Smart Water Tank Monitoring System Using Conductive Sensors and LoRa Technology

TERM PROJECT REPORT

ARCHITECTURE AND PROTOCOLS FOR INTERNET OF THINGS (CS61066)

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INTRODUCTION

The Smart Water Tank Tracking System is a cutting-edge solution designed to automate the monitoring and management of water levels in large water storage tanks. As the global demand for water continues to increase and concerns about water conservation grow, innovative approaches to water management are becoming critical. This system leverages advanced technologies, including Internet of Things (IoT) sensors, long-range communication (LoRa), and machine learning (ML), to provide real-time monitoring, predictive analytics, and efficient resource management.

The core of the system involves five metal conductors strategically placed at different levels (0%, 25%, 50%, 75%, and 100%) within the water tank. These conductors serve as sensors that detect the water level at specific intervals. When the water reaches the 50% level, for example, the conductors at 0% and 50% become connected, signaling that the tank has filled to that level. These connections are then transmitted via an ESP32 module, which serves as the communication bridge between the tank's sensors and a LoRa transmitter. The LoRa (Long Range) technology ensures that the data can be transmitted over long distances, even in areas with poor network coverage, making it ideal for remote water tanks.

Once the data is transmitted by the LoRa sender located at the tank, it is received by a LoRa receiver situated in a remote location, typically at a household or control center. This remote receiver continuously receives updates regarding the water level in the tank. The collected data is then stored in a structured PostgreSQL database, ensuring that historical water level information is preserved for future analysis. This real-time data collection not only allows for efficient monitoring of the tank’s water levels but also ensures that users can be alerted when the tank is approaching full capacity or if the water levels fall below a desired threshold.

In addition to real-time monitoring, the system incorporates a predictive element based on machine learning. The goal of the machine learning model is to analyze the water usage patterns over time and provide insights into how much water will be required in the future, as well as how water consumption fluctuates based on various factors such as temperature, time of day, and the number of people using water. This predictive capability can significantly optimize water usage, enabling better resource allocation and the ability to anticipate high-demand periods.

The machine learning model is built using historical data from the PostgreSQL database. To ensure that the model's predictions remain accurate as time progresses, the system includes a retraining mechanism. This retraining process is triggered periodically, ensuring that the model adapts to any changes in water usage patterns or other external variables. The process starts by extracting all available data from the database and transforming it into a format suitable for analysis. This data is then preprocessed, with missing values handled through forward filling and categorical variables encoded using techniques such as label encoding.

For the core predictive model, the system employs SARIMAX (Seasonal AutoRegressive Integrated Moving Average with eXogenous regressors). SARIMAX is a powerful time series forecasting model that is particularly effective in handling seasonal trends and external variables (exogenous factors) that may influence water usage, such as temperature or the number of people using water at a given time. By incorporating external variables, the SARIMAX model can capture the complex interactions between water usage and environmental factors, providing more accurate forecasts.

After preprocessing the data, feature scaling is applied to normalize the input features and ensure that they are comparable, which is particularly important for machine learning algorithms. The scaled data is then split into training and test sets, and the SARIMAX model is trained on this data. Once trained, the model can predict future water demand and usage trends. The output from the model is periodically stored and updated in the database, and the system continuously learns from new data to improve its predictions.

