

Design of ESP32-Based Smart Urban System for Automated Water Level Monitoring and Efficient Energy Management

Pothunuri Srinidhi^{1*}, Vallala Sai Kumar², Sirupa Rakesh², Nalla Harshitha²

¹Assistant Professor, ²UG Student, ^{1,2}Department of Electronics & Communication Engineering

^{1,2}Vaagdevi Engineering College, Bollikunta, Warangal, 506005, Telangana, India.

*Correspondence: Pothunuri Srinidhi (vecsri487@gmail.com)

Abstract

The rapid growth of urban populations and smart city initiatives has increased the demand for efficient urban utility management systems, with over 55% of the global population living in cities and municipal inefficiencies causing nearly 20–30% resource wastage annually, while IoT-based smart city solutions are projected to grow at over 19% annually. Additionally, issues such as water overflow, inefficient streetlight operation, and manual pump control contribute to energy loss, safety hazards, and increased operational costs. Traditional urban utility management systems rely heavily on manual monitoring and fixed schedules, which often lead to delayed responses, water wastage, overflow incidents, and inefficient energy consumption. Furthermore, conventional systems lack real-time data visibility, remote accessibility, and automated control mechanisms, reducing their effectiveness in dynamic urban environments. To address these challenges, the proposed IoT Urban Utilities Management System utilizes the ESP32 microcontroller to develop an intelligent and automated municipal management solution. The system integrates ultrasonic sensors to monitor manhole water levels and prevent overflow, while a GSM module sends real-time alerts to authorities. An RTC module enables scheduled control of water pumps and streetlights, ensuring efficient energy usage. The ESP32 processes sensor data and supports IoT connectivity for remote monitoring and data visualization, while an LCD and buzzer provide local alerts and system status updates. This smart system enhances operational efficiency, reduces resource wastage, improves public safety, and supports the development of sustainable and intelligent urban infrastructure management.

Keywords: Internet of Things, Manhole Monitoring, Municipal Automation, Real-Time Monitoring, Smart City Infrastructure, Streetlight Automation, Ultrasonic Sensor, Water Pump Control

1. Introduction

The rapid growth of urban populations and the expansion of smart city initiatives have significantly increased the demand for efficient urban utility management systems [1]. Currently, over 55% of the global population resides in urban areas, and municipal inefficiencies contribute to nearly 20–30% resource wastage annually, affecting water, energy, and infrastructure management. Additionally, the adoption of IoT-based smart city solutions is growing at a rate exceeding 19% annually, highlighting the transition toward intelligent and automated urban

systems [2]. In environments such as municipal water networks, drainage systems, urban streets, and smart city infrastructures, there is a critical need for solutions that provide real-time monitoring, automated control, and efficient resource utilization to ensure sustainability and public safety.

Traditional urban utility management systems rely heavily on manual monitoring, fixed schedules, and basic control mechanisms [3]. Water pumps, streetlights, and drainage systems are often operated without considering real-time environmental conditions, leading to inefficiencies such as water overflow,

unnecessary energy consumption, and delayed responses to critical situations [4]. These systems lack integration with modern communication technologies, preventing remote monitoring and centralized control [5]. Additionally, the absence of real-time data visibility limits the ability of authorities to make informed decisions, reducing the overall effectiveness of urban management processes [6].

In real-time scenarios, these limitations result in several critical challenges affecting urban sustainability and safety. Water overflow in drainage systems and manholes can cause flooding, infrastructure damage [7], and public health risks, especially during heavy rainfall. Inefficient streetlight operation leads to unnecessary energy consumption and increased operational costs. Manual pump control often results in water wastage and delayed responses to changing conditions. Furthermore, the lack of automated alert systems prevents timely intervention, increasing the risk of accidents and inefficiencies. These challenges highlight the need for an intelligent, IoT-based urban utility management system capable of real-time monitoring, automated control, and instant alert generation, ensuring improved efficiency, reduced resource wastage, enhanced public safety, and sustainable urban development.

