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Design and Development of a Microcontroller-Based Water Usage Monitoring and Control System

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A R T I C L E I N F O

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A B S T R A C T

Water is one of the fundamental human necessities that plays a crucial role in supporting daily domestic activities. However, uncontrolled water consumption frequently results in excessive usage and increased household water expenditure. This study aims to design and implement a microcontroller-based water usage monitoring and control system to improve water-use efficiency and facilitate real-time monitoring. The proposed system utilizes the Wemos D1 R1 as the primary microcontroller integrated with a water flow sensor to detect water discharge, a water level sensor to monitor water levels in the storage tank, relays, a water pump, a solenoid valve, an LCD 20x4 display, and Firebase database integration for Android-based data communication and monitoring. The research methodology consists of analysis, design, testing, implementation, and maintenance stages. The implementation results demonstrate that the system is capable of monitoring water usage discharge, displaying water level information, and performing automatic control of the water filling process in the storage tank. The developed system is expected to improve household water-use efficiency and assist users in controlling water consumption more effectively and systematically.

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I. INTRODUCTION

Clean water is one of the fundamental necessities that plays a vital role in sustaining human life, particularly in supporting domestic activities, public health, sanitation, and economic productivity. In the household context, the availability and optimal utilization of water resources are essential factors in maintaining the quality of life of communities. However, uncontrolled water consumption frequently leads to various issues, including resource wastage, increased household operational costs, and low efficiency in water consumption management. Such conditions are generally attributed to limited user awareness in monitoring water usage patterns, inadequate monitoring systems, and the limited ability of some users to interpret information provided by conventional water meters [1].

Conventional water meters generally provide only cumulative information regarding water consumption volume without offering real-time monitoring capabilities or analytical insights into daily consumption patterns. Consequently, users often encounter difficulties in identifying excessive water usage, potential leakage in water distribution systems, and inefficient consumption behavior. In addition, monitoring water capacity in storage tanks is still predominantly performed manually, thereby increasing the risk of water shortages or overflow due to delays in controlling water distribution systems.

Along with the rapid advancement of Internet of Things (IoT) technology, various innovations have been introduced to support monitoring and automation systems in domestic environments, including water resource management. IoT technology enables the integration of sensors, microcontrollers, communication networks, and mobile-based applications, allowing data acquisition, transmission, and visualization processes to be conducted automatically and continuously. In this study, a water flow sensor is utilized to measure water discharge and consumption, while a water level sensor is employed to monitor the water level in the storage tank in real time. Furthermore, system integration with an Android-based platform enables users to access water usage information anytime and anywhere, thereby facilitating a more flexible, responsive, and efficient monitoring process [2].

Based on these issues, this study aims to design and implement a microcontroller-based water monitoring and control system integrated with IoT technology. The proposed system is designed to monitor water discharge, observe storage tank water levels, and automatically regulate water distribution through the utilization of a solenoid valve and water pump. The implementation of this system is expected to improve household water-use efficiency, reduce the risk of water wastage, simplify water monitoring activities, and support the development of a more effective, measurable, and sustainable water resource management system [3].

II. MATERIALS AND METHODS

This study employed a systematic system development approach consisting of several stages, namely analysis, design, testing, implementation, and maintenance. This approach was adopted to ensure that the developed water monitoring and control system satisfies user requirements, achieves a high level of reliability, and can operate effectively within household environments.

The analysis stage was conducted as an initial step to identify problems related to household water usage, particularly in terms of water consumption monitoring, storage tank management, and water-use efficiency. Data collection was performed through direct observation and interviews with users in residential areas of Adiwerna District, Tegal Regency. The observation process aimed to understand water consumption patterns, water distribution and storage mechanisms, user behavior in water management, and challenges encountered in conventional water monitoring practices. Meanwhile, interviews were conducted to obtain information regarding user requirements for a more effective, practical, and real-time water monitoring and control system. Findings from this stage served as the basis for determining the functional and non-functional requirements of the system [4].

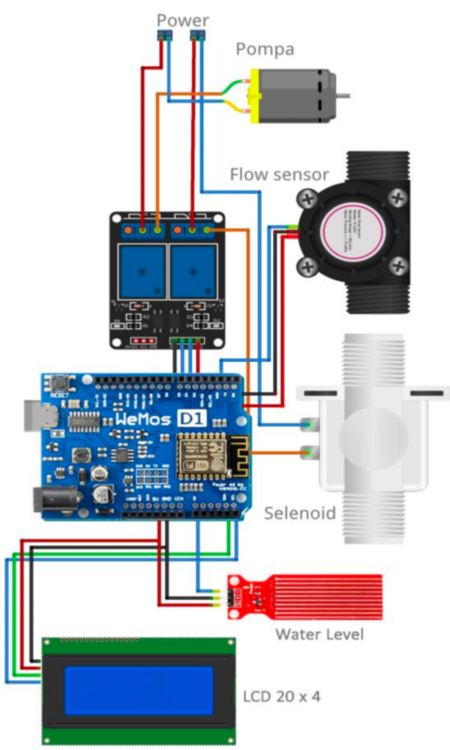

Figure 1. Schematic diagram

The design stage involved the development of both hardware and software architectures to support system operation. In terms of hardware, the system utilized the Wemos D1 R1 as the primary microcontroller functioning as the central controller and communication unit for Internet of Things (IoT)-based operations. A water flow sensor was implemented to measure water discharge and usage volume, whereas a water level sensor was employed to continuously detect water levels within the storage tank. In addition, a two-channel relay module was used as an actuator to automatically control the water pump and solenoid valve, while an LCD 20x4 display served as a local interface for presenting system status and water consumption parameters. On the software side, the system was developed using the Arduino Integrated Development Environment (Arduino IDE) as the microcontroller programming platform, integrated with Firebase Realtime Database for cloud-based data storage and synchronization. Furthermore, an Android-based application was employed as the user interface to facilitate remote monitoring and system control [5].

