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IoT-Based Smart Wastewater Management System

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Abstract - *Textile wet-processing activities produce wastewater whose quality changes with the materials and operations used in each production cycle. This paper describes a small-scale, IoT-oriented prototype intended to support observation of selected water-quality indicators during a four-step treatment process. The arrangement has a nominal capacity of about 2 L per batch and uses settling, sand filtration, activated-carbon filtration and reverse-osmosis membrane filtration. An ESP32-based unit reads pH-, total-dissolved-solids (TDS)- and turbidity-related analogue signals, together with temperature from a DS18B20 sensor. A PHP/MySQL web application provides screens for the latest stored values and historical records. The supplied project files show that sensor acquisition and the web application exist as separate software paths; a complete firmware-to-server data-upload mechanism is not present in the archive. Water transfer between stages was carried out with manually operated pumps, so automatic closed-loop actuation is not claimed. To illustrate how readings may be reported across the treatment sequence, the paper includes one simulated dataset. In that example, turbidity falls from 145 to 3.5 NTU (a calculated illustrative change of 97.59%) and TDS falls from 720 to 675 ppm (6.25%). These figures are synthetic examples rather than measurements from the prototype or laboratory evidence. The paper therefore documents the prototype configuration, identifies integration gaps and outlines the validation needed before treatment performance can be established.*

Key Words: Textile wastewater, IoT, ESP32, pH, turbidity, total dissolved solids, reverse osmosis, water-quality monitoring.

1. INTRODUCTION

Water is used at several points in textile processing, including desizing, scouring, bleaching, dyeing, printing and finishing. The resulting effluent is not uniform: its properties are influenced by the fibre being processed, the chemicals and dyes selected, the sequence of operations and any water-recovery practices in place. Depending on these factors, the wastewater may carry colour, suspended particles, dissolved salts, organic compounds and substances information about the incoming water and about how selected indicators change as the water passes through successive treatment steps.

Laboratory analysis remains essential for identifying contaminants and determining whether treated water is suitable for a proposed use or discharge route. However, laboratory sampling alone may not provide operators with a continuous view of changing process conditions. A sensor-and-dashboard arrangement can offer more frequent readings of a limited set of indicators and make those readings easier to review. Such monitoring is complementary to, rather than a replacement for, laboratory analysis: a small group of low-cost sensors cannot detect every pollutant or demonstrate compliance with effluent limits.

The prototype discussed here forms part of a project titled Textile Industry Water Purification and Actuation Monitoring. The project materials supplied for this study include ESP32 firmware for sensor reading, a PHP/MySQL application, a database definition and a browser-based dashboard. Examination of these materials is important because the functions described as project goals are not all present in the available implementation. The paper consequently reports the physical treatment arrangement and the software components that can be verified, while identifying the communication and actuation functions that remain to be completed.

2. RELATED WORK

Forhad et al. presented an IoT-based real-time water-quality monitoring system for water-treatment plants, demonstrating the use of connected sensing for ongoing observation [1]. Nishan et al. described a multi-level IoT system for monitoring industrial wastewater quality [2]. These studies provide context for networked water monitoring. Their results are not used as performance benchmarks here because the sensor configurations, calibration procedures, sample characteristics, treatment processes and evaluation methods have not been shown to be equivalent. The present prototype is narrower in measurement scope. It considers pH, TDS, turbidity-related output and temperature. It does not measure colour, chemical oxygen demand (COD), biochemical oxygen demand (BOD), individual dyes, heavy metals or microbiological quality. Those characteristics require additional instrumentation or laboratory procedures.. The scope of the current work is therefore monitoring selected indicators and documenting the prototype architecture, rather than providing a complete chemical assessment of textile effluent.

3. PROBLEM STATEMENT AND OBJECTIVES

The practical problem addressed is how to observe a small set of water-quality indicators during treatment and make the resulting records available for review. The proposed arrangement brings together an ESP32 sensor interface, a database-backed dashboard and a physical treatment sequence. The supplied implementation demonstrates sensor readings locally and provides a web interface for records already stored in the database. It does not yet verify the complete transfer of live sensor readings to the server, nor does it demonstrate automatic control of pumps or valves.