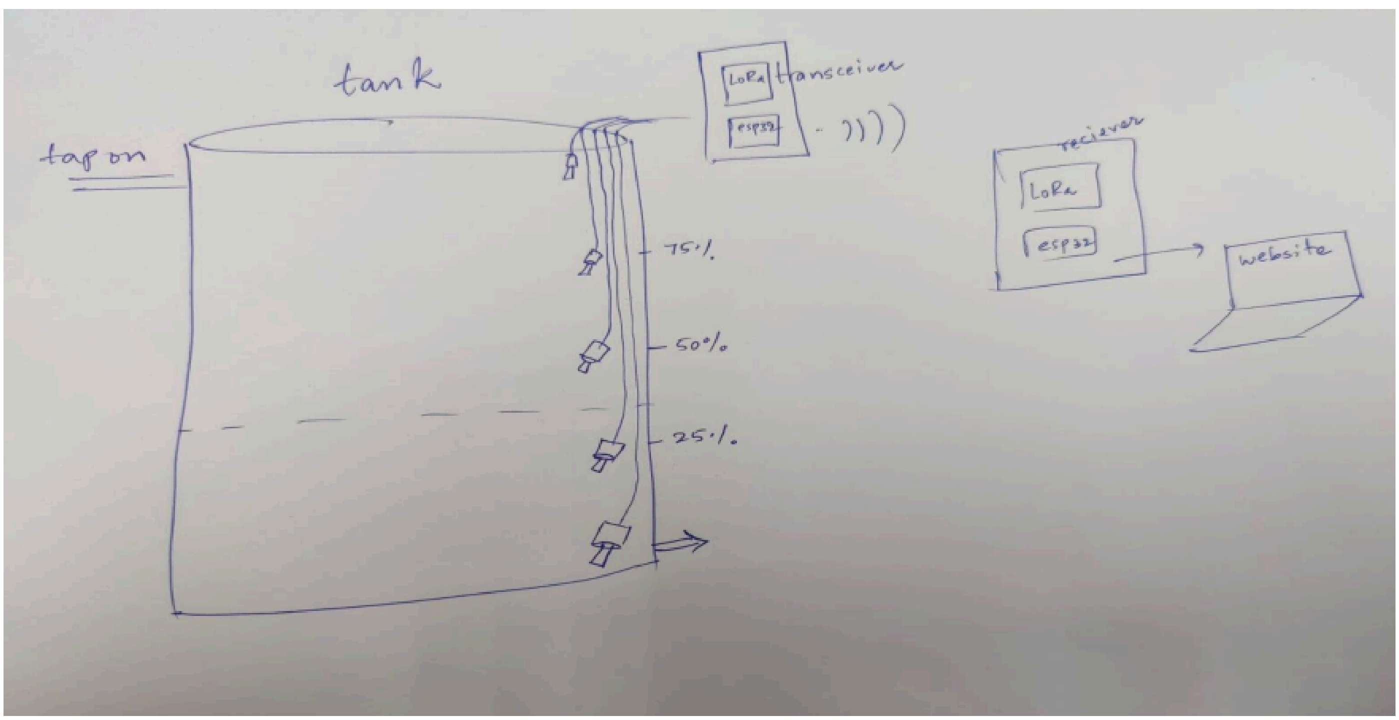
To ensure the longevity and reliability of the system, the trained SARIMAX model is saved and stored in a dedicated models directory. The model’s coefficients, which represent the relationship between the various input variables and the predicted water usage, are also saved to a separate file. These coefficients are critical for understanding how different factors (such as temperature or time of day) influence water demand. By saving both the model and the coefficients, the system ensures that it can be easily restored or updated if necessary.

Beyond the core functionality of monitoring water levels and predicting usage, the Smart Water Tank Tracking System integrates seamlessly with a user-friendly web interface. This interface provides users with a visual representation of their water tank’s current status, including the water level, historical trends, and future predictions. Users can access this information from any device with internet connectivity, allowing for constant updates and easy monitoring, even when they are away from home. Additionally, the system is designed to send alerts when water levels reach critical thresholds, helping users avoid overflow or water shortages.

The real-world applications of the Smart Water Tank Tracking System are vast. In urban areas, it can help optimize water consumption in residential and commercial buildings, ensuring that water is available when needed while avoiding waste. In rural or agricultural settings, the system can help farmers track water levels in irrigation tanks, improving crop management and ensuring that water is used efficiently. The system's ability to predict water demand also makes it valuable in areas experiencing water scarcity, as it can help prioritize water usage during periods of drought.

The integration of IoT, machine learning, and data analytics in this project represents a significant leap forward in the field of water management. By automating water level monitoring and using predictive analytics, the system offers a smarter, more efficient way to manage water resources. The combination of real-time data collection, machine learning-based predictions, and remote monitoring not only helps reduce water wastage but also empowers users to make more informed decisions about their water consumption. With further advancements, the system has the potential to be scaled and adapted for broader use, making it a crucial tool for sustainable water management in both urban and rural settings.

In conclusion, the Smart Water Tank Tracking System offers a comprehensive solution to modern water management challenges. Through the use of IoT sensors, LoRa communication, and advanced machine learning models, it provides users with real-time insights into their water consumption patterns and predictions for future usage. This system is poised to contribute significantly to more sustainable water usage practices, helping to conserve valuable resources and improve water management efficiency worldwide.



