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AI-IoT Enabled Smart Municipal Infrastructure System for Intelligent Water Supply, Streetlight Fault Detection, and Drainage Overflow Management

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Abstract
This research presents an IoT-based Municipal Utilities Management System developed using the ESP32 microcontroller for intelligent monitoring and automation of urban infrastructure. The system integrates ultrasonic sensing, GSM communication, RTC-based scheduling, LCD display, and buzzer alerts to monitor drainage levels, automate water pump operations, and control streetlights efficiently. The ultrasonic sensor continuously measures the water level inside municipal drainage or manholes and detects overflow conditions in real time. When the water level exceeds the predefined threshold, the ESP32 activates a buzzer alert and sends warning messages remotely through the GSM module for quick response and preventive maintenance. The RTC module provides accurate timing control for automatic streetlight and pump scheduling, reducing manual intervention and improving energy efficiency. An LDR sensor is additionally used to monitor lighting conditions and detect streetlight faults automatically. The LCD module displays real-time system status, sensor readings, and timing information for local monitoring. Developed using Embedded C programming and IoT technology, the proposed system enhances urban safety, minimizes maintenance efforts, and supports smart city infrastructure management. Future enhancements may include cloud connectivity, AI-based fault prediction, and advanced remote monitoring features for intelligent municipal automation.

Keywords: IoT, ESP32, Municipal Water Management, Induction Motor Pump Control, Manhole Monitoring, Ultrasonic Sensor, GSM Communication, RTC Scheduling, Streetlight Automation, Embedded Systems.

1. INTRODUCTION

Around 5% of the total electrical energy consumption is associated with street lighting and other public utility lighting systems [1], where a considerable amount of energy is wasted due to inefficient manual operation and the absence of intelligent monitoring mechanisms. Conventional municipal utility systems generally rely on fixed schedules and human intervention for streetlight operation, water pump management, and drainage monitoring, resulting in excessive power consumption, delayed fault detection, and increased maintenance requirements. To address these limitations, this work proposes an IoT-based smart municipal utility management system implemented using a GSM-GPRS shield and the ATmega-328p microcontroller. The proposed system supports fully automated, semi-automated, and manual operational modes for flexible and efficient control of urban utilities.

The GPRS module enables internet connectivity for automatic streetlight operation based on sunrise and sunset timings, while the GSM and RTC modules provide additional scheduling capabilities through predefined timings or mobile message-based control. The system also includes transformer fault detection features for improved reliability and maintenance support. IoT technology [2] has become an essential component of modern smart infrastructure by enabling automation, remote monitoring, and efficient resource utilization. Through IoT-enabled communication and sensor integration, the system significantly reduces electricity consumption and minimizes manual intervention.

In addition to smart lighting automation, the project incorporates an intelligent water pump control mechanism using the IC555 timer circuit [3] and a crystal oscillator-based sensing arrangement to monitor water tank levels continuously. The system automatically switches the water pump OFF when the tank reaches its maximum level, thereby preventing water overflow and reducing unnecessary electricity usage [4]. Similarly, when the water level decreases, the sensing mechanism activates the pump automatically to maintain proper water availability. Signals generated by the oscillator are processed through the IC555 timer and transmitted to a relay circuit that controls the motor operation efficiently.

The proposed design also integrates essential electronic components such as diodes, voltage regulators, crystal oscillators, relays, and RC timing circuits to ensure reliable and stable system performance under varying operating conditions [5]. The RC timing configuration provides accurate delay generation and timing control for automation tasks, thereby improving operational precision and system stability. Overall, the proposed IoT-enabled municipal management system enhances operational efficiency, reduces manual effort, minimizes energy and water wastage, and supports the development of sustainable smart city infrastructure [6].