- To acquire temperature, pH, TDS and turbidity-related sensor signals using an ESP32 DevKit.
- To calculate and display preliminary sensor values for local inspection.
- To provide a PHP/MySQL web interface for viewing the latest and historical records stored in the database.
- To define the missing communication and actuation interfaces required for a fully integrated IoT treatment-monitoring system.
- To establish a repeatable test and calibration protocol before reporting treatment performance.

4. SYSTEM ARCHITECTURE

The project files describe two distinct parts of the software. The first is the embedded sensing program: pH, TDS and turbidity probes are connected to analogue inputs on the ESP32, while a DS18B20 device supplies temperature readings through the OneWire interface and DallasTemperature library. In the firmware loop, the calculated values are written to the serial monitor; the loop includes a nominal delay of approximately two seconds. This provides a local view of the sensor output but, by itself, does not send the readings to the web application.

The second part is the dashboard application. Its MySQL database, named textileInd, contains fields for temperature, turbidity, TDS, pH and the record timestamp. The PHP scripts get_latest.php and get_history.php retrieve stored rows and return them in JSON format. On the client side, dashboard.js periodically requests these read-only endpoints and refreshes the displayed indicators and history charts. The supplied archive does not contain a corresponding save_data.php script or ESP32 networking code that submits new measurements. For this reason, the architecture treats the sensor-to-server connection as an outstanding integration task rather than a completed feature.

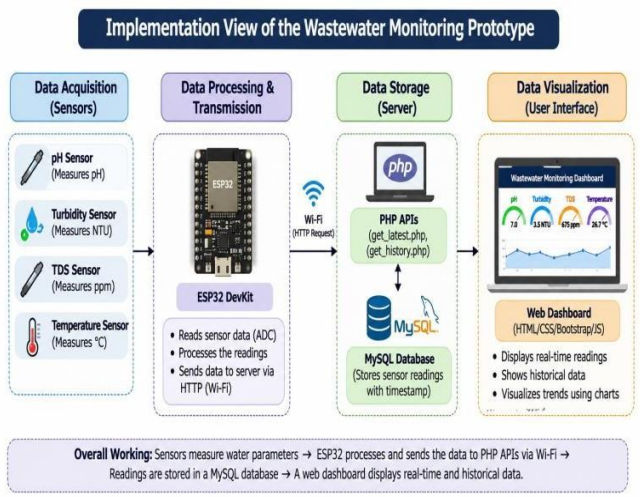

Fig. 1. Proposed integrated architecture of the wastewater monitoring prototype. The ESP32-to-PHP HTTP upload path is a required integration step and is not present in the supplied firmware.

The proposed diagram shows the intended end-to-end data path. In the supplied project files, the ESP32 firmware reads the sensors and prints values to the serial monitor, while the PHP endpoints retrieve records already stored in MySQL. No ESP32 HTTP uploader or PHP data-ingestion endpoint was included; therefore, the Wi-Fi upload and automatic database update must be implemented and tested before this complete path can be claimed as operational. Pump switching and chemical dosing are also not implemented in the supplied firmware; the treatment stages are operated manually.

5. HARDWARE AND SOFTWARE IMPLEMENTATION

5.1 Sensor acquisition and ESP32 firmware

In the firmware, GPIO 34 is assigned to the pH input, GPIO 35 to TDS, GPIO 32 to turbidity and GPIO 27 to the DS18B20 data connection. The analogue-to-digital converter is configured for 12-bit readings. To reduce short-term variation, readAverageRaw() collects 50 samples from an analogue channel, pauses for 5 ms between samples and returns their mean. The pH calculation converts the averaged ADC reading to voltage and applies a linear expression. The TDS routine uses a polynomial voltage relationship, while the turbidity routine maps the voltage between two configured reference levels to a value limited to a 0–100 range. Temperature is obtained through the DS18B20 software library.