2. Literature Survey

Ramos et al. [8] proposed a smart water grid framework integrated with digital twin technology to enhance efficiency and management of water distribution networks. Brahmhatt et al. [9] proposed a digital twin-assisted decision support system for quality regulation and leak localization in large-scale water distribution networks. Farah et al. [10] proposed a comprehensive review of water leak detection methods, analyzing acoustic, pressure-based, and data-driven approaches.

Giudicianni et al. [11] proposed an overview of energy management and leakage control systems for smart water grids, focusing on monitoring strategies and optimization techniques. Xylem [12] proposed a virtual district metered area (DMA) approach for optimizing leak detection using advanced monitoring and data analytics.

Kowalski et al. [13] proposed an impact assessment of DMA formation on monitoring system sensitivity in water supply networks. The system evaluated how network segmentation improved leak detection performance. Jenks et al. [14] proposed a mobile DMA testing methodology for leakage assessment in water distribution systems using field-based monitoring techniques. The system enabled flexible and localized leak detection. T

Kowalska et al. [15] proposed a method for dividing water supply networks into district metered areas using WaterGEMS software for improved monitoring and management. Malialis et al. [16] proposed a deep learning-based approach for urban water consumption forecasting using correlated district metered areas.

Deb et al. [17] proposed a water distribution system design methodology using QGIS and EPANET tools for efficient planning and simulation. Kanakoudis et al. [18] proposed a water pipe network management approach aimed at reducing non-revenue water through monitoring and control strategies. Farley [19] proposed best practices for leakage management and control in water distribution systems, covering detection, prevention, and maintenance strategies.

3. Proposed System

Figure 1 illustrates an IoT-based smart municipal services system built around the ESP32, designed to automate water supply, street lighting, and manhole monitoring. The system integrates multiple input modules including an ultrasonic sensor for water level

detection, LDR for light sensing, RTC for scheduling, IoT interface, and a mobile app for user interaction. A regulated power supply (RPS) ensures stable operation. The ESP32 processes all inputs and controls outputs such as LCD display, buzzer alerts, GSM communication, and relay-driven devices including water pumps and streetlights. This system enables real-time monitoring, automation, and fault detection, improving the efficiency and reliability of municipal infrastructure.

Step 1: Power Supply Initialization: The regulated power supply (RPS) provides stable DC voltage to the ESP32 and all connected components, ensuring uninterrupted operation.

Step 2: Scheduled Water Supply using RTC: The Real-Time Clock (RTC) module is programmed with predefined schedules for water distribution. At the scheduled time, the ESP32 activates Relay1 to turn ON the water pump, ensuring timely water supply.

Step 3: Pump Monitoring and Alerts: If the pump fails to operate or abnormal conditions are detected, the ESP32 triggers a buzzer alert and sends an SMS notification via the GSM module to authorities.

Step 4: Smart Streetlight Control using LDR and RTC: The RTC schedules streetlight operation, while the LDR sensor monitors ambient light conditions. If a streetlight fails to turn ON despite low light conditions, the system detects the fault and generates alerts.

Step 5: Relay-Controlled Streetlight Operation: Relay2 is used to control streetlights automatically. Based on time and light intensity, the ESP32 switches streetlights ON/OFF efficiently.

Step 6: Manhole Water Level Monitoring: An ultrasonic sensor continuously measures the water level inside the manhole. If the level exceeds a predefined threshold, it indicates blockage or overflow.

Step 7: Emergency Alert System: In case of overflow or faults, the system activates a buzzer for local alerts and sends SMS notifications via GSM to municipal authorities for immediate action.

Step 8: IoT-Based Remote Monitoring: The ESP32 transmits all system data (water supply status, streetlight condition, manhole levels) to a cloud platform. Authorities can monitor and control the system remotely through a dashboard or mobile app.

Step 9: LCD Display Output: The LCD provides real-time display of system parameters such as water supply status, streetlight condition, and sensor readings for local monitoring.

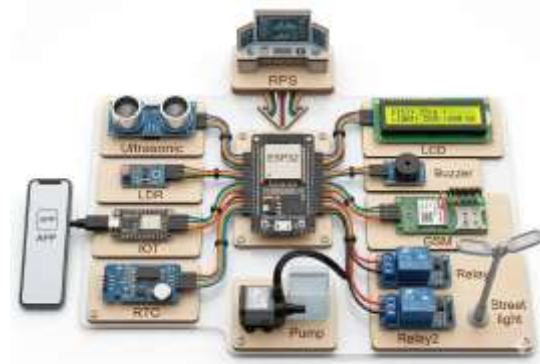


Figure 1. Proposed Block Diagram.

