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IoT Enabled Solar Powered Water Quality Monitoring System

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Abstract: Ensuring safe and clean water is a major challenge due to increasing pollution and lack of continuous monitoring systems. This paper presents aimplementation of an Internet of Things (IoT)-based solar powered water quality monitoring system designed to provide real-time assessment of water parameters without automated tank control. The system utilizes sensors to measure key indicators such as pH, total dissolved solids (TDS), turbidity, and temperature, enabling accurate evaluation of water quality. An ESP32 microcontroller collects and processes sensor data and transmits it tocloud platforms for visualization and analysis. Users can monitor real-time data, receive alerts, and access historical records through mobile or web applications. Unlike conventional systems, this approach focuses solely on quality monitoring, making it simpler, cost-effective, and easier to deploy in diverse environments such as households, water treatment facilities, and rural areas. The study highlights the effectiveness of IoT in improving water safety, enhancing data accessibility, andsupporting preventive actions. The system provides a scalable and efficient solution for modern water quality management and contributes to sustainable environmental monitoring practices [1]–[3].
Keywords: IoT, Water Quality MonitoringSensors, Cloud Computing, Smart Monitoring, solar power,ESP32

I. INTRODUCTION

Water quality plays a crucial role in human health, agriculture, and industrial applications. Contaminated water can lead to severe health risks and environmental issues, making continuousmonitoring essential. Traditional methods of water quality assessment involve manual sampling and laboratory analysis, which are time-consuming, expensive, and incapable of providing real-time insights [1].

With the advancement of the Internet of Things (IoT),modernwatermonitoring systemshaveevolvedto provide continuous and remote monitoring capabilities. Thesesystems integrate sensors, microcontrollers, and cloud platforms to collect, process, and analyze water quality datain real time. IoT-based solutions offer improved accuracy, efficiency, and accessibility compared to conventional approaches [2], [4].

Several studies have explored automated water management systems combining both quality monitoring and tank control mechanisms. However, in many applications such as environmental monitoring, river analysis, and water supply assessment, only water quality evaluation is required without automated control systems. Eliminating automation components reduces system complexity, cost, and maintenance requirements while still providing essential monitoring capabilities [3].

This paper focuses on a simplified IoT-based water quality monitoring system that excludes automatic tank filling mechanisms. The objective is to analyze the system design, sensor integration, data transmission, and benefits of real- timemonitoring. The studyalso evaluates the applicability of such systems in diverse environments and highlights theirrole in ensuring water safety and sustainability.

II. LITERATURE SURVEY

Recent advancements in the Internet of Things (IoT) have significantly enhanced water quality monitoring systems by enabling real-time data acquisition, remote accessibility, and intelligent analysis. Numerous studies have explored the integration of sensors, wireless communication, and cloud computing for efficient and scalable monitoring solutions.

A structured review conducted in recent years analyzed IoT- based embedded systems combined with machine learning techniques for water quality monitoring. The study emphasized the importance of parameters such as pH, turbidity, and temperature, while highlighting the role of intelligent algorithms inidentifyingcontaminationpatterns.

However, issues such as increased system complexity and higher implementation cost werenoted as keychallenges [9].

Another systematic review focused on sensor-based water monitoring systems developed over recent years.

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Itconcluded that IoT-based approaches provide continuousand real-time monitoring compared to traditional manualsampling methods, which are often delayed and less reliable. The studyalso identified inconsistencies in sensor calibration and data standardization as limitations [10].

A comprehensive survey of IoT-enabled water quality monitoring systems discussed the integration of sensing technologies with wireless communication frameworks. The research highlighted that accurate data acquisition andreliable transmission are critical for effective monitoring. It also emphasized the growing use of low-power communication protocols to enhance system efficiency [11].

Research on smart water quality monitoring system design demonstrated the use of multi-parameter sensing units integrated with IoT platforms. The study showed that real- time monitoring improves response time and helps in preventing the use of contaminated water. It also reinforced the importance of cloud-based visualization for better user interaction [12].

Another study reviewed IoT-based smart water management frameworks and analyzed different system architectures. It identified key components such as sensors, microcontrollers, and cloud platforms, and concluded that IoT significantly improves operational efficiency whilereducingmanual effort [13].

A critical review focusing on IoT combined with machine learning models explored advanced data-driven approaches for water qualityprediction. The studyhighlighted the use of algorithms such as neural networks and regression models to enhance monitoring accuracy and enable predictive analysis [14].

Further research evaluated IoT-based monitoring systems in terms of sustainability and environmental impact. It emphasized that real-time monitoring supports earlydetection of pollutants and contributes to better waterresource management. The study also pointed out the needfor cost-effective and energy-efficient designs for large-scale implementation [15].