The project archive does not include calibration records

showing how the conversion constants were established. Before the values are used quantitatively, the pH channel should be checked with suitable buffer solutions and the TDS channel should be verified for the probe and sample conditions. A further inconsistency concerns turbidity: the firmware produces a bounded percentage-like value, whereas the database and dashboard identify the field as NTU. These are not interchangeable units. A calibrated conversion and consistent unit definition are required before the dashboard can present turbidity in NTU or before such values can be compared with reference limits.

5.2 Database and web dashboard

The web application connects to MySQL through MySQL and selects the textileInd database. Its schema defines a data table with decimal columns for the four monitored indicators and a timestamp. The latest-record endpoint returns the most recent entry, while the history endpoint supplies up to 50 recent records in chronological order. JavaScript uses these responses to refresh the dashboard cards and Chart.js plots. The interface also applies programmed thresholds to assign status labels. Those labels are application logic only; they should not be interpreted as official textile-effluent limits. Similarly, sample rows or demonstration statistics in the database are not evidence of readings collected during a physical trial.

5.3 Treatment train and manual actuation

The authors' prototype photographs show a compact treatment assembly intended for batches of approximately 2 L. Water is passed through four stages in sequence: a settling stage, a sand filter, an activated-carbon filter and a reverse-osmosis (RO) membrane unit. Transfer between stages was performed by manually switching the pumps. The material supplied does not establish automatic valve operation or feedback-based pump control. The arrangement is therefore described as a manually operated treatment train supported by a separate electronic monitoring concept. Details such as pump capacity, filter-bed dimensions, membrane model, flow rate and holding time at each stage were not documented in the available project information and are not inferred in this paper.

6. PROTOTYPE PHOTOGRAPHS AND PHYSICAL CONFIGURATION

The photographs in this section record the physical prototype and the dashboard interface supplied by the authors. The hardware views show the controller and sensor connections, while the screen capture shows the web interface used to present water-quality indicators. They are included to document the form of the prototype and its user interface. The images do not verify sensor calibration, database connectivity from the ESP32 or the accuracy of the illustrative values reported later.

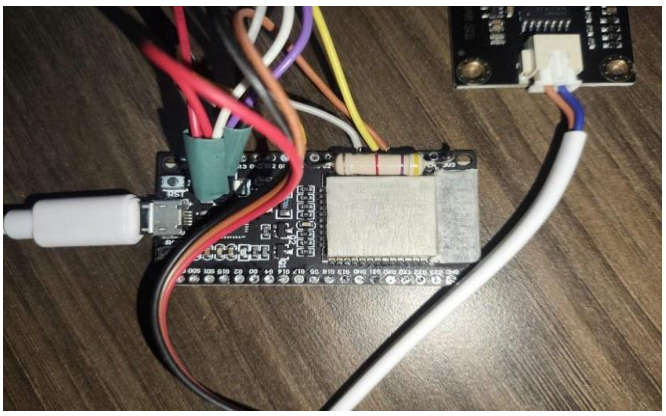

Fig. 2. Photograph of the prototype sensing and controller arrangement.



Fig. 3. Close-up view of the sensor/controller connections.



Fig. 4. Screenshot of the web dashboard displaying water-quality indicators.

7. METHODOLOGY AND TESTING

A single representative dataset is used in this paper to show the format of a stage-by-stage treatment record. It is a simulated example prepared for illustration; it was not captured from the installed sensors and was not produced by laboratory analysis. Five points in the process are represented: untreated influent, post-settling water, post-sand filtration, post-activated-carbon filtration and post-membrane filtration.

The values should be read only as an example of how a future measured dataset could be organised.

For each of the five points, the example lists pH, turbidity, TDS and temperature. A physical evaluation would need to follow a documented sampling procedure, use calibrated instruments, identify the wastewater source and maintain consistent operating conditions. Raw readings should be recorded with timestamps and the relevant treatment-stage details. Independent laboratory testing would then be needed to determine whether the treated sample meets the requirements for its intended reuse or discharge destination.

