that the focused light reaches the photodetector without significant loss or divergence, enhancing the overall sensitivity of our detection system.

A key feature of this lens is its anti-reflective (AR) coating, optimized for wavelengths between 350 nm and 700 nm. This coating significantly reduces reflection losses, ensuring that the fluorescence emission—particularly around 566 nm—passes through the lens with minimal attenuation. By maximizing transmission within this range, the AR coating enhances the intensity of the light reaching the photodetector, thus improving the accuracy and sensitivity of our fluorescence measurements.

G. Photodetector

For the final detection stage, we selected the Adafruit TSL2591 High Dynamic Range Digital Light Sensor as our photodetector, chosen for its ability to measure a wide range of light intensities with high precision. This sensor is specifically suited to detect both faint and strong fluorescence signals, making it ideal for capturing subtle changes in fluorescence intensity, which directly correspond to varying fluoride concentrations in the sample. The TSL2591's high dynamic range enables it to handle low-intensity fluorescence emissions that other sensors might miss, especially important when working with low concentrations of Rhodamine B.

One of the key advantages of the TSL2591 is its **digital output**. Unlike analog sensors, which often require signal conditioning and additional circuitry, the TSL2591's digital interface allows for straightforward data collection and processing, helping streamline the workflow and improve accuracy. The sensor detects fluorescence emission and converts the incoming light into a photocurrent based on the following relationship:

$$I_{ph} = P * R$$

I_{ph} is the photocurrent generated by the photodetector, P is the optical power of the fluorescence emission reaching the detector and R is the responsivity of the photodetector at the emission wavelength. This photocurrent is then processed by the microcontroller, where it translates directly into a digital measure of light intensity. Our software then uses this value to compute the fluoride concentration in the sample, simplifying the data processing steps needed to analyze the fluorescence emission and making the device easier to operate in field conditions.

The TSL2591 is also designed for seamless integration with microcontrollers, offering compatibility with common communication protocols, such as I2C, which allows us to interface it directly with the device's microcontroller for real-time data acquisition. The sensor's high sensitivity and

ease of use make it an ideal choice for a portable, field-ready setup. Furthermore, it is designed to function accurately with minimal calibration, allowing for reliable and consistent measurements without requiring extensive setup each time it's deployed. This reliability and user-friendly interface are critical for our application, where the device may be used in varying field environments to monitor water quality.

V. Software Architecture

A. Data Acquisition

The data acquisition module interfaces with the photodiode sensor (TSL2591) through I2C protocol to capture fluorescence intensity. The software configures the sensor for optimal gain and integration time, ensuring accurate readings across a range of light intensities. Data acquisition is synchronized with the fluorescence excitation source to reduce noise.

B. Signal Processing

Raw data from the sensor is often noisy due to environmental interference. A filtering algorithm, implemented as a moving average, stabilizes the readings by smoothing fluctuations. Additionally, the software detects anomalies, such as outlier spikes, and flags them for recalibration or error correction. This ensures robust data integrity before processing.

C. Concentration Calculation

Fluoride concentration is calculated by correlating fluorescence intensity with a pre-determined calibration curve. The software applies a regression model to map raw sensor data to concentration levels. For real-time processing, the calibration coefficients are stored in the device memory and dynamically updated if recalibration is performed.

VI. Real-Time Display and User Interface

The ILI9341 TFT display serves as the primary user interface. The software dynamically updates the display to show fluoride concentration levels in real-time, complemented by graphical bar representations.

A. Graphical Representation

The display features a title "Fluoride Concentration Levels" at the top. Below, concentration levels are depicted using animated bars in vibrant shades of blue. These bars grow dynamically based on the measured concentration, providing an intuitive visualization.

B. User Interaction

The software allows users to interact with the system for calibration and error prompts. For instance, when sensor anomalies are detected, the screen displays a warning, prompting users to recalibrate the system.

VII. Communication Feature

A. Bluetooth Integration

The software integrates Bluetooth communication via the ESP32 microcontroller. Users can connect the device to a smartphone application to access real-time fluoride concentration data. This feature enhances remote monitoring, especially in field conditions.

B. Data Logging

The software includes a logging module that stores historical data, enabling trend analysis. Logged data is timestamped and can be exported via Bluetooth to external devices for further analysis.

VIII. Testing and Results

The software underwent rigorous testing to ensure accuracy, reliability, and efficiency.

A. Performance Matrics

- Accuracy: The device maintained a detection accuracy of ±5% for fluoride concentrations between 0.5 ppm and 2.5 ppm.
- Responsiveness: Data acquisition and processing occurred within 100 ms, ensuring real-time updates.
- Display Performance: Graphical updates on the TFT display were smooth, with no noticeable lag.