Additionally, recent work proposed advanced IoTframeworks integrating edge computing with cloud analytics for improved performance. Thestudydemonstrated enhanced system reliability, reduced latency, and efficient handling of large datasets. It also highlighted the scalability of such systems for industrial and environmental applications [16].

The data acquisition unit comprises multiple sensors used to measure key water quality parameters:

- pHSensor:Measuresacidityoralkalinityof water
- TDS Sensor: Determinesdissolved solids concentration
- TurbiditySensor:Detectssuspendedparticlesand water clarity
- TemperatureSensor:Monitorsthermalvariations affecting water properties

These sensors continuously collect real-time data from the water source. The selection of these parameters is based on their importance in determining water safety and quality, as highlighted in previous studies [10], [12].

ProcessingUnit

An ESP32 microcontroller is used as the central processing unit of the system. It receives analog or digital signals from the sensors and converts them into meaningful data values. The ESP32 is selected due to its low power consumption, built-in Wi-Fi capability, and efficient processing performance [11].

Themicrocontrollerperformsthefollowingfunctions:

- Sensordataacquisition
- Signalconditioningandprocessing
- Threshold-basedanalysisforsafetyevaluation Communication and Cloud Integration

The processed data is transmitted to cloud platforms such as Firebase or Blynk using Wi-Fi connectivity. Cloudintegration enables:

- Real-timedatavisualization
- Storageofhistoricaldata
- Alertgenerationforabnormalconditions
- Remotemonitoringviamobileorwebapplications

This approach enhances accessibility and allows users to monitor water qualityfrom anylocation, improving decision- making and response time [15].

III. SYSTEMDESIGN AND METHODOLOGY

The overall working of the system can be summarized in the following steps:

1) Sensors measure water quality parameters continuously
2) ESP32collectsandprocessesthesensordata

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3) Processeddataistransmittedtothecloudplatform
4) Usersaccessdatathroughadashboardinterface
5) Alertsaregeneratedifparametervaluesexceedsafe limits

Thesystemoperatescontinuously,ensuringuninterrupted monitoring of water quality.

Advantages of Proposed Methodology

Theproposedmethodologyoffersseveraladvantages:

- Reducedcomplexity:Noautomationhardware required
- Cost-effective: Lower implementation and maintenance cost
- Scalable:Canbedeployedinmultiplelocations
- Reliable:Focusonaccuratemonitoringwithout control dependencies
- User-friendly:Easyaccessthroughcloudplatforms Limitations

Despiteitsadvantages,thesystemhascertainlimitations:

- Requiresperiodicsensorcalibration
- Dependentoninternetconnectivityforcloudaccess
- Limitedpredictivecapabilitywithoutadvanced analytics

IV. HARDWARE IMPLEMENTATION

TheimplementationoftheproposedIoT-basedwaterquality monitoring system involves the integration of hardware components, software programming, and cloud-based data management.Thesystem isdesignedtooperateinrealtime, ensuringcontinuous monitoringofwaterparameterswithout incorporating any automatic control mechanisms.

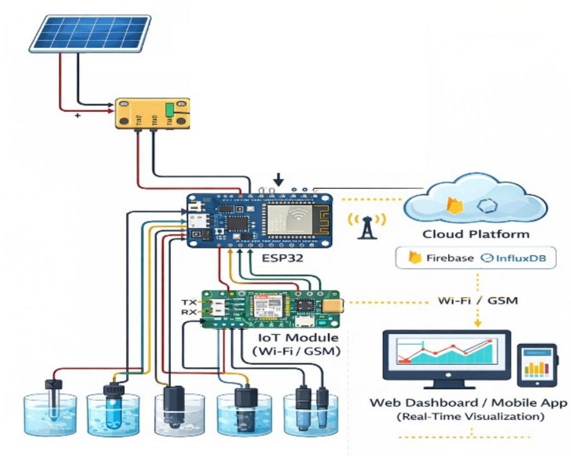

Fig.1 Hardware implementation

1) *Hardware Implementation*

Thehardware setup consists of sensors, a microcontroller, andacommunicationinterface.Thefollowingcomponents are used:

- pHSensor:Measurestheacidityoralkalinityof water
- TDSSensor:Detectsdissolvedsolidsconcentration
- TurbiditySensor:Monitorswaterclarity
- TemperatureSensor:Measureswatertemperature
- ESP32Microcontroller:Actsasthecentral processing and communication unit

All sensors are interfaced with the ESP32 through appropriateanaloganddigitalinputpins.TheESP32collects real-time data from each sensor and processes it for further transmission. Proper power supply and grounding are maintained to ensure stable operation of the system.