Motivation

Water scarcity is a critical issue affecting many urban areas, including major cities like Bangalore, where periodic water shortages have significant impacts on daily life, agriculture, and local economies. The motivation behind the development of the Smart Water Level Tracking System stems from a desire to address these issues proactively. By creating a system that can accurately monitor water levels and predict future water usage, users can take necessary measures to manage water resources effectively, reduce waste, and prevent potential shortages.

One of the primary goals of this project is to offer a predictive tool for water management that goes beyond simple monitoring. With a machine learning model that forecasts water usage based on historical and real-time data, users can anticipate how much water will be needed in the near future and make informed decisions. This foresight enables households, communities, and businesses to adapt their water usage based on expected demand, helping to optimize resources, reduce dependency on emergency water supply measures, and contribute to sustainable water management practices.

Another key motivation for this project is to address the limitations of traditional water level sensors. Conventional sensors, such as ultrasonic or distance sensors, are often unsuitable for prolonged use in water due to direct exposure to moisture. Continuous contact with water can degrade these sensors over time, reducing accuracy and leading to frequent maintenance or replacement. Such durability issues make them unsustainable for reliable, long-term water level monitoring, especially in large tanks or reservoirs.

In response, we opted for a more robust solution by implementing conductivity sensors. These sensors, placed at various levels within the water tank, are specifically designed to withstand the humid environment without compromising their effectiveness. By detecting the conductivity of water at different levels (0%, 25%, 50%, 75%, and 100%), the system can determine the exact water height with high accuracy and minimal maintenance. This approach not only extends the lifespan of the monitoring components but also provides a more reliable data source for tracking water levels.

Overall, the Smart Water Level Tracking System addresses critical challenges in water conservation and resource management. By combining real-time monitoring, predictive analytics, and sustainable sensor technology, this project is designed to empower users to make informed choices about their water usage, contribute to the prevention of water shortages, and promote sustainable practices for water conservation.

Contribution of the Project

The Smart Water Tank Tracking System was developed collaboratively by the project team, with each member contributing significantly to different aspects of the project. The contributions are as follows:

Subhash:

1. **System Design and Architecture:** Designing the overall system architecture, which included selecting the appropriate technologies and hardware for the project. He evaluated various sensor types and communication methods, ultimately choosing metal conductors and LoRa technology for monitoring the water levels and transmitting data. He designed the placement of the metal conductors at different levels (0%, 25%, 50%, 75%, and 100%) within the water tank to ensure reliable and accurate water level detection. Subhash also developed the layout for the IoT components, including the integration of the ESP32 module and LoRa transmitter, to transmit water level data to the remote receiver.
2. **IoT and Communication Setup:** Setting up the IoT system, including programming the ESP32 module and configuring the LoRa communication for transmitting data from the tank. He ensured that the data could be sent effectively from the water tank to the receiver located at a remote location, such as a home or control center. He also managed the configuration of the remote LoRa receiver, ensuring that it received the data and successfully passed it to the central database for storage and processing.
3. **Database Integration:** Integrated the system with the PostgreSQL database, designing the database schema to store water level data. He ensured that the database could support large amounts of data and allow for efficient retrieval of historical data for future analysis and forecasting. Subhash developed the necessary logic to update the database continuously as new data was received from the water tank, ensuring that the system maintained accurate and up-to-date information.

Siva:

1. **Machine Learning Model Development:** Led the development of the machine learning component of the system. He was responsible for collecting, cleaning, and preprocessing the historical data from the PostgreSQL database to prepare it for model training. He designed the retraining mechanism for the machine learning model, ensuring that it could adapt to changing water usage patterns over time. Siva also handled the feature scaling, label encoding, and management of missing values within the dataset. Additionally, he built the SARIMAX (Seasonal AutoRegressive Integrated Moving Average with

