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IoT-Based Smart Utility Control System

*Khansa Niazi [a], Waleed Ahmed [a], Hassan Nadeem [b]

[a] *Impact Solutions, Pvt. Ltd. Islamabad Pakistan*
[b] *Aivatek, Pvt. Ptd. Islamabad Pakistan*

* *Corresponding Author: Khansa Niazi (khanzanizi07@gmail.com)*

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Abstract

In countries such as Pakistan, water scarcity, soaring gas prices, load shedding, and climate change are major threats. Although, the existing literature has many solutions to manage the better and more efficient utilization of water motors and geysers either they are costly or lack integration. In this research work, an IoT-based low-cost solution is proposed that integrates both solutions via a mobile App. The system has two main modules: Smart Water Management and Smart Gas Geyser Control. The Smart Water Management module prevents wastage of water by real-time water level monitoring of storage and distribution tanks and remotely controlling the water pump/motor switch. The Smart Gas Geyser Control unit monitors the availability of gas in the main utility pipeline and then controls the geyser burner using an electric spark. Additionally, a schedular is used that can be controlled via a mobile app to set the timer as per user requirements. Our proposed systems provide cost-effective and efficient solutions, particularly for residential areas that have a short supply of water and gas utilities.

Keywords: Internet of Things (IoT), Automation, Geyser control, Water management, Smart Utility Management

1. Introduction

In an era of rapid technological advancements, the Internet of Things (IoT) has emerged as a transformative force, enhancing automation and resource management across various domains. One critical area where IoT can drive significant improvements is utility management, particularly in regions facing resource scarcity and economic constraints. Countries like Pakistan struggle with challenges such as water shortages, inefficient energy consumption, and rising utility costs. According to the Pakistan Council of Research in Water Resources (PCRWR), the country could face severe water scarcity by 2025 if conservation measures are not adopted [1]. Similarly, inefficient gas consumption, especially in household water heating systems, contributes to high energy bills and gas shortages during peak seasons [2]. Existing IoT-based utility management systems have demonstrated potential in optimizing resource consumption and providing remote control functionalities. However, many of these solutions are either expensive or require sophisticated infrastructure, making them inaccessible to the average consumer in developing countries. There is a critical need for a cost-effective, user-friendly, and scalable solution to enable sustainable resource management at the household level.

The remainder of this paper is structured as follows: Section 2 discusses related work, the research gap leading to the motivation behind the research, and the list of contributions. Section 3 details the system model, followed by design and implementation in section 4. Section 5 presents the results and discussion. Finally, Section 6 concludes with future research directions.

2. Related Work

In this section, a brief review of the related literature is presented, mainly focusing on IoT-based solutions for managing geysers and water distribution.

In [3], the authors explain the development of a smart, remote-controlled electrical geyser switching system meant to reduce home energy consumption. The system has a mobile app linked to an Arduino-based microcontroller, which allows users to remotely control their geyser by switching it on or off and setting usage timers. The process of development takes an Agile programming approach to deal with the challenge of high power consumption associated with geysers, which tend to stay on unnecessarily when owners are not present or when they are not able to switch them off. In reference [4], the authors propose a smart geyser controller to cut down energy use and expenditure in South Africa. The system uses wireless monitoring and optimization techniques to efficiently plan the operation of the geysers so that utilization is reallocated to non-peak periods in order to ease the load and reduce emissions. An SGC based on IoT and machine learning is proposed in [5], which optimizes geyser utilization and reduces energy usage as well as expense. It has manual, semi-automatic, and automated modes, and predictive control mechanisms have been installed to enhance efficiency and sustainability.

In reference [6], a smart water tank level sensor and motor pump control system has been designed based on Internet of Things (IoT) technology to minimize wastage of water. The system integrates sensors, microcontrollers, and a mobile app, enabling users to view water levels in real-time and automatically regulate the pump. Through remote control of water levels, the system efficiently addresses problems such as water shortages and tank overflows, thereby enhancing water efficiency and promoting sustainability. In addition, a geyser time controller is proposed in [7] to maximize electricity and water consumption through temperature control based on time and level. This technology reduces energy wastage, prolongs the lifespan of the geyser, and offers a space-saving, cost-effective solution compared to existing approaches. An IoT-based water level control system is detailed in [8], which uses an ESP8266 microcontroller and an ultrasonic sensor to prevent overflow.

