



Automatic Water Tank Cleaning Using Digital Twin Technology for Industrial Application

P. RanjithKumar^{1*}, Dharani², Hema Navanethem³, Malathi⁴

¹Professor, Department of Electronics and Communication Engineering, PSR Engineering College, Sivakasi, India

²³⁴Student, Department of Electronics and Communication Engineering, PSR Engineering College, Sivakasi, India

edharaniv@gmail.com, hemanavaneetham563@gmail.com, malathikarunakaran17@gmail.com

Corresponding Author E-mail: ranjithkumar@psr.edu.in

ABSTRACT: For water quality to be maintained in commercial, industrial, and residential settings, water tanks must be kept clean. Conventional cleaning techniques are time-consuming, frequently dangerous, and inconsistently ineffective. Through the use of digital twin technology, this project suggests an automated water tank cleaning system that enables real-time monitoring, predictive maintenance, and tank cleaning process control. The Digital Twin is a computerized model of the actual water tank and cleaning equipment that continuously monitors the tank's condition by measuring things like sediment buildup, turbidity, and water level. Through the integration of data-driven algorithms and Internet of Things sensors, the system allows for remote control and the creation of ideal cleaning schedules based on current conditions. This automation minimizes the need for manual intervention, conserves water, and guarantees consistent hygiene standards, offering a practical, economical and sustainable solution for water tank maintenance.

Keywords: sensor based monitoring, Internet of things, sediment buildup detection, Digital Twin Technology.

1. Introduction

Water tanks are fundamental to the infrastructure of residential, commercial, and industrial facilities, storing and supplying clean water to meet the diverse needs of occupants. In various industries, the uninterrupted availability of clean water is critical, impacting hygiene, manufacturing processes, and health standards. However, over time, these water tanks are prone to sediment accumulation, microbial growth, and contamination, all of which can degrade water quality and pose significant health risks. These issues are particularly prevalent in large tanks, where the interior can remain stagnant for long periods, facilitating sediment buildup and creating conditions for microbial proliferation.

Consequently, regular tank cleaning becomes essential to preserve water quality and ensure the safety of those who rely on it. Traditional cleaning methods for water tanks, often labor-intensive, involve draining the tank entirely, followed by manual scrubbing or chemical treatments to eliminate accumulated contaminants. This process is disruptive, as it necessitates downtime in water supply, which can hinder both residential users and industrial operations. Additionally, such methods are time-consuming and require significant human intervention, increasing costs, and posing safety hazards to the personnel involved. With the rising awareness of water safety and increased demand for operational efficiency, the need for an automated, efficient,

and less disruptive water tank cleaning solution has become evident. This project presents an Automatic Water Tank Cleaning System designed to overcome these limitations by utilizing Digital Twin Technology and IoT to facilitate real-time monitoring, predictive maintenance, and fully automated cleaning of water tanks. The application of Digital Twin Technology introduces a virtual replica of the physical tank, allowing it to continuously mirror real-time conditions, including critical parameters such as water level, turbidity, sediment deposition, and temperature. This digital representation not only enables efficient monitoring but also supports data-driven decision-making, as it provides actionable insights into the tank's status, detecting contamination early and triggering cleaning processes only when needed. Incorporating IoT sensors within the tank's physical structure enables the system to capture and transmit real-time data on water quality and environmental conditions. Through a network of sensors and data processors, the system monitors essential parameters, with data flowing seamlessly to the digital twin model, creating a dynamic and highly accurate virtual simulation of the tank's internal state. With this virtual model, predictive algorithms can analyze historical data and pattern changes, identifying optimal cleaning cycles based on real-time water conditions. This approach mitigates unnecessary cleaning processes, reducing energy and water waste, while maximizing operational efficiency.

The system architecture is organized into three primary layers: the physical layer, digital twin layer, and communication layer, each serving a distinct purpose.

Physical Layer: The Physical Layer includes IoT sensors for monitoring parameters like turbidity and temperature, an Arduino Uno for data processing, and an ESP-WIFI 32 module for connectivity. It enables real-time monitoring, control, and remote access to the system.

Digital Twin Layer: The Digital Twin Layer creates a real-time virtual replica of the tank, enabling predictive maintenance and proactive cleaning by simulating conditions and analyzing data from IoT sensors.

Communication Layer: The Communication Layer enables data exchange between the physical tank, digital twin, and remote systems, allowing real-time monitoring, control, and cleaning actions through mobile or web applications for enhanced system reliability.

2. Recent Works

Tao et al. [1] provided a comprehensive overview of Digital Twin applications in industry, focusing on how real-time data synchronization between physical and virtual models optimizes system performance. Their study emphasized predictive maintenance, process automation, and enhanced operational efficiency through continuous data exchange. This research demonstrated that Digital Twin technology is essential for smart industrial systems.