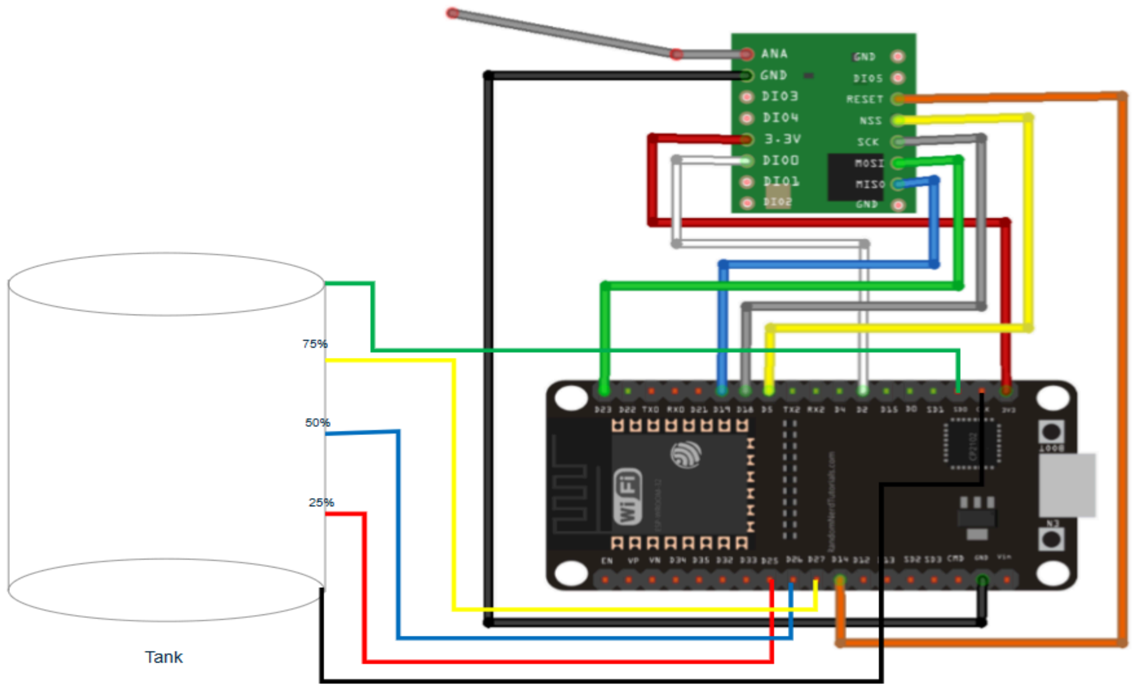
eXogenous regressors) model for time series forecasting, optimizing its parameters to ensure accurate water usage predictions.

2. **Predictive Analytics and Model Evaluation:** Evaluated the performance of the machine learning model using metrics like mean squared error (MSE), mean absolute error (MAE), and R-squared (R^2). He fine-tuned the model by adjusting its hyperparameters to improve its predictive accuracy and reliability. He also ensured that the model's predictions could be used effectively to forecast future water demand based on historical data, environmental factors, and other variables.
3. **System Monitoring and Optimization:** Iimplementing the periodic retraining process of the machine learning model. This process ensured that the model remained up-to-date, with new data continuously incorporated into the system to maintain prediction accuracy. Siva also handled the saving of the trained model and its coefficients, ensuring that the system could store and use the model for future predictions.
4. **Web Interface and Visualization:**Contributed to the development of the user-friendly web interface, providing a visual representation of real-time water level data, historical trends, and future predictions. The web application enabled users to monitor the water tank remotely and receive alerts about water levels or potential water usage issues. He ensured the web interface was intuitive and provided accurate, real-time information to users, making it easy for them to track water consumption and receive notifications when certain thresholds were reached.