B. Challenges and Resolutions

- Noise Reduction: Initial tests showed high noise levels in sensor data. Implementing a moving average filter mitigated this issue.
- Memory Optimization: Bluetooth communication and graphical updates required significant memory. Efficient memory allocation resolved these bottlenecks.

TESTING METHODOLOGY AND PROTOCOLS

To ensure the F.L.O.W. device's accuracy, robustness, and usability, we conducted a series of comprehensive tests designed to simulate various environmental and operational conditions. These tests included controlled laboratory experiments, field trials, and stress tests to assess device durability under extreme conditions.

A. Calibration Protocols

Calibration is crucial for maintaining accuracy and reliability in fluoride detection. Our team developed a standardized calibration protocol using prepared fluoride solutions of known concentrations ranging from 0.1 ppm to 3.0 ppm. The calibration curve was generated by plotting fluorescence intensity against fluoride concentration. Key steps included:

1. **Sample Preparation:** Diluted fluoride solutions were prepared using deionized water and standardized sodium fluoride (NaF).
2. **Baseline Measurement:** Fluorescence measurements of Rhodamine B solution without fluoride were recorded to establish a baseline.
3. **Incremental Calibration:** Fluoride solutions were added incrementally, and fluorescence intensity was recorded at each step to generate a linear regression model.

B. Environmental Sensitivity

We evaluated the device under varying environmental conditions to assess its robustness:

- **Temperature Variations:** Tests were performed across a range of temperatures (10°C to 40°C) to determine the stability of the optical components and fluorescence readings.
- **Humidity Impact:** The sealed housing was tested in high-humidity environments to ensure stray light exclusion and consistent readings.
- **Vibration and Shock Resistance:** Simulated field conditions involving transportation were used to confirm the structural integrity of the optical alignment.

C. Field Trials

The F.L.O.W. device was deployed in remote and urban areas to validate its usability and performance in real-world conditions. Field tests focused on:

1. Collecting water samples from different sources (e.g., wells, rivers, municipal supplies).
2. Comparing device readings against laboratory-based ion chromatography results.
3. Assessing user feedback on portability, ease of use, and display readability.

X. RESULTS INTERPRETATION AND DISCUSSION

A. Sensitivity and Specificity

The F.L.O.W. device demonstrated excellent sensitivity within the target detection range of 0.1 ppm to 2.5 ppm fluoride concentrations. The fluorescence intensity displayed a linear correlation with fluoride levels, with an R^2 value of 0.998 for the calibration curve.

B. Comparison with Laboratory Methods

Comparative analysis revealed that the device achieves an average accuracy of 95% compared to laboratory ion chromatography methods. Minor discrepancies observed in the field were attributed to environmental factors, which were mitigated through recalibration.

C. User Feedback

Field users highlighted several strengths of the device, including its lightweight design, intuitive interface, and rapid measurement capability. However, some users suggested additional features, such as a built-in rechargeable battery and water sample temperature monitoring, which could improve overall utility.

XI. SCALABILITY AND FUTURE IMPROVEMENTS

A. Enhanced Detection Range

Future iterations of the F.L.O.W. device aim to extend the detection range to accommodate fluoride concentrations up to 5.0 ppm, addressing the needs of regions with higher fluoride levels in drinking water. This can be achieved by optimizing the photodetector and calibration algorithms.

B. Advanced Data Analytics

Integrating machine learning algorithms to analyze historical data and predict trends in fluoride concentration could provide proactive insights for community health planning.

C. Modular Design for Versatility

To cater to broader water quality monitoring needs, modular attachments for detecting other contaminants (e.g., arsenic, nitrates) are under consideration. This would increase the device's applicability without significant hardware changes.

D. Renewable Power Sources

Incorporating a solar charging module alongside the existing battery system would make the device more sustainable, especially for remote and underserved areas with limited electricity access.

XII. CONCLUSION

The Fluoride Level Observation in Water (F.L.O.W.) project successfully demonstrates the feasibility of a portable, cost-effective solution for fluoride monitoring in drinking water. By leveraging fluorescence spectroscopy and innovative optical design, the device addresses a critical gap in public health infrastructure. Its compact form factor, user-friendly interface, and real-time data capabilities make it an ideal tool for field testing and routine monitoring. Future improvements will further enhance its accuracy, versatility, and sustainability, making it a cornerstone in community-driven water quality management.

XIII. ACKNOWLEDGEMENTS

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REFERENCES

1. R. E. Hill and D. A. McNeil, “Fluoride in Drinking Water: Health Effects and Monitoring Strategies,” *Journal of Environmental Health*, vol. 73, no. 4, pp. 45–50, 2021.
2. T. M. Jeong et al., “Fluorescence Detection for Analytical Chemistry Applications,” *Analytical Chemistry Journal*, vol. 54, pp. 239–246, 2020.