Wang et al. [2] explored the role of Cyber-Physical Systems (CPS) in modern manufacturing, particularly in bridging digital and physical environments. Their work highlighted how CPS frameworks integrate IoT sensors, machine learning, and cloud computing to enhance real-time process monitoring and automation. The authors concluded that CPS is a foundational element for the successful deployment of Digital Twins in industrial setups.

Grieves and Vickers [3] introduced the concept of Digital Twin models as a solution for mitigating unpredictable system behaviors in industrial automation. Their research provided a framework for developing self-adaptive and self-optimizing industrial processes using sensor-driven data insights. They also discussed how Digital Twins improve decision-making through AI-powered predictive analytics, ensuring higher efficiency in industrial operations.

Shukla et al. [4] proposed an IoT-based water quality monitoring system that tracks pH, turbidity, and dissolved oxygen in industrial tanks. The research demonstrated that sensor-based water quality assessment significantly reduces manual testing efforts while ensuring real-time contamination detection. This implementation resulted in improved water quality management and reduced maintenance costs.

Lee et al. [5] integrated Industrial Artificial Intelligence (AI) into IoT-driven water monitoring to enhance automated decision-making in industrial environments. Their system utilized machine learning algorithms to predict cleaning schedules and optimize filtration processes, reducing manual intervention and improving efficiency. They concluded that AI-powered Digital Twins can enable self-regulating cleaning systems.

Kumar and Mallick [6] explored how Digital Twin technology combined with IoT sensors enhances industrial automation and control. Their research emphasized that real-time data feedback loops enable dynamic cleaning processes, allowing industries to reduce water wastage. Their proposed framework proved effective in monitoring contamination levels and triggering automated cleaning cycles when necessary.

Zheng et al. [7] developed an intelligent water quality monitoring system leveraging IoT and Digital Twin technology for real-time tracking and predictive cleaning mechanisms. Their study highlighted the importance of data-driven optimization in industrial cleaning, reducing human intervention and maintenance costs. The authors showcased how sensor data and analytics can optimize industrial water management to improve resource utilization and system efficiency.

Stark et al. [8] reinforced the significance of Digital Twins in industrial process monitoring, particularly in technical system automation. Their work demonstrated how continuous real-world condition updates in a virtual model enhance

predictive diagnostics and maintenance strategies. The study concluded that Digital Twin-based real-time monitoring ensures system longevity and operational efficiency.

Kitchenham [9] conducted a systematic review on software engineering methodologies for Digital Twin implementation, outlining best practices for designing and deploying IoT-integrated industrial cleaning systems. The study emphasized that structured development frameworks are critical for scalability, interoperability, and security in Digital Twin applications. Their insights serve as a reference for developing robust industrial Digital Twin systems.

Wan et al. [10] applied an IoT-based smart water quality monitoring system to large-scale aquaculture, demonstrating how real-time analytics enhance water resource management. Their findings indicated that IoT-driven automation significantly reduces contamination risks while improving cleaning efficiency. This approach ensures sustainable water management strategies for industrial and agricultural applications.

Rashid and Sulaiman [11] conducted a comprehensive review of Digital Twin applications in smart manufacturing, focusing on automation, predictive maintenance, and cost reduction. They identified that Digital Twin-driven manufacturing systems improve production efficiency, energy optimization, and asset tracking. Their study concluded that Digital Twins enable industries to transition into fully automated, AI-driven production environments.

Longo et al. [12] elaborated on the integration of Digital Twin technology in industrial applications, emphasizing how bridging physical and digital environments enhances operational efficiency. Their research presented case studies demonstrating the reduction of downtime, enhanced asset management, and improved risk assessment in industries utilizing Digital Twins.

Sharma et al. [13] investigated real-time IoT and Big Data analytics for smart water management, proposing an automated system that minimizes manual intervention. Their research illustrated how machine learning-driven insights optimize cleaning schedules, ensuring hygiene and resource efficiency.

3. Proposed Work Explanation

The proposed system uses Digital Twin Technology to create a dynamic virtual model of the water tank and its cleaning mechanisms, connected to IoT sensors and data analysis modules.

Digital Twin Model A digital replica of the tank that provides a comprehensive view of its physical condition, capturing data such as water quality (e.g., turbidity, pH), sediment buildup, and water level.

Automated Cleaning Mechanism Embedded scrubbing devices, UV disinfection units, and controlled water jets to automatically clean the tank based on the Digital Twin's recommendations.

Predictive Maintenance Machine learning algorithms analyze sensor data to predict the optimal cleaning times and maintenance schedules, reducing downtime and prolonging system life.