2. LITERATURE REVIEW

Suseendran et al. [7] represented the brightness controlling of the street light using sensors, based on IoT (Internet of Things), video vehicle detection and LDR (Light Decreasing Resistance) sensor. Each lamp unit encompassed two sensors- video vehicle detection sensor and LDR sensor. All the data were collected and processed on a regular basis which required a huge data processing system. Lavric et al. [8] revealed a practical implementation of street light monitoring and controlling system employing WSN (Wireless Sensor Network System). The authors had focused on the software-based method and then performed a realtime implementation using limited number of lights. This archetype included a Doppler sensor to allow vehicle detection. According to the appearance of vehicle, lights for that particular region increased intensity. Archibong et al. [9] worked with IoT based PV solar self-powered lighting system for street with anti-vandalism monitoring and tracking competency. LDR sensor switched the lights on-off along with an IR (InfraRed) sensor having the ability to save power. The anti-vandalism system was installed with a User Interface (UI), where the street lights communicated with the people and devices through wi-fi module at the control station. Prasad et al. [10] projected a case-study of Nagpur Street lighting system, where LED lights were utilized along with motion detection system. The arbitration showed that energy consumption was lessen by 55% per month. Abdullah et al. [11] worked to provide a suitable system to minimize the power dissipation. The prototype comprised LDR, IR, battery and LED along with Arduino uno, which was skilled in increasing the intensity of light based on the speed of the vehicle. This project concluded that, this system will retain about 40% energy per month. Smart street lighting system also practiced in another way by Sukhothai et al. [12] using Lora WAN in accompany with motion detector and illuminance sensor to mitigate the power consumption. In this model, every street light had been furnished with Lora WAN communication module, which controlled the LED lights by exchanging data with main server. Mary et al. investigated on the control of street lights using lamp unit, sensor unit and access unit. The lamp and the sensor units accommodated sensors for identifying motion and brightness of controller, LED device and communication device. For the access unit, Zigbee was used. Whenever there was any motion, lights' brightness was proliferated otherwise it was dimmed or low. All the above divulged papers are prototype based. Only the work with WSN network system represented a field work with implementing the concept only for controlling four lighting units. This paper portrays a practically implemented method with control of 300 lights of 2.5km distance.

3. PROPOSED SYSTEM

The proposed IoT-based Municipal Utilities Management System is designed around the ESP32 microcontroller, which acts as the central processing and control unit for all sensing, monitoring, and

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automation operations. The system integrates multiple sensors and communication modules to provide intelligent control of municipal infrastructure such as drainage monitoring, streetlight automation, and water pump management. The ultrasonic sensor continuously measures the drainage or manhole water level and sends the measured data to the ESP32 for real-time analysis. When the detected water level crosses the predefined threshold, the controller activates the buzzer and transmits alert notifications through the GSM module to prevent overflow situations and improve public safety.

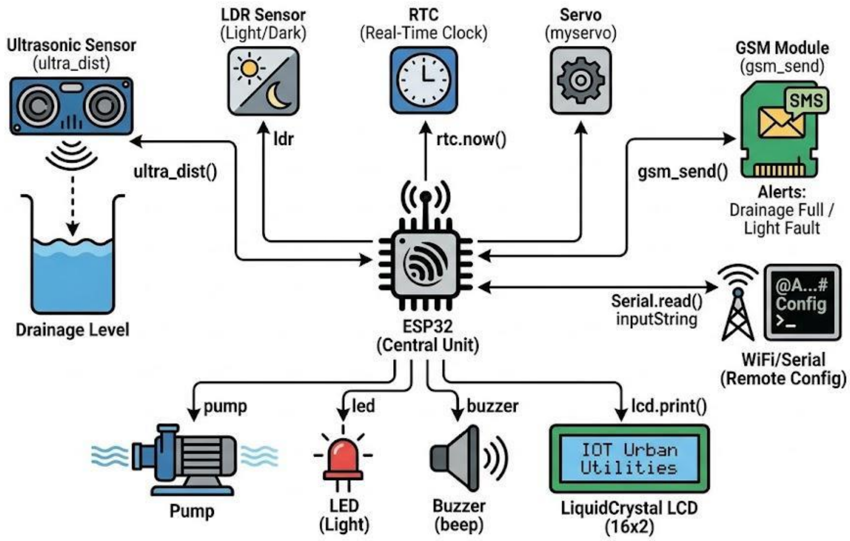

Figure 1: The proposed IoT-based municipal utilities management system

The LDR sensor is used to monitor ambient light conditions and determine whether the environment is in light or dark mode. Based on the sensor readings and predefined schedules, the ESP32 automatically controls the streetlight operation to reduce unnecessary power consumption. The RTC module provides accurate real-time clock information for scheduled automation of the pump and lighting system, allowing the system to operate efficiently without continuous human intervention as shown in Figure 1.

