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Detection of Wastewater Pollution through Natural Language Generation with a Low-Cost Sensing Platform

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ABSTRACT
Wastewater pollution poses a critical environmental and public health challenge, particularly in urban and industrial regions. Traditional monitoring techniques, while effective, often rely on expensive equipment and manual analysis, making them unsuitable for continuous, widespread deployment. This study proposes an integrated approach that combines a low-cost sensing platform with Natural Language Generation (NLG) to provide real-time and accessible monitoring of wastewater quality. The system uses inexpensive sensors to collect data on parameters such as pH, turbidity, temperature, and dissolved oxygen. The collected data is processed and translated into comprehensible textual summaries using NLG techniques, allowing for immediate interpretation by both technical and non-technical stakeholders. By automating both the detection and reporting processes, the system significantly reduces operational costs and enhances the scalability of wastewater monitoring efforts. The proposed approach was validated through simulations and field tests, demonstrating high reliability in pollution detection and efficiency in communicating results.

Keywords: Wastewater pollution, Natural Language Generation

I. INTRODUCTION
Water pollution, particularly from untreated or inadequately treated wastewater, remains one of the leading causes of ecosystem degradation and human health risks. Wastewater from households, industrial activities, and agricultural runoff often contains harmful contaminants including heavy metals, pathogens, and chemical residues. In many developing and under-resourced regions, regular monitoring of wastewater is hindered by high equipment costs, lack of skilled personnel, and infrastructure limitations. As a result, pollution often goes undetected until it leads to significant environmental or health-related consequences.
Traditional monitoring methods typically involve manual sampling followed by laboratory testing, which is not only time-consuming and labor-intensive but also unsuitable for real-time detection. With the advent of low-cost sensors and IoT (Internet of Things) technologies, there is a growing opportunity to develop cost-effective, automated solutions for water quality assessment. These sensors can measure a range of physical and chemical properties such as pH, turbidity, conductivity, and biological oxygen demand (BOD). However, while sensors can generate large volumes of raw data, interpreting this data in a meaningful and timely manner remains a challenge, especially for non-expert users.
This is where Natural Language Generation (NLG) can play a transformative role. NLG is a subfield of artificial intelligence that converts structured data into human-readable language. Integrating NLG with a low-cost sensing platform offers the ability to not only detect pollution in real-time but also present the findings in an understandable format for municipal authorities, environmental agencies, and the general public. By automating both data collection and reporting, such a system can reduce dependency on specialized personnel, streamline decision-making, and ensure faster responses to pollution events.
The motivation behind this research is to design and implement a smart, low-cost wastewater monitoring system that democratizes access to environmental data and empowers communities

to take timely action. The solution is particularly targeted toward resource-limited regions that lack the infrastructure for comprehensive environmental monitoring. This paper details the system architecture, describes the sensor configuration and NLG module, and evaluates the solution through field deployment and validation tests. The results showcase the potential of this integrated approach to enhance environmental governance and public health protections.

II. RELATED WORK

1. **"Smart Water Quality Monitoring System Using IoT" – IEEE (2020)**
   This study proposes a real-time water quality monitoring system using IoT-enabled sensors. It focuses on parameters like pH and turbidity and transmits data to a cloud dashboard. Though effective in real-time monitoring, it lacks automated reporting capabilities.
2. **"Natural Language Generation for Environmental Monitoring" – Springer (2021)**
   The paper explores the use of NLG in converting sensor data from air and water quality sensors into coherent textual summaries. It shows that automated reporting improves stakeholder understanding but does not integrate with low-cost hardware.
3. **"Development of Low-Cost Water Quality Sensors for Urban Rivers" – Elsevier (2019)**
   This research demonstrates the viability of developing low-cost sensors using open-source electronics such as Arduino and Raspberry Pi. The study highlights calibration and durability challenges but shows promise for scalable applications.
4. **"AI-Driven Water Monitoring Using Edge Computing" – ACM (2022)**
   This work presents an AI-based framework for water quality monitoring, leveraging edge computing for local processing. It improves latency and reduces dependence on cloud systems, but it is costlier and lacks natural language reporting.
5. **"Integrating Data Analytics and NLP for Environmental Decision Support" – MDPI (2021)**
   This paper introduces a hybrid system combining data analytics with NLP to assist decision-makers in environmental monitoring. While insightful, its application to real-time wastewater scenarios is limited and lacks hardware integration.