Real-Time Monitoring and Alerts a user interface that provides live data visualization, with notifications for issues like high turbidity or unexpected drops in water level.

Remote Access and Control Allows for remote initiation of the cleaning process, making the system accessible and manageable from anywhere.

3.1 Block Diagram

The Figure 1 The system is powered by converting AC to DC and regulating voltage levels for components like the Arduino Uno, sensors, and actuators. The Arduino acts as the control unit, receiving data from sensors (ultrasonic and turbidity) to control components such as relays, valves, motors, and LCD. It measures distance or water levels, sending data for decision-making based on the input. The turbidity sensor assesses water clarity, helping decide when to filter or clean. Relays switch high-power devices like motors and valves, activated by low-power Arduino signals. The motor provides rotational motion, enabling tasks like pumping water. The valve controls water flow by opening or closing. The LCD displays real-time information, including water levels, turbidity, and system status, offering continuous feedback to the user.

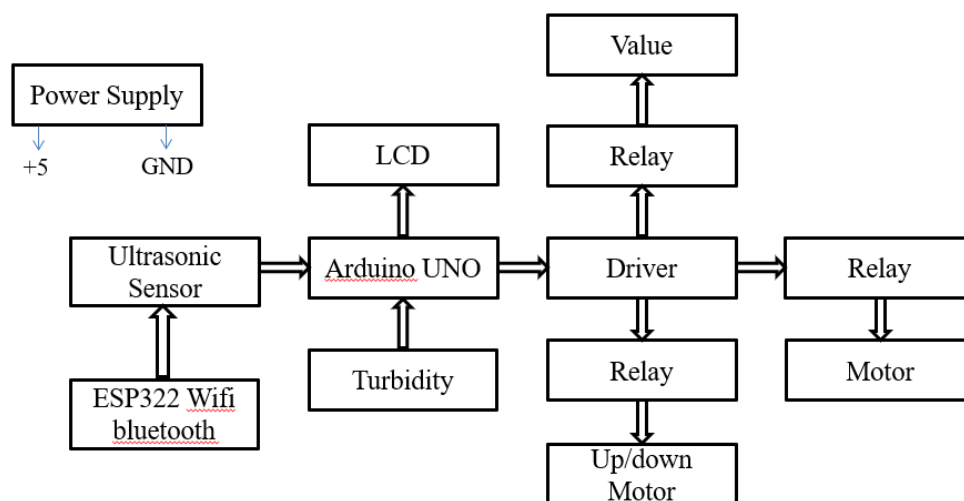
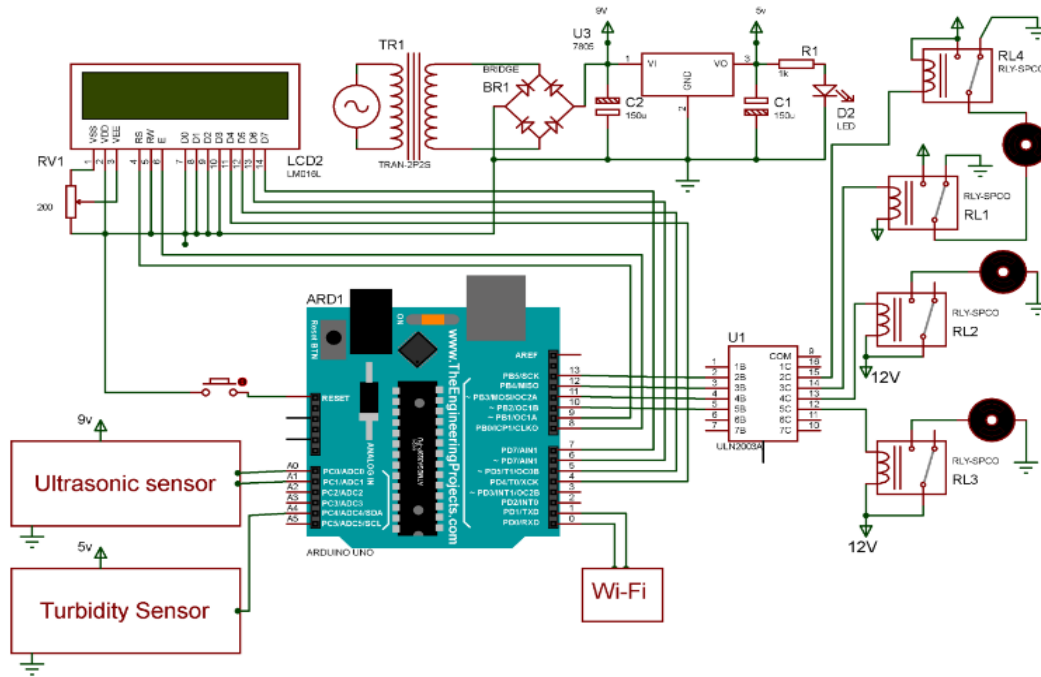


Figure 1: Block diagram of Digital Twin Technology

3.2 Circuit Diagram



sanitary standards. The ESP32 module enables remote access, allowing customers to watch and control the cleaning process from a mobile app. This smart technology provides a practical, cost-effective, and ecological alternative for water tank repair.