The implementation stage involved integrating all hardware and software components into an IoT-based water monitoring and control prototype system. During this stage, communication among sensors, the microcontroller, cloud database, and Android application was configured to ensure synchronized operation in monitoring and controlling water usage. The system was designed to provide real-time information, including water discharge, tank water level status, and operational conditions of the water pump and automatic valve.

Subsequently, the testing stage was conducted to evaluate the functionality, accuracy, and reliability of the developed system. The testing process included evaluation of the water flow sensor to verify the accuracy of water discharge measurements, testing of the water level sensor to validate tank water level detection, assessment of the data transmission mechanism to Firebase, examination of information displays on the LCD and Android application, and testing of the automatic control functions of the water pump and solenoid valve. These tests were intended to ensure that the system operates according to user requirements, supports effective water consumption monitoring, and improves household water-use efficiency [6].

Finally, the maintenance stage was performed to maintain system stability, sustainability, and performance optimization following implementation. This stage included performance monitoring, error correction (debugging), software updates when necessary, and evaluation of potential feature enhancements to improve long-term system effectiveness.

III. RESULTS AND DISCUSSION

The implementation results indicate that the microcontroller-based water usage monitoring and control system was successfully realized in the form of a prototype capable of monitoring water consumption conditions and automatically controlling water distribution in an integrated manner. The system was developed using the Wemos D1 R1 as the primary control unit responsible for managing sensor data acquisition, information processing, cloud database communication, and actuator control according to system operational conditions. The implementation of this system was designed to support more efficient household water management through an Internet of Things (IoT)-based monitoring mechanism that enables real-time access to water consumption information.

From the monitoring perspective, the system utilizes a water flow sensor to continuously detect water discharge and consumption volume during the water distribution process. The sensor operates by measuring the flow rate passing through the distribution pipeline and converting it into quantitative data that can be used to estimate the level of household water consumption. In addition, a water level sensor was implemented to monitor the water level condition within the storage tank. The sensor functions to identify water availability status, including low, moderate, and full conditions, thereby serving as the basis for decision-making in the automatic control process of the water pump and distribution valve (solenoid valve) [7].

Figure 2. System Implementation

Monitoring data are displayed locally through an LCD 20x4 interface to provide users with direct information regarding water consumption conditions, flow discharge, and storage tank status at the system location. Furthermore, all monitoring data are transmitted to Firebase Realtime Database as a cloud-based storage platform that enables real-time data synchronization with an Android application [8]. This integration allows users to remotely monitor water usage conditions (remote monitoring), enabling information regarding water discharge, tank capacity, and system operational status to be accessed anytime and anywhere in a more flexible manner [9].

Based on the testing results, the water flow sensor demonstrated the capability to continuously detect water discharge with stable responsiveness during the water distribution process. Meanwhile, the water level sensor consistently detected changes in tank water levels, enabling the system to identify minimum and maximum water capacity thresholds. The information generated by the sensors was subsequently utilized by the system to automatically activate or deactivate the water filling process through a control mechanism involving relays, the water pump, and the solenoid valve.

From the control aspect, the relay serves as the logical switching interface between the microcontroller and actuator devices, while the water pump regulates the water filling and distribution process automatically according to the detected water level conditions. On the other hand, the solenoid valve functions as an automated mechanism for regulating water flow by opening or closing the distribution channel based on system instructions. The implementation results demonstrate that all actuator components operate synchronously and responsively according to sensor conditions, thereby enabling automatic water management without requiring continuous manual intervention.

Overall, the integration of sensors, microcontroller, cloud database, Android application, and actuator devices produced a water monitoring and control system capable of improving transparency in household water usage. The developed system facilitates users in monitoring daily water consumption patterns, understanding water utilization in a more measurable manner, and minimizing potential wastage commonly associated with conventional water management systems lacking adequate monitoring and control mechanisms. Therefore, the implementation of this system not only supports improved water-use efficiency but also contributes to more effective, adaptive, and sustainable household water resource management.

IV. CONCLUSIONS

This study successfully designed and implemented a microcontroller-based water monitoring and control system capable of performing real-time monitoring of water discharge and storage tank levels. The system successfully integrates a water flow sensor, water level sensor, relay module, solenoid valve, water pump, and Firebase as the data communication platform connected to an Android-based application [10]. The implementation of the developed system provides users with greater convenience in monitoring and controlling water usage more efficiently, thereby reducing the potential for water wastage and improving the effectiveness of household water consumption management.

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