Blynk IoT and PHP are utilized for remote monitoring, ensuring efficient water management with minimal errors. The system demonstrates stable Wi-Fi connectivity and effective automation. In [9], a cost-effective Bluetooth-based smart home system is proposed, incorporating Arduino, sensors, and a smartphone to remotely control up to 18 devices. It provides general-purpose automation, such as water level sensing and automated irrigation, with a focus on seamless integration into current homes. In [10], IoT-based smart water management systems are discussed, focusing on their relevance in light of growing water conservation demands. A comparison of current systems is done, concerning main parameters like water level, pH, turbidity, and salinity, and identifying critical features for new designs. An IoT- and machine learning-based architecture is further proposed to enhance efficiency through predictive analytics. n [11], a smart water level sensor is proposed that uses IoT technology to provide early warning for floods and management of dams. When the water rises, warnings are sent via smartphone and sirens, and remote control of the water gates is possible. It includes necessary materials like the ESP32, Arduino Uno, and servo motors, with development using the Agile model. Users have given positive responses about its functionality and safety features. Moreover, [12] introduces a home-based water level and leakage detection system with a focus on effective water management and quality monitoring. The system utilizes sensors to track water levels, identify leaks based on pressure changes, and measure water quality. A microcontroller analyzes the data gathered, providing SMS alerts to notify users of any problem. Through automation of water management, this system reduces water wastage, saves energy, and ensures health protection.

Research Gap and Motivation

Existing IoT-based utility management solutions are often costly or inaccessible to average users, particularly in economically disadvantaged areas. While some systems offer remote geyser control and water management, they may lack affordability and comprehensive integration. Additionally, existing models for geyser control lack multiple stages with different time intervals.

Contributions:

The contributions of our work are manifold. In most of the existing literature, the problems of automatic control and monitoring of Geysers and water management have been presented separately resulting in increased expenses. Due to political and economic turmoil, usually availability of some latest equipment in particular cheap sensors and micro-controllers is problematic. Automation is not the only issue, one has to deal with the load shedding problem, where the availability of both water and gas utility to the consumer is not guaranteed. Our proposed solution not only integrates solutions to both above-posed problems using a simple user-friendly mobile application, but also the equipment used is readily available in the Pakistani market as of today.

3. System Model

Our IoT-based proposed solution mainly consists of two separate modules to effectively deal with household water management and automatic geyser control mainly targeted at residential customers living in a country like Pakistan. The water management module uses ultrasonic sensors to check the water levels in the storage tanks (usually located on the ground floor) and the distribution tank (located on the rooftop) and is connected to a Firebase-based mobile application via ESP32 microcontroller. In case the water level in the distribution tank gets below 10%, an automatic alarm is generated in the mobile app. The user/customer then can remotely switch ON the water pump/motor that fills the distribution tank from the water storage tank. When the water level in the distribution tank reaches 90%, an alarm is generated in the mobile app indicating the tank is full and the customer can remotely turn the switch OFF. As an extra precaution, the water level check on the storage tank is also placed so that if the water level is below 10%, an alarm is generated on the mobile app to indicate a low water level in the storage level. Additionally, the current water levels can also be monitored in the app. The geyser automation module consists of a relay module controlling a solenoid valve connected to the burner of the geyser. The geyser water tank is equipped with a temperature sensor to monitor the water temperature. The ignition kit connected to the burner is also controlled by a relay module. Both relays and temperature sensors are connected to an ESP32 microcontroller that connects to the mobile app. The burner can be turned on through the ignition kit from the mobile app. A flame sensor is used to sense whether the burner is turned on or not. If the ignition kit fails to switch ON the burner in three attempts (5-10 sec delay in each attempt), indicating the gas is not coming to the valve, then an alarm is generated in the app, showing the unavailability of gas. The customer can set the timer to retry after a particular time or even give a time interval to switch ON/OFF the geyser or also maintain a water temperature to automatically switch ON/OFF the geyser