The GSM module enables remote communication by sending warning messages related to drainage overflow and streetlight faults. Remote configuration commands can also be provided through serial or wireless communication for updating system parameters dynamically. The LCD display continuously presents system information such as drainage level, lighting status, and operational messages for local monitoring. Additionally, the buzzer acts as an emergency alert mechanism during abnormal conditions. The integration of sensing, communication, automation, and monitoring modules makes the proposed system highly suitable for smart city and municipal utility management applications.

4. RESULTS AND DISCUSSION

The Results and Discussion section presents the experimental evaluation of the proposed smart irrigation and soil monitoring system. The integrated sensors, control modules, and irrigation components were tested under different soil moisture conditions to assess system performance. Experimental results indicate that the system accurately detects variations in soil moisture and automatically controls water delivery without human intervention. The real-time monitoring and display functionalities operated reliably, providing continuous feedback on field conditions.

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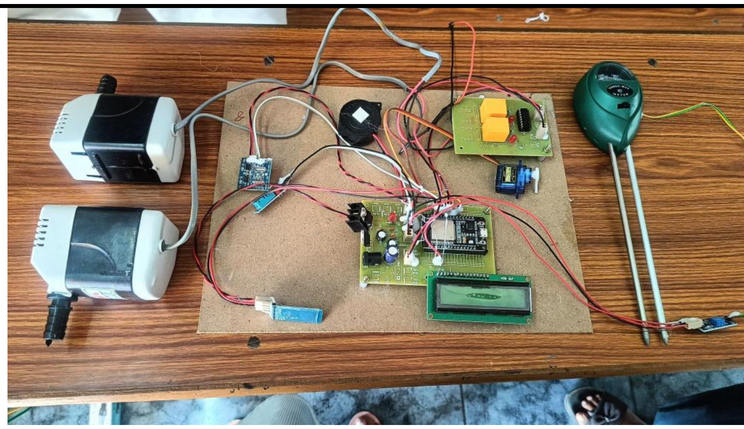

Figure 2. Experimental prototype of the smart irrigation and soil monitoring system

Figure 2 illustrates the developed smart irrigation and soil monitoring system designed for automated agricultural applications. The prototype integrates an ESP32 microcontroller, soil moisture sensor, environmental sensing modules, water pumps, relay control circuitry, servo motor, buzzer, and LCD display for real-time monitoring and control. The soil moisture sensor continuously measures the water content in the soil and transmits the data to the controller for analysis. Based on the sensed moisture level, the system automatically activates or deactivates the irrigation pump to maintain optimal soil conditions. The LCD module provides real-time status updates, while the relay and actuator modules ensure efficient water management. Experimental results demonstrate the system's capability to automate irrigation processes, conserve water resources, and enhance agricultural productivity through intelligent monitoring and control.

5. CONCLUSION

This project successfully demonstrates an IoT-based municipal automation system that enhances water pump control, manhole monitoring, and streetlight management using the ESP32 microcontroller. By integrating IoT connectivity, ultrasonic sensors, an RTC module, and a GSM alert system, the solution ensures real-time monitoring, automated operations, and timely alerts, significantly reducing manual intervention. The system optimizes water distribution, prevents manhole overflows, and improves streetlight efficiency, contributing to better public safety, resource management, and urban sustainability. Future enhancements will focus on AI-driven predictive maintenance and advanced data analytics to further enhance system reliability and efficiency, making it a scalable and smart solution for modern urban infrastructure.

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