The four monitored indicators do not describe every feature of textile effluent. Depending on the process and the intended end use, a fuller assessment may require laboratory measurements of COD, BOD, colour, total suspended solids, conductivity, selected metals and other process-specific substances. The applicable regulatory or reuse criteria must be consulted for the location and discharge pathway concerned. A dashboard category based on a programmed threshold cannot, on its own, establish that treated water is compliant or safe for reuse.

8. RESULTS AND DISCUSSION

In the illustrative dataset, turbidity is listed as 145 NTU at the inlet and 3.5 NTU after the final membrane stage. Applying the usual percentage-change calculation gives an illustrative decrease of 97.59%. The corresponding TDS values are 720 ppm and 675 ppm, giving a calculated decrease of 6.25%. Across the same two points, pH changes from 7.2 to 7.0 and temperature from 27.1 °C to 26.7 °C. Every value in this comparison is simulated; none represents an observed treatment result.

These calculations demonstrate how an inlet-to-outlet comparison may be presented, but they do not measure the performance of the prototype. In particular, the large turbidity change is a feature of the constructed example and must not be reported as an experimentally achieved removal rate. The example also shows a smaller change in TDS. In a real system, the contribution of each treatment stage would need to be established from repeated measurements, with appropriate calibration and laboratory confirmation. The actual outcome will depend on the wastewater composition and the operating conditions of the filters and membrane.

8.1 Representative simulated test dataset

Table 1 gives the five stage-wise observations in the one simulated example. The entries are illustrative values only and should not be cited as measurements collected during prototype operation.

Table 1. Single representative simulated test readings at each treatment stage

Treatment stage	pH	Turbidity (NTU)	TDS (ppm)
Initial wastewater	7.2	145	720
After settling	7.1	78	710
After sand filtration	7.0	28	704
After activated carbon	7.0	17	690
After membrane filtration	7.0	3.5	675

9. LIMITATIONS AND FUTURE WORK

Several limitations affect the conclusions that can be drawn from this prototype. First, the paper contains one simulated dataset rather than measurements from a physical treatment trial. Second, the supplied files do not show a complete ESP32-to-server upload path or a server endpoint for inserting live readings. Third, calibration evidence for the sensors is unavailable. Fourth, the firmware's turbidity output is percentage-like, whereas the database and dashboard use the label NTU. Finally, the supplied firmware does not implement automatic pump, valve or dosing control. These limitations prevent the present work from establishing verified treatment efficiency or a fully automated IoT system. The next development stage should begin with repeated physical trials using wastewater samples whose source and composition are documented. Each sensor should be calibrated using suitable reference standards, and the turbidity calculation and displayed unit should be made consistent. The ESP32 should then be connected to a secure data-ingestion endpoint, with timestamps and error handling, so that live readings can be distinguished

from demonstration records. If automatic operation is pursued, relay or driver circuits, safe interlocks and control logic must be implemented and tested separately. Finally, influent and effluent samples should be analysed in a laboratory for relevant parameters such as COD, BOD, colour and dissolved constituents. Performance claims should be based only on reproducible measured data.

10. CONCLUSION

This paper documents a small-batch textile-wastewater prototype that combines an ESP32 sensor-acquisition unit, a four-stage treatment arrangement and a PHP/MySQL dashboard. The available project files confirm local sensor-reading firmware and a web interface for displaying database records, but they do not establish live firmware-to-server communication or automatic actuation. One simulated dataset is included to demonstrate stage-wise reporting; its calculated changes in turbidity and TDS are examples only, not experimental findings. Completing the communication interface, calibrating the sensors, validating the treatment process through repeated trials and obtaining independent laboratory results are necessary before the system's treatment performance can be assessed.

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DECLARATIONS

Data statement: The readings and percentage calculations are simulated for illustration, not measured prototype or laboratory results. The prototype photographs were supplied by the authors. References are provided for material drawn from prior work. Author approval and disclosures: All authors should verify and approve the final manuscript and complete funding, conflict-of-interest and source-code availability statements accurately before submission. Remove database credentials from any shared project files.

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