Figure 4: *Web Portal Details*

In Figure 4, This image represents the web portal interface of the Automated Water Tank Cleaning System using Digital Twin Technology. The display shows the real-time water level (Level: 58) inside the tank, captured through IoT sensors integrated with the system. The background visual represents digital connectivity, symbolizing the digital twin framework that continuously monitors the tank's condition. This system ensures efficient water management by providing accurate, real-time insights into tank conditions. Additionally, it helps optimize cleaning schedules, reducing water wastage and maintenance costs while ensuring consistent hygiene standards.

4.1 Preparation of Figures and Tables

The proposed methodology for automated water tank cleaning using Digital Twin (DT) technology is designed to offer a smart and efficient solution for industrial water management. The system is divided into two primary phases hardware implementation and remote monitoring working together to reduce manual labor, prevent contamination, and optimize cleaning schedules based on real-time data analytics. In the hardware phase, various sensors are deployed to collect real-time water quality parameters, including turbidity

and pH values. These sensors are connected to the ESP32 microcontroller, which acts as the central processing unit. The ESP32 is selected for its low power consumption, integrated Wi-Fi capability, and compatibility with IoT-based systems.

The mechanical cleaning of the tank is facilitated by a 12V DC brush motor, which is automatically triggered when the system detects that water quality has deteriorated below predefined threshold levels. An LCD display module is used to provide instant feedback to users, showing current sensor values and system status during the cleaning operation. This user interface plays a crucial role during testing and local observation of the cleaning process. The entire system is powered by a regulated 12V power supply to ensure consistent performance without voltage fluctuations.

In the second phase of the system, a Digital Twin model is used to simulate the real-time conditions inside the water tank. The data captured by the sensors is continuously uploaded to a cloud-based dashboard via Wi-Fi, providing a virtual representation of the tank's physical environment. This enables remote monitoring and predictive maintenance, allowing stakeholders to view system performance and anticipate cleaning needs without physical inspection. The integration of Digital Twin technology also facilitates data logging, analytics, and future system upgrades without altering the core hardware.

The list of hardware components used, along with their specifications and functions, is presented in Table 1. These components collectively form the foundation of the system's real-time sensing and automation capabilities.

Table 1: *Hardware specification*

Component Name	Specification	Functions
ESP32	32-bit, Dual-core, Wi-Fi enabled	Main controller for data processing
Turbidity Sensor	0–1000 NTU	Detects water clarity for cleaning
PH Sensor	0–14 pH	Monitors water acidity/basicity

Brush Motor	12V DC Motor	Mechanically scrubs tank interior
LCD Display	16x2 Alphanumeric	Displays real-time sensor values
Power Supply	Power Supply	Powers motor, sensors, and ESP32

5. Conclusion

In conclusion, the automated water tank cleaning system utilizing digital twin technology and IoT offers an innovative solution to improve maintenance efficiency and water quality in industrial applications. By combining IoT sensors with a virtual replica, this system enables real-time monitoring and predictive maintenance, streamlining the cleaning process and reducing downtime. The advantages are substantial: first, IoT sensors provide accurate, up-to-the-minute data on tank conditions, minimizing the need for manual inspection and intervention, thereby enhancing operational efficiency. Secondly, the digital twin allows for advanced analysis and simulation, offering insights that enable proactive decision-making and resource optimization. The integration of IoT and digital twins contributes to enhanced water quality management by identifying contaminants and predicting cleaning schedules, ultimately promoting a safer water environment. Furthermore, the data collected can be analyzed for trends, allowing for continual improvement in maintenance protocols and system performance. In summary, the automated water tank cleaning system is a transformative approach to industrial cleaning, offering significant benefits in efficiency, water quality, and reliability. This technology aligns with the evolving needs of smart industries and contributes to a sustainable future by ensuring efficient resource management.

In the future, incorporating AI and machine learning into this system could further enhance predictive capabilities, allowing for even greater automation and precision in maintenance. Additionally, integrating secure cloud storage will enable remote monitoring and control, increasing flexibility and convenience for users. As these systems evolve, they will become crucial

components in industrial water management, advancing both productivity and environmental sustainability. However, it is essential to address cybersecurity and data privacy concerns as the use of digital twins becomes more widespread.

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