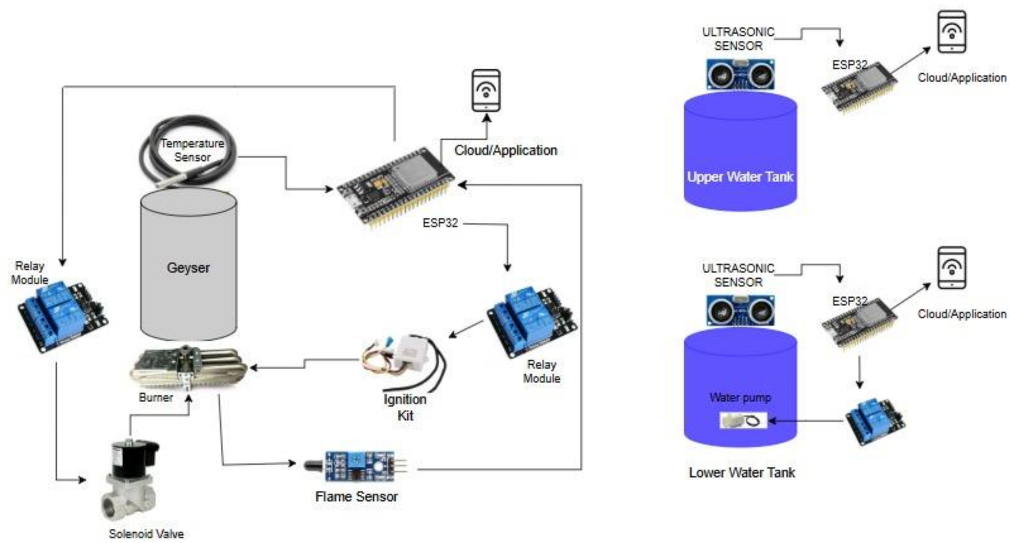

Figure 1 system model

4. Design and Implementation

The IoT-Based Smart Utility Control System is designed to automate and optimize the control of household utilities, focusing on water level monitoring and geyser automation. The system consists of hardware components, software integration, and cloud-based communication for real-time monitoring and control.

Hardware Components:

- **ESP32 Microcontroller:** The central processing unit that collects sensor data, processes it, and communicates with Firebase.

- **Ultrasonic Sensors:** Measure water levels in the main and supply tanks to prevent overflow and optimize water usage.

- **Temperature Sensor & Geyser Module:** Monitors water and environmental temperatures, ensuring energy-efficient heating.

- **Flame Sensor:** Detects the flame in the gas geyser for safety monitoring.

- **Solenoid Relay & Ignition Kit:** Automates the geyser's ignition and shutdown, reducing gas wastage and enhancing user convenience.

- **Water Pump:** Automatically turns on/off based on the water levels detected by ultrasonic sensors.

- **Arduino IDE:** Used for programming the ESP32 microcontroller.

- **Firebase Real-time Database:** Stores sensor data and user commands for cloud-based access.

- **Mobile Application (Android-based):** Allows users to monitor and control the system remotely.

Implementation:

The implementation process involves integrating hardware, software, and cloud services to create a fully functional smart utility system.

Water Level Monitoring and Pump Control:

a) Ultrasonic sensors detect the water levels in the main and supply tanks.

b) The ESP32 microcontroller processes the data and sends it to Firebase in real-time.

c) The mobile app fetches the water level data and displays it to the user.

d) If the supply tank is low, the system automatically turns on the water pump. Once the tank is full, it shuts off the pump to prevent overflow.

Smart Geyser Automation:

a) The temperature sensor monitors the current water temperature inside the geyser.

b) Users can set a desired temperature and schedule via the mobile app.

c) The ESP32 microcontroller processes the set values and activates the solenoid relay to turn on the geyser.

d) The ignition kit safely ignites the geyser, and the flame sensor ensures proper operation.

e) Once the set temperature is reached, the system automatically turns off the geyser, preventing energy wastage.

f) Users receive real-time updates and notifications about geyser status and water temperature.