3.1 Working Procedure

This research utilizes an ESP32 microcontroller to automate and optimize municipal services, including scheduled water supply, smart streetlight control, and manhole monitoring. The system integrates a RTC, ultrasonic sensors, an LDR, IoT connectivity, and a GSM module to ensure efficient and reliable operation as shown in Figure 2.

This fully automated IoT-based system significantly enhances municipal service efficiency by eliminating manual intervention, ensuring reliable water supply, optimizing streetlight operation, and preventing manhole overflows. By integrating IoT, real-time monitoring, and automated alerts, the system

improves urban infrastructure sustainability, safety, and responsiveness.

Figure 3 illustrates the circuit diagram of an ESP32-based smart street lighting and safety monitoring system integrated with IoT and GSM communication. The system is powered by a regulated power supply unit consisting of a step-down transformer, bridge rectifier, filter capacitors, and a 7805-voltage regulator to deliver a stable +5V output.

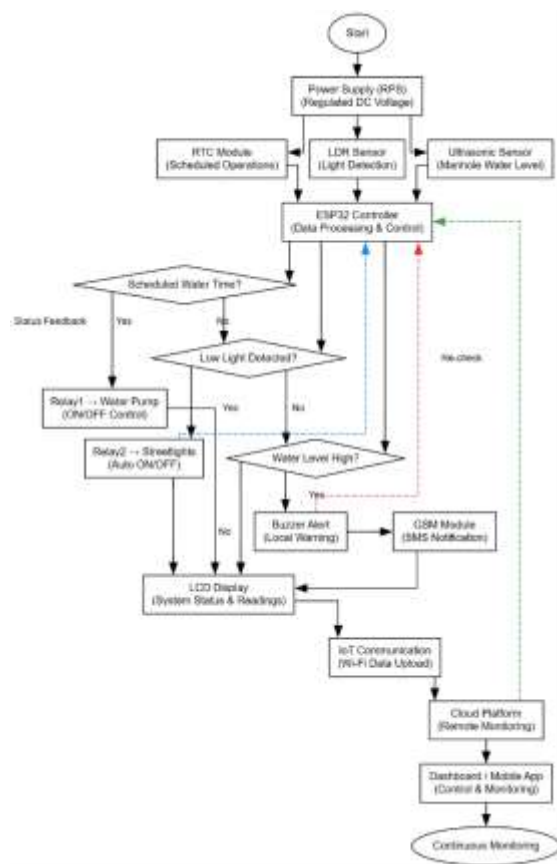


Figure 2. Proposed Flowchart.

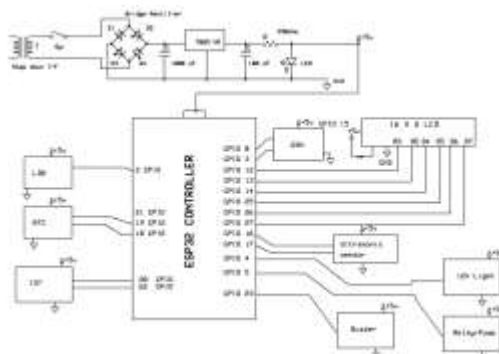


Figure 3. Circuit Diagram.

The ESP32 microcontroller acts as the central controller, interfacing with an LDR sensor for automatic light intensity detection, an RTC module for time-based control, and an ultrasonic sensor for motion or obstacle detection. Based on sensor inputs, the system controls a 12V streetlight and a relay-driven pump for additional safety or utility operations. A GSM module enables alert messaging and communication, while an IoT module allows remote monitoring and control. The system also includes a 16×2 LCD to display real-time status and a buzzer for alert notifications. This integrated design ensures energy-efficient lighting, automated operation, and enhanced safety in smart city applications.