Theabsenceofactuatorssuchaspumpsorvalvessimplifies the circuit design and reduces hardware complexity compared to automated systems [13].

2) Software Implementation

Thesoftwareimplementation iscarriedout usingembedded programming for the ESP32. The system is programmed using the Arduino IDE or similar development platforms.

Thesoftwareperformsthefollowingtasks:

- Initialization ofsensorsandcommunication modules
- Continuousdataacquisitionfrom sensors
- Conversionofrawsensorsignalsintomeaningful values
- Thresholdcomparisonfor waterqualityassessment
- Datatransmissiontocloudplatforms

The program operates in a loop, ensuring continuous monitoring.Calibrationconstantsareincludedinthecodeto improve measurement accuracy, as sensor precision is a critical factor in IoT-based systems [10].

3) CloudIntegration

The processed data istransmittedtocloud platforms such as Firebaseor Blynk usingtheESP32’sbuilt-in Wi-Fimodule. Thecloudplatformactsasacentralrepositoryforstoringand visualizing data.

Keyfeaturesofcloudintegrationinclude:

- Real-timedatadisplaythroughdashboards
- Storageofhistoricaldataforanalysis
- Alertnotificationswhenparametersexceedsafe limits
- Remoteaccessviamobileorwebapplications

This enables users to monitor water quality from any location,improvingaccessibilityandsystemusability[15].

4) SystemDeployment

The system isdeployed byplacingthe sensorsin thewater source, such asa storagetank,river, or supplyline. Careis takentoensureproper sensorpositioningtoobtainaccurate readings.

Once powered on, the system automatically begins monitoringandtransmittingdata.Theuser can viewthedata on theclouddashboardwithout anymanualintervention.The simplicityofthesystemallowseasyinstallation inboth urban and rural environments.

5) PerformanceConsiderations

Duringimplementation,thefollowingfactorsareconsidered to ensure efficient system performance:

- Sensor Calibration:Requiredfor accurate measurements
- Power Stability:Ensuresconsistentoperation of ESP32 and sensors
- NetworkConnectivity:Necessaryforreal-time data transmission
- DataAccuracy:Dependsonsensorqualityand environmental conditions

Properhandlingofthesefactorsimprovesthereliabilityand efficiency of the system [12].

V. EXPERIMENTAL RESULTS AND PERFORMANCE EVALUATION

The proposed IoT-based water quality monitoring systemwas evaluated through a series of experimental observations to analyze its performance in real-time conditions. Thesystem was tested using different water samples, includingtap water, stored water, and untreated water, to examine variations in quality parameters such as pH, total dissolved solids (TDS), turbidity, and temperature.

A. Experimental Setup

The sensors were immersed in water samples, andtheESP32 microcontroller continuously collected data at regular intervals. The acquired data was transmitted to a cloud platform for visualization and storage. The system operated under normal environmental conditions with stable power supply and internet connectivity.

Multiple readings were recorded over time to ensure consistency and reliability of the results. The collected data was analyzed to evaluate system accuracy andresponsiveness.

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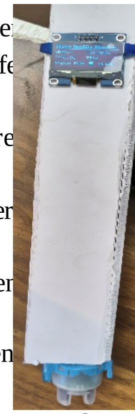
B. ObservedResults

The system successfully measured all selected parameters in real time. The obse  are summarized below:

- pH Values: The system recorded pH values within expected ranges for diffe samples. Slight variations were observed due to environmental conditions and sensor sensitivity.
- TDS Levels: Higher TDS values were detected in untreated water compare or tap water, indicating the presence of dissolved impurities.
- Turbidity: Turbidity levels were significantlyhigher in unfiltered water co suspended particles.
- Temperature: Temperature readings remained relatively stable but influen pa ly pH and turbidity.

These observations confirm that the system is capable of differentiating between o .