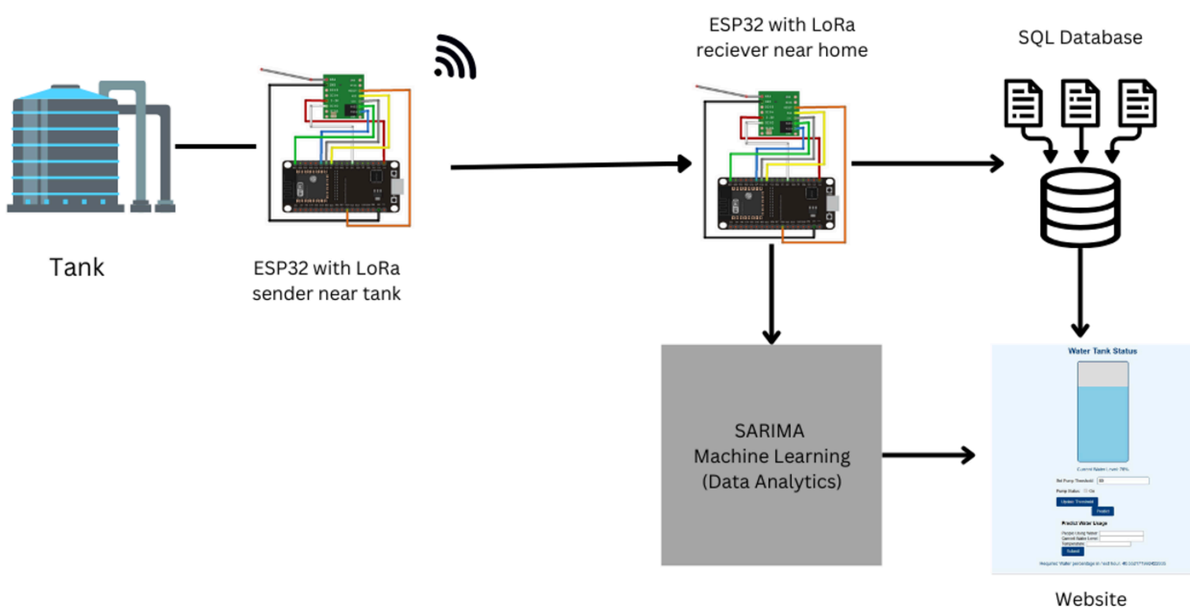
Methodology Used

1. **System Design and Architecture:**
   - **Hardware Selection**: Chose metal conductors to detect water levels at 0%, 25%, 50%, 75%, and 100% of tank capacity.
   - **IoT Integration**: Used ESP32 microcontroller and LoRa(RFM95) for transmitting water level data from the tank to a remote receiver.
   - **Database Setup**: Designed an PostgreSQL database to store water level data and historical records.
2. **Water Level Monitoring:**
   - **Sensor Placement**: Installed metal conductors at levels in the tank to detect water height.
   - **Data Transmission**: Programmed the ESP32 to send data using LoRa to a receiver located at the user's home, which then updated the database.
3. **Data Collection and Preprocessing:**
   - **Data Gathering**: Collected water level and environmental data over time.
   - **Data Cleaning**: Applied techniques like forward filling for missing values and scaling numerical features such as water level, temperature, and water usage.
4. **Machine Learning Model Development:**
   - **Model Selection**: Used SARIMAX (Seasonal ARIMA with eXogenous variables) for time-series forecasting of water usage.
   - **Feature Engineering**: Included relevant features like timestamp,current_water_level ,people_using_water,temperature, season, time_of_day, water_usage_last_hour, required_water
   - **Training the Model**: Trained the model using historical data and evaluated its performance using metrics like mean squared error (MSE) and R-squared (R^2).
5. **Web Interface and Visualization:**
   - **Web Development**: Designed a web interface to display real-time water levels and takes threshold value and notifies us whenever the water level crosses that, usage predictions , and historical trends.
   - **Data Presentation**: Integrated real-time data updates and alerts for users regarding water levels or abnormal consumption patterns.
6. **Testing:**
   - **System Testing**: Validated the system's performance by simulating water usage scenarios and

evaluating the accuracy of water level monitoring and predictions.