4. Results and Discussion

Figure 3 shows the complete hardware setup of the IoT Urban Utilities Management System. The system includes the ESP32 microcontroller board, ultrasonic sensor for drainage level monitoring, relay modules for pump and streetlight control, LCD display for real-time monitoring, and other supporting circuits. The setup demonstrates how the system integrates sensing, control, and communication components to manage urban utilities.

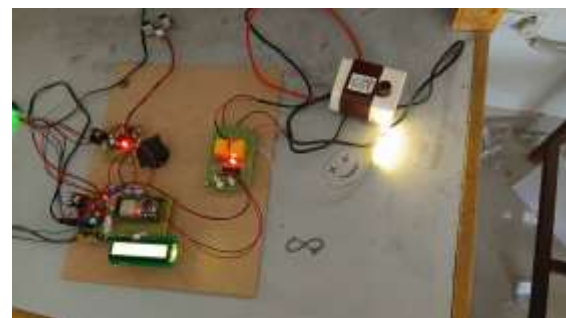


Figure 3. Hardware Implementation of IoT Urban Utilities Management System



Figure 4. LCD Display Showing System Status

The LCD display as shown in Figure 4 shows the system initialization message “IOT Urban Utilities Management.” This confirms that the microcontroller and connected modules have successfully started and are ready for monitoring and control operations.

Figure 5 shows the LCD displaying the current date and time obtained from the RTC module. Accurate time information allows the system to automatically control streetlights and schedule pump operations according to predefined timings.



Figure 5. LCD Display Showing System Date and Time

S.No	Drainage	Light Status	Pump	Date
1	Drainage_Level04	Light_Fault		2026-02-09 13:04:46
2	Drainage_Level_Ful03	Light_OFF		2026-02-09 13:02:40
3	Drainage_Level_Ful08	Light_OFF		2026-02-09 13:28:30
4	Drainage_Level_Ful05	Light_OFF		2026-02-09 13:18:30
5	Drainage_Level_Ful02	Light_OFF		2026-02-09 13:12:30
6	Drainage_Level_Ful02	Light_OFF		2026-02-09 13:04:40
7	Drainage_Level_Ful02	Light_OFF		2026-02-09 13:04:36
8	Drainage_Level_Ful02	Light_OFF		2026-02-09 14:38:04
9	Drainage_Level_Ful02	Light_OFF		2026-02-09 14:07:40
10	Drainage_Level_Ful03	Light_OFF		2026-02-09 14:07:33
11	Drainage_Level204	Light_Fault		2026-02-09 13:02:39
12	Drainage_Level231	Light_Fault		2026-02-09 13:02:22
13	Drainage_Level231	Light_OFF	OFF	2026-02-09 13:28:26
14	Drainage_Level234	Light_OFF	OFF	2026-02-09 13:28:39
15	Drainage_Level233	Light_OFF	ON	2026-02-09 13:18:20
16	Drainage_Level_Ful02	Light_OFF		2026-02-09 13:12:12
17	Drainage_Level_Ful04	Light_OFF		2026-02-09 13:02:12
18	Drainage_Level208	Light_Fault		2026-02-09 13:18:30

Figure 6. Web Server Monitoring Interface

The IoT web server interface as shown in Figure 6 displays real-time data collected from the system. The table includes parameters such as drainage level, streetlight status, pump operation, and timestamp. This web-based monitoring platform allows municipal authorities to remotely monitor infrastructure conditions and respond quickly to potential problems such as drainage overflow or lighting faults.

5. Conclusion

The proposed IoT Urban Utilities Management System presents an efficient and intelligent approach to modern urban infrastructure by integrating real-time monitoring, automation, and IoT connectivity. By utilizing the ESP32 microcontroller along with ultrasonic sensors, GSM communication, and RTC-based scheduling, the system effectively manages critical utilities such as water levels, pumps, and streetlights. It enables early detection of overflow conditions, automated control of operations, and instant alert notifications to authorities, thereby reducing resource wastage and preventing potential hazards. The inclusion of LCD and buzzer modules ensures local awareness, while IoT integration provides remote monitoring and data-driven decision-making. This system overcomes the limitations of traditional manual methods by offering adaptive, reliable, and energy-efficient solutions. Finally, it enhances urban safety,

optimizes resource utilization, and contributes significantly to the development of sustainable, smart city infrastructure.

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