TABLEI:ObservedWaterQualityParameterValues

S.No	WaterType	pH	TDS (ppm)	Turbidity(NTU)	Temp(°C)
1	TapWater	7.2	180	2.1	26.2
2	TapWater	7.3	195	2.3	26.5
3	StoredWater	7.0	320	5.8	27.8
4	StoredWater	6.9	345	6.2	28.0
5	UntreatedWater	6.4	610	18.4	28.5
6	UntreatedWater	6.2	650	20.1	29.0
SafeLimit	—	6.5–8.5	<500	<4.0	20–30

Red/bold valuesindicatereadingsoutsideWHO/BISsafelimits. Safelimitsshowninshadedrow

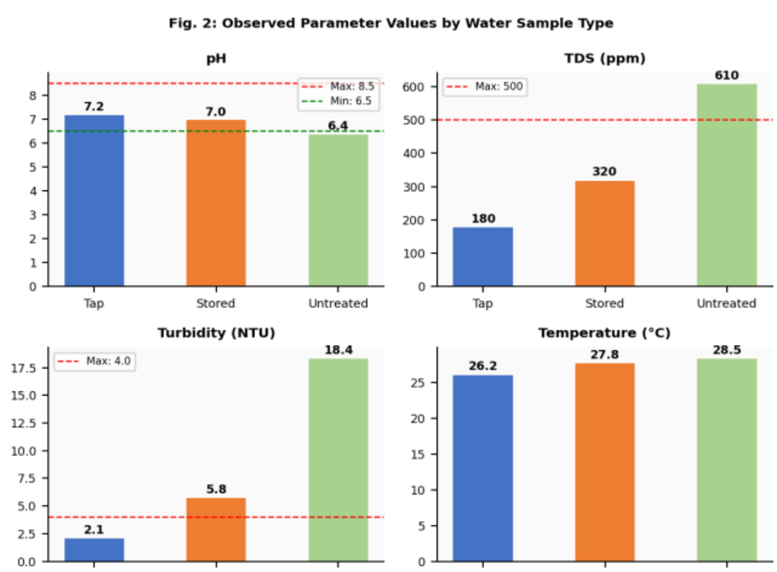


Fig.2:ObservedParameterValuesAcrossSampleTypes(dashed lines = safe limits)

C. PerformanceEvaluation

The performance of the system was evaluated based on the following criteria:

1) Accuracy

The sensor readings were compared with standard reference values, showing acceptable accuracy for low-cost IoTsensors. Minor deviations were observed due to calibration limitations, which is consistent with findings in similarstudies [10].

2) ResponseTime

The system demonstrated fast response times, with data updates occurring almost instantly on the cloud platform.This ensures real-time monitoring and quick detection of changes in water quality.

3) Reliability

The system operated continuously without major interruptions. Stable performance was achieved under consistent network connectivity, highlighting its reliabilityfor long-term monitoring [15].

4) Scalability

The system design allows easy integration of additional sensors and deployment across multiple locations. Thismakes it suitable for large-scale environmental monitoring applications.

5) CostEfficiency

By eliminating automation components such as solenoid valves and pumps, the system significantly reduces implementation cost while maintaining essential monitoring functionality[13].

ImplementationCost	₹2500-₹3500	Lowcost	✓ Met

Fig.3: Working Model Of Proposed System

TABLEII:SystemPerformanceEvaluation

PerformanceMetric	Observed	Expected	Status
Accuracy(pH)	±0.15pH	±0.1 pH	✓ Good
Accuracy(TDS)	±12ppm	±10ppm	✓ Good
UpdateInterval	~2sec	<5sec	✓ Excellent
CloudDelay	<1sec	<2sec	✓ Excellent
SystemUptime	98.7%	>95%	✓ Excellent

D. Discussion

The experimental results demonstrate that the proposed system effectively monitors water quality parameters in real time with acceptable accuracy and reliability. Compared to traditional monitoring methods, the IoT-based approach provides continuous data collection and remote accessibility, significantly improving efficiency and usability.

Although the system performs well, certain limitations suchassensor calibration and dependence on internet connectivity must be addressed for further improvement. Future enhancements may include integration of data analytics or machine learning models for predictive monitoring.

VI. CONCLUSION

Thispaper presentedareviewandimplementation analysis of an Internet of Things (IoT)-based water quality monitoring system designed to provide real-time assessment of essential water parameters without incorporating automatic control mechanisms. The system integrates multiple sensors to measure pH, total dissolved solids (TDS), turbidity, and temperature, enabling continuous monitoring and accurate evaluation of water quality. The use of an ESP32 microcontroller and cloud platforms facilitates efficient data processing, remote accessibility, and real-time visualization.

The experimental results demonstrate that the system performs reliably with acceptable accuracy and fast response time,makingitsuitablefor practical deploymentin domestic, environmental, and industrial applications. By eliminating automation components such as pumps and solenoid valves, the proposed system reduces complexity, cost, and maintenance requirements while maintaining essential monitoring functionality.

Although the system depends on proper sensor calibrationand stable internet connectivity, it provides a scalable and cost-effective solution for water quality assessment. The adoption of such IoT-based monitoring systems can significantly contribute to improved water safety, resource management, and sustainable environmental practices.

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