The IoT-Based Smart Utility Control System is designed with an integrated hardware-software approach, ensuring automated, real-time control of household utilities such as water management and geyser automation. The hardware architecture revolves around the ESP32 microcontroller, which serves as the central processing unit, gathering data from ultrasonic sensors, temperature sensors, and flame detectors while executing control commands for the water pump, solenoid relay, and ignition kit. The ultrasonic sensors continuously monitor water levels in both the main and supply tanks, relaying data to Firebase, where users can track tank levels via a mobile application. When water levels drop below a predefined threshold, the system automatically activates the water pump, ensuring efficient water distribution and preventing wastage. Similarly, the smart geyser automation module functions by utilizing a temperature sensor to detect the current water temperature, allowing users to set temperature preferences and schedules via the mobile app. Upon receiving a heating command, the ESP32 microcontroller triggers the solenoid relay, activating the geyser's ignition system while the flame sensor monitors combustion safety. Once the water reaches the desired temperature, the system automatically shuts down the geyser, optimizing gas usage and enhancing energy efficiency. The entire system is programmed using the Arduino IDE, with Firebase as the real-time database, ensuring cloud-based data storage and user access from anywhere. The mobile application provides an intuitive interface for users to monitor water levels, control the geyser, and receive real-time status notifications. By seamlessly integrating IoT technology, smart automation, and cloud communication, the system enhances efficiency, safety, and resource conservation, making it an ideal solution for regions facing water shortages and high energy costs.

V. Results and Discussion

The proposed IoT-based smart utility system was tested in a residential home with one floor and a rooftop. The solution demonstrated reliable performance in monitoring and control of both automation modules. The water levels were 95% accurate and we had 85% accuracy in switching the water pump remotely. Similarly, for the geyser automation, the results of monitoring were >90% for time scheduling is almost 95%. The overall system resulted in reducing the water and gas consumption by approximately 20-25% thereby achieving efficient resource management resulting in user satisfaction.

Table 1 Experimental Results

Sr.	Problems	Result	discussions
1	**Water Wastage due to Manual Control**	Automatic pump control based on water levels; manual override available.	Automated water level monitoring prevented overflow and wastage, enhancing water conservation.
2	**High Energy Consumption of Geysers**	Geyser automation reduced unnecessary heating cycles, lowering energy bills.	Scheduled and remote control of the geyser improved energy efficiency and reduced gas consumption.
3	**Lack of Real-Time Monitoring**	Real-time data is displayed on the mobile app via Firebase integration.	Instant updates enabled users to make informed decisions about energy usage.
4	**Inconvenience in Manual Operation**	Remote control via mobile app for both geyser and water pump.	Improved user convenience by allowing control from anywhere, enhancing daily life ease
5	**Overheating and Safety Issues in Geysers**	Flame sensor integration for real-time flame detection and automated safety shutdown	Improved safety by detecting flame failures promptly and automatically shutting down the geyser, preventing potential hazards like gas leaks or overheating.
6	**Inconsistent Water Availability**	Automated refill of the supply tank maintained consistent water levels.	Reliable water availability addressed daily needs without manual intervention.
7	**Complexity in User Interaction**	Intuitive mobile app interface for easy interaction and control.	Simplified control through user-friendly design, making it accessible to non-technical users.

8	**Limited Scalability of Existing Systems**	Easily scalable with additional sensors and devices.	Future-proof design allows expansion for more devices and advanced functionalities.
9	**Limited Accessibility in Remote Areas**	Wi-Fi enabled access allowing remote control from anywhere.	Empowered users with control over utilities regardless of physical location.

The results indicate that the IoT-based system effectively optimizes household utilities by enhancing convenience and reducing wastage. Remote monitoring and automated controls ensure timely responses to water and gas needs, improving resource utilization. The main reasons for inaccuracy in measurement and control were the unavailability of the internet and unannounced load-shedding in the residential area.

6. Conclusion

The IoT-Based Smart Utility Control System successfully addresses critical challenges related to water conservation, energy efficiency, and user convenience. By integrating IoT technology, real-time monitoring, and automation, the system optimizes the management of household utilities, particularly water pumps and geysers. The implementation of ultrasonic sensors, temperature sensors, flame sensors, relays, and the ESP32 microcontroller has enabled an efficient, low-cost, and user-friendly solution. The Firebase-powered mobile application allows users to monitor and control their appliances remotely, ensuring optimal resource utilization and cost savings. The system's ability to automatically regulate water pumps based on tank levels and schedule geyser heating based on user preferences contributes significantly to reducing water wastage and excessive energy consumption. This smart utility control system demonstrates how IoT-based automation can be leveraged to create a sustainable, efficient, and cost-effective solution for households. With further advancements, such as AI-based predictive analytics and renewable energy integration, the project has the potential to contribute even more significantly to environmental conservation and smart living solutions in the future

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