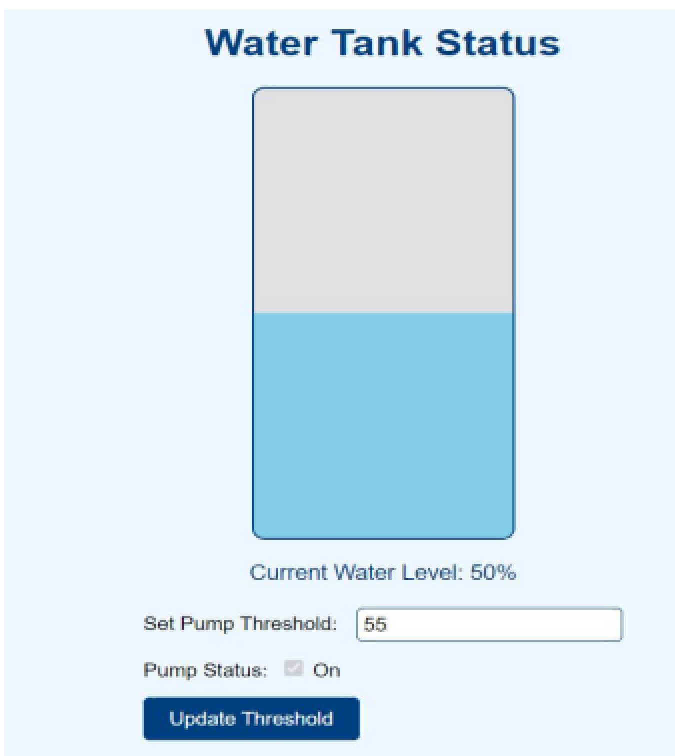
Wired Conenction setup near Tank



System Architecture

Experiments/Simulation

1. **Water Level Detection and Monitoring Test:**
   - **Objective**: To verify the accuracy and reliability of water level detection using the metal conductors and ESP32.
   - **Setup**: The metal conductors were placed at different levels (0%, 25%, 50%, 75%, and 100%) in the water tank, and the system was tested by gradually filling the tank with water.
   - **Procedure**: Water was added in incremental steps, and the ESP32 microcontroller transmitted data to the LoRa receiver and eventually updated in the website. The data was logged and cross-verified with manual measurements of water level.
   - **Results**: The system successfully detected water levels at all predefined points and transmitted the correct data, demonstrating reliable functionality.



Water level successfully changing according to the level of water in tank

2. **LoRa Communication and Data Transmission Test:**
    - **Objective**: To evaluate the efficiency of LoRa communication in transmitting water level data over long distances.
    - **Setup**: The tank was located at a remote location, and the LoRa sender and receiver were set up to transmit data to the home receiver and update the database.
    - **Procedure**: Water level data was collected in real-time and transmitted to the receiver over varying distances. Network conditions (e.g., signal strength) were simulated to test the robustness of communication.
    - **Results**: The LoRa communication maintained a stable connection even over long distances and in varying environmental conditions, ensuring reliable data transmission.

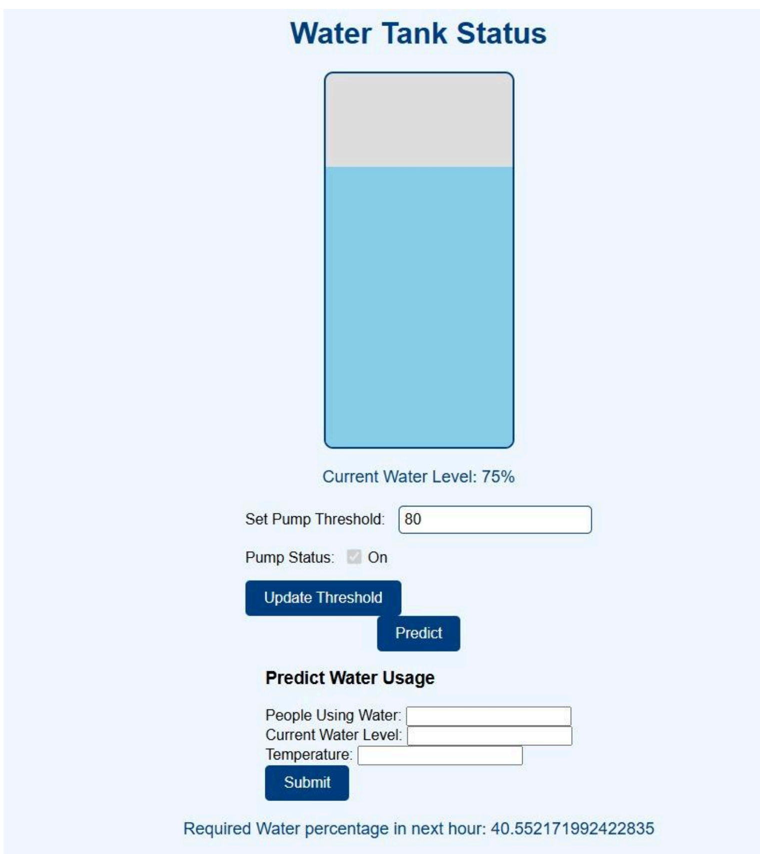
```
Received data: Received message: 75
Water level received: 75%
Database updated with water level: 75
Received data: Water level is at 75%.
Non-numeric data received, ignoring: Water level is at 75%.
Received data: RSSI: -100
Received data: Received message: 75
Water level received: 75%
Database updated with water level: 75
Received data: Water level is at 75%.
Non-numeric data received, ignoring: Water level is at 75%.
Received data: RSSI: -99
Received data: Received message: 75
Water level received: 75%
Database updated with water level: 75
Received data: Water level is at 75%.
Non-numeric data received, ignoring: Water level is at 75%.
Received data: RSSI: -99
Received data: Received message: 75
Water level received: 75%
Database updated with water level: 75
Received data: Water level is at 75%.
Non-numeric data received, ignoring: Water level is at 75%.
Received data: RSSI: -98
```