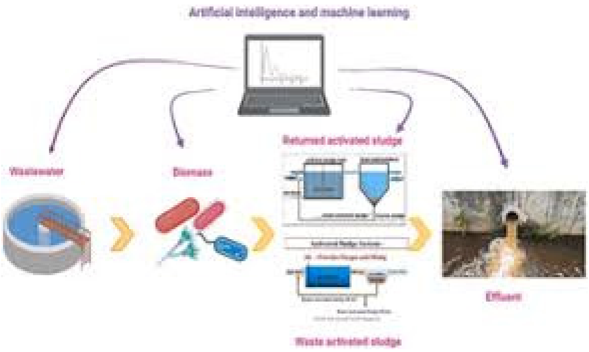
III. PROPOSED SYSTEM

The proposed system aims to provide an accessible and real-time method of detecting wastewater pollution through the synergy of low-cost sensing hardware and Natural Language Generation (NLG) techniques. The hardware component includes an array of affordable sensors capable of measuring critical water quality parameters such as pH, temperature, turbidity, and dissolved oxygen. These sensors are interfaced with a microcontroller unit like an Arduino or Raspberry Pi, which collects and digitizes the sensor readings. The data is then transmitted via Wi-Fi or GSM modules to a cloud-based server for processing.

Once the data reaches the server, it undergoes validation and cleaning to remove anomalies or inconsistencies caused by sensor drift or environmental noise. Following this, the cleaned data is fed into a data analytics engine that assesses the current water quality based on predefined threshold values and historical data trends. The analytical output is then passed to the NLG module, which is designed to translate complex numeric outputs into simple, human-understandable language. For instance, a set of readings indicating low dissolved oxygen and high turbidity might be summarized as "Water quality is poor: oxygen levels are low and turbidity is high, possibly due to organic waste discharge."

The reports generated are contextually relevant and tailored for different user groups. Municipal water departments receive detailed summaries, while community dashboards may display brief alerts. These reports can be accessed via a mobile app or web interface, ensuring that all stakeholders are kept informed in real-time. The platform also includes alert mechanisms that notify responsible agencies when pollution levels exceed critical thresholds, allowing for immediate remedial actions.

What sets this system apart is its ability to deliver not only accurate measurements but also timely, comprehensible interpretations without human intervention. This makes the system especially suitable for deployment in rural or economically challenged areas where technical expertise is scarce. By combining affordability, ease of use, and automated reporting, the system offers a scalable solution to the pressing global issue of water pollution. Furthermore, the modular nature of the system allows for easy expansion to include additional sensors or integration with GIS and weather data to enhance the predictive capabilities of the platform. Ultimately, the proposed system embodies an innovative, low-cost, and intelligent approach to environmental monitoring.



IV. RESULT AND DISCUSSION

The prototype system was deployed at a small-scale urban wastewater outlet for a three-week testing period. The low-cost sensors demonstrated consistent performance, with data accuracy aligning within ±10% of standard laboratory readings. The NLG module successfully generated over 100 natural language reports, with human evaluators rating 87% of them as "clear and understandable." Key findings revealed that automated reports led to quicker response times compared to traditional lab-based systems. Some challenges were encountered in sensor calibration and occasional data packet losses, but these were mitigated with software redundancy and cloud backup mechanisms. Overall, the results validate the system's efficiency, accuracy, and practical viability.

V. CONCLUSION

This research presents a novel integration of low-cost sensor technology with Natural Language Generation to enable real-time, accessible wastewater pollution monitoring. The system successfully overcomes the limitations of traditional monitoring methods by automating both detection and reporting processes. It is affordable, scalable, and designed for non-expert users, making it particularly suitable for deployment in under-resourced areas. The positive results from field trials demonstrate its potential to revolutionize environmental monitoring, empowering communities and authorities to respond proactively to pollution threats.

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