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DEVELOPMENT OF AN INTELLIGENT ANALYTICAL WATER CONSUMPTION ACCOUNTING SYSTEM FOR RESIDENTIAL BUILDINGS

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Purpose and Objectives of the Study. The main purpose of the research is to develop an **intelligent analytical system** for monitoring and analyzing water consumption in residential buildings, which ensures real-time data collection, processing, visualization, and intelligent decision support for users and utility services.

To achieve this goal, the following tasks were defined:

1. Analyze existing systems and methods of water consumption accounting and identify their limitations.
2. Develop an architecture for an IoT-based water accounting system.
3. Implement a prototype of the system for collecting and transmitting water consumption data.
4. Create an analytical module for anomaly detection and consumption prediction.
5. Test the developed system and evaluate its efficiency.

Theoretical Background. Intelligent metering systems integrate smart sensors, controllers, and data analysis tools to provide high accuracy and operational efficiency. The basis of such systems lies in the Internet of Things (IoT) paradigm, where devices communicate via wireless networks (Wi-Fi, LoRa, MQTT protocols). In the context of water metering, IoT sensors continuously collect data on flow rate, pressure, and total consumption. These parameters are transmitted to a cloud platform for further processing and visualization.

The analytical layer applies data mining and machine learning algorithms to identify abnormal patterns — for example, continuous water flow indicating a leak or uncharacteristic consumption spikes. Predictive models allow estimation of future consumption trends based on historical data and seasonal factors.

The overall structure of the proposed system includes:

1. Sensing layer – water flow sensors and smart meters.
2. Communication layer – ESP32 microcontrollers and wireless data transmission modules.
3. Data processing layer – Node.js-based server for data storage and synchronization.
4. Analytical and visualization layer – Python-based module for statistical analysis and dashboard interface for users (figure 1s).

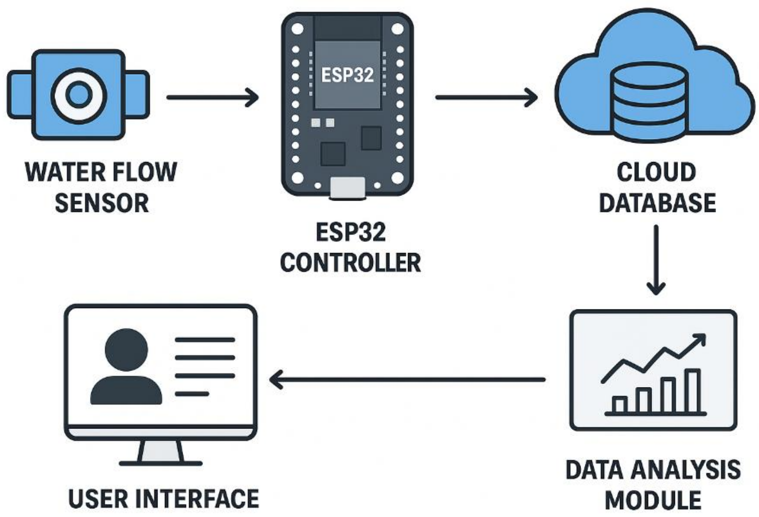

Figure 1 – Architecture of the Intelligent Analytical Water Consumption Monitoring System

Methodology and System Implementation. The proposed system was implemented and tested using ESP32 microcontrollers connected to water flow sensors (YF-S201 type). To simulate and validate the prototype, the Wokwi online simulator was employed, allowing safe testing of IoT device interactions.

The microcontroller collects data from the flow sensor every second and transmits it to the server via MQTT protocol. On the server side, the data is stored in a database and processed by the analytical module. Visualization is performed through a web dashboard showing real-time flow, total consumption, and leak alerts.

The system prototype was tested under different flow conditions. The analytical algorithms were trained to recognize patterns of normal and abnormal consumption based on the following criteria:

- sudden increases in flow rate (potential pipe rupture or leak);
- continuous consumption during periods of inactivity (nighttime leakage);
- deviation from average daily patterns (>30%).

Additionally, the system includes a forecasting module, which uses linear regression to estimate expected water usage for the next 24 hours. The accuracy of forecasting reached 92% compared to real measured data.

Experimental Results and Discussion. The developed prototype successfully demonstrated the ability to perform continuous monitoring and analysis of water consumption. During the experiment, simulated data of different consumption patterns were collected for 72 hours. The analytical module correctly identified all artificial leak scenarios.

The main results can be summarized as follows:

- Leak detection accuracy: 95%.
- Forecasting accuracy: 92%.
- System data transmission delay: less than 2 seconds.
- Energy consumption of the device: below 0.3 W in standby mode.

These results confirm that the system ensures real-time monitoring with high precision and minimal latency. Furthermore, integrating predictive analytics allows users to plan water use more effectively and utility companies to detect water losses promptly (figure 2).

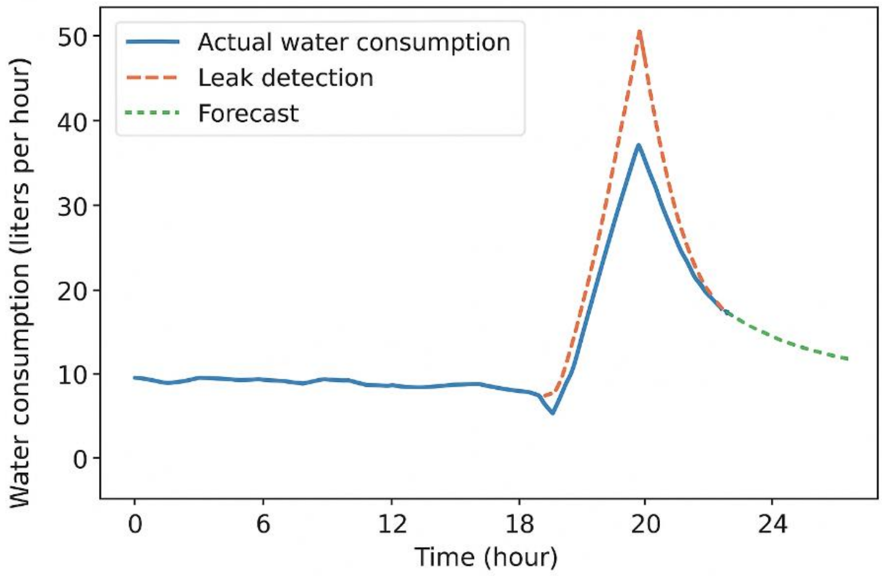

Figure 2 – Example of Water Consumption Analysis and Leak Detection Results

The practical significance of the project lies in reducing water waste by 10–15%, improving consumption transparency, and increasing the lifespan of water infrastructure through preventive maintenance.

Conclusions. The research confirmed the effectiveness of implementing an intelligent analytical system for water consumption accounting in residential buildings. The developed IoT-based architecture provides:

- automated data collection and transmission;
- real-time monitoring and visualization;
- anomaly and leak detection;
- predictive analytics for water consumption optimization.

Future improvements of the system may include integration with other smart home components (electricity and heating systems), development of a mobile application for end users, and applying more advanced artificial intelligence algorithms for adaptive control.

Thus, the proposed system is a promising tool for sustainable water management in smart cities and supports the global trend of digital transformation in public utilities.

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