Lora Communication successfully received at reciever

3. **Machine Learning Model Training and Validation:**
    - **Objective**: To test the performance of the SARIMAX model in predicting water usage.
    - **Setup**: Historical data on water levels, usage, temperature, and other features were collected and preprocessed.
    - **Procedure**: The dataset was split into training and testing sets, with training performed on past data and testing done using unseen data. The model was evaluated using metrics like mean squared error (MSE) and R-squared (R^2).
    - **Results**: The SARIMAX model demonstrated good predictive performance, with low error rates and high R^2 values, confirming its suitability for forecasting water usage.

```
Mean Squared Error (MSE): 127.974768001122
Mean Absolute Error (MAE): 7.974339784645742
R-squared (R²): 0.5051328521961631
```

4. **Model Retraining Simulation:**
   - **Objective**: To assess how well the machine learning model adapts to new data over time.
   - **Setup**: New water usage data was periodically added to the system, simulating real-world conditions where water usage patterns change.
   - **Procedure**: The model was retrained on the updated dataset, and its performance was evaluated against previous predictions.
   - **Results**: The model successfully adapted to the new data, improving its predictions over time, demonstrating the effectiveness of the retraining process.



Challenges

Delay in Updating Water Level Diagram on the Website

- **Problem**: One of the key challenges encountered during the development of the Smart Water Tank Tracking System was the delay in reflecting real-time updates on the water level diagram on the web interface. When the water level data in the database was updated, the changes were not reflected immediately on the website. As a result, users had to manually refresh the webpage to view the updated water percentage, which led to a less dynamic and seamless user experience.
- **Solution Implemented**: To address this issue, AJAX (Asynchronous JavaScript and XML) was utilized to enable the automatic updating of the water level diagram. AJAX allows the webpage to fetch the latest water level data from the server in the background without requiring a full page reload. This ensures that the water level diagram on the website is automatically updated in real-time, providing a smoother and more dynamic user experience without interruptions.

Identifying a Suitable Model for Predicting Water Usage Patterns

- **Problem**: Selecting an appropriate machine learning model to predict water usage accurately was another significant challenge. Given the seasonal and hourly variations in water consumption, the model needed to account for these fluctuations to make reliable forecasts. Many traditional models failed to capture the complexity of the data, either underestimating peak usage or being overly sensitive to outliers, leading to inaccurate predictions.
- **Solution Implemented**: After evaluating various predictive models, we selected the SARIMAX (Seasonal AutoRegressive Integrated Moving Average with eXogenous factors) model due to its effectiveness in handling seasonal patterns and external influencing variables. SARIMAX can incorporate both time-based trends and external factors such as temperature and time of day, which affect water usage. This choice allowed the system to adapt to seasonal and daily water usage patterns, providing more accurate and actionable predictions. Additionally, an automated retraining process was set up, allowing the model to continually learn from new data, enhancing its accuracy over time.

Synchronizing and Integrating the Machine Learning Model with the Django Web Application for Hourly Execution

- **Problem**: Integrating the machine learning model into the Django web application presented a technical challenge. For effective water usage prediction, the model needed to run every hour, generating insights based on the latest data stored in the database. However, setting up an hourly model execution within a web application required careful synchronization to ensure smooth operation without interrupting the user experience.
- **Solution Implemented**: To address this, we employed Django's background task management and asynchronous job scheduling to automate the model's hourly execution seamlessly.This integration ensured that the website consistently displayed up-to-date water usage forecasts, and it allowed the application to function smoothly, with accurate predictions available to the user in real-time. This approach provided an effective way to integrate complex ML workflows into a Django-based system for continuous, reliable operation.

Model Accuracy and Retraining with New Data

- **Problem**: Another challenge was ensuring that the machine learning model remained accurate over time, especially as new data was collected. When the model was initially trained, it was based on historical water usage data, but as new data was continuously added, there was a risk that the model's predictions could become less accurate without periodic retraining.
- **Solution Implemented**: To overcome this, a retraining mechanism was developed that allows the model to be updated periodically with the latest data. This ensures that the model adapts to new trends in water usage patterns and maintains high accuracy in predictions. The retraining process was automated using background tasks to ensure that the model is always up-to-date without manual intervention.

Regular Database Updates for Hourly Water Usage Prediction

- **Problem**: One of the main challenges was ensuring that the system updated the tank's water level status to the database every hour. This regular, hourly data logging was essential to provide accurate predictions of water usage patterns. However, synchronizing data between the tank sensors and the database at this frequency posed issues with system reliability, as any delay in updates could impact the accuracy of predictions and the overall user experience.
- **Solution Implemented**: To address this challenge, an automated background process was

implemented to ensure timely updates to the database every hour. This process consistently pushes the latest water level data to the database, where it can then be analyzed and used to train the machine learning model for predicting water usage. By using asynchronous communication methods, such as background tasks, the system effectively maintains accurate, up-to-date records.

Conclusion

The Smart Water Tank Tracking System project has been a significant achievement in the development of an intelligent and automated solution for monitoring water levels and usage in real-time. The primary goal of the project was to create an IoT-based system that could accurately track the water level in a tank, transmit this data wirelessly, and predict future water consumption using machine learning algorithms. This system not only helps conserve water but also provides users with detailed insights into their water usage patterns, allowing for more informed decision-making and better resource management.

The project has successfully met its objectives through the integration of various technologies, including metal conductors for water level detection, ESP32 microcontrollers for IoT communication, LoRa technology for long-range data transmission, and machine learning models for water usage prediction. Each of these components was carefully selected and configured to work together in a seamless and efficient manner.

One of the core elements of the system is the real-time monitoring and updating of water levels. The metal conductors at various levels inside the tank are able to detect the water height with a high degree of accuracy, ensuring that users always have up-to-date information. The use of LoRa technology for data transmission allowed for reliable communication over long distances, even in challenging environmental conditions. This ensures that data collected from the tank is transmitted to a remote location, where it is stored in a database and used for further analysis.

The integration of machine learning into the project has provided a powerful tool for predicting future water consumption. By training the system on historical data, the model is able to forecast water usage patterns based on a variety of factors, including the time of day, temperature, and previous water usage. This predictive capability enables users to plan and manage their water resources more effectively. The SARIMAX model, specifically designed for time-series forecasting, was chosen for its ability to handle seasonal variations and external variables, making it ideal for this type of predictive analysis. The retraining mechanism ensures that the model remains accurate over time by continuously learning from new data.

A major challenge faced during the project was ensuring that updates to the database were reflected in real-time on the web interface. Initially, the webpage required manual refreshing to display updated data, which detracted from the user experience. To address this issue, AJAX was implemented to automatically fetch the latest data and update the water level diagram without the need for a full page reload. This solution enhanced the user experience, providing real-time updates in a dynamic and seamless manner.

Another significant challenge was maintaining the accuracy of the machine learning model over time. As more data was collected, the model had to be retrained periodically to adapt to changing water usage patterns. This was handled by developing a background task that automatically retrained the model with new data, ensuring that the predictions remained accurate and relevant. Additionally, the system was optimized to handle large volumes of data without compromising performance, making it scalable for future expansion.

Through testing and experimentation, the system proved to be robust and reliable. The water level detection system worked as expected, with accurate data being transmitted to the database and displayed on the web interface. The machine learning model demonstrated good predictive accuracy, with the ability to forecast water usage with a high degree of confidence. The system was also able to handle multiple users and large datasets efficiently, ensuring that the application could scale with growing user demand.

In conclusion, the Smart Water Tank Tracking System has achieved its primary objectives and has the potential to revolutionize the way water usage is monitored and managed. By providing real-time data, predictive analytics, and automated updates, the system empowers users to conserve water, optimize usage, and make more informed decisions. The integration of IoT and machine learning technologies has provided a solid foundation for future developments in water management systems, and the project sets the stage for further enhancements, such as the inclusion of additional sensors or the integration with other smart home systems. This project not only demonstrates the power of technology in addressing critical resource management challenges but also paves the way for future innovations in the field of environmental sustainability.

The system is scalable, and with additional data and improved models, it can provide even more accurate predictions, helping users to better manage their water resources. The lessons learned from this project can be applied to other areas of resource management, such as energy or waste management, where similar IoT-based systems could be developed to monitor and optimize usage. Moving forward, continuous improvements to the system’s hardware, software, and machine learning models will ensure that it remains a cutting-edge solution for water conservation and management.

Ultimately, the Smart Water Tank Tracking System is a step forward in using advanced technology for sustainability, and it can serve as a model for future smart systems aimed at conserving natural resources.