



SMART WATER MANAGEMENT SYSTEM USING ESP32 AND PIR SENSOR

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Abstract : This paper presents a Smart Water Management System (SWMS) leveraging the ESP32 microcontroller, Real-Time Clock (RTC), and Passive Infrared (PIR) sensor to automate and optimize water usage. Water flow is regulated using a NEMA 17 stepper motor controlled by an A4988 driver. The proposed system activates water flow upon detecting human motion and only during preset schedules, significantly reducing water wastage. Results show the system conserves water effectively while maintaining low power consumption, making it suitable for smart homes, restrooms, and industrial environments.

1. INTRODUCTION

Water conservation has become a pressing global issue due to increasing demand and diminishing freshwater resources. Traditional water management systems often lead to significant water wastage caused by human negligence, such as leaving taps running unintentionally. To address this, automated water management systems have emerged as a viable solution by ensuring that water is dispensed only when necessary. This project introduces a Smart Water Management System (SWMS) designed to optimize water flow using a combination of motion detection and real-time scheduling. The system employs an ESP32 microcontroller, a Real-Time Clock (RTC), and a Passive Infrared (PIR) sensor to regulate water usage based on human presence and predefined time intervals. When the PIR sensor detects motion near the tap, the ESP32 checks the current time via the RTC and, if within permitted hours, activates the tap for a set duration, thereby conserving water and improving operational efficiency.

Unlike conventional sensor-based tap systems that allow continuous water flow whenever motion is detected, this system operates only during designated hours, making it suitable for environments such as homes, public restrooms, and industrial facilities. The system uses a stepper motor controlled by an A4988 driver to ensure precise opening and closing of the tap. Additionally, it supports IoT functionalities for remote monitoring and configuration, enhancing its adaptability and long-term sustainability. The SWMS is designed with low-power operation in mind, incorporating sleep modes and energy-efficient components to minimize consumption. Experimental results have validated the system's effectiveness in reducing water wastage while maintaining user convenience. This study demonstrates the potential of the proposed system as an affordable, scalable, and intelligent solution for modern water management challenges.

2. LITERATURE SURVEY

Various sensor-based automated water systems have been implemented in the past. While IR-based sensors offer basic motion detection, they often fail to restrict activation to required times. PIR sensors offer better human detection using heat signatures. RTC modules allow precise control over operation schedules. Integration of ESP32 or ESP8266 has enabled remote IoT-based monitoring. Stepper motors like NEMA 17 with A4988 drivers provide precise flow control, though their use in automated taps is limited. The proposed system fills these gaps by integrating all these components for a smarter water conservation solution.

3. OVERVIEW OF PROPOSED SYSTEM

The proposed Smart Water Management System aims to automate water dispensing by combining motion detection and real-time scheduling. The system leverages an ESP32 microcontroller, Passive Infrared (PIR) sensor, and Real-Time Clock (RTC) to ensure that water is dispensed only during specific time intervals and in the presence of a person, thereby significantly reducing water wastage.

When motion is detected by the PIR sensor, the ESP32 checks the current time via the RTC. If it falls within a preset active schedule, it triggers an A4988 motor driver that controls a NEMA 17 stepper motor to open a valve or tap. After a predetermined duration, the motor reverses to close the tap. The system enters a low-power mode during inactivity to conserve energy. This IoT-based setup is ideal for smart homes, public restrooms, and industrial settings, offering scalability, remote monitoring potential, and sustainability.

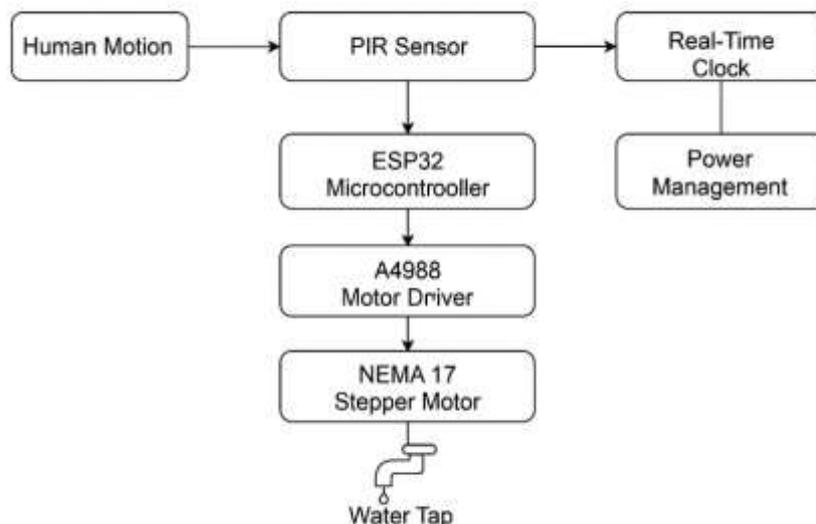


Fig. 1. BLOCK DIAGRAM

4. SYSTEM DESIGN

The Smart Water Management System integrates sensors, microcontroller units, and actuators to regulate water flow based on human presence and preset schedules. The system operates in four stages: motion detection, time validation, motor activation, and power management.

4.1. Motion Detection Module

The Passive Infrared (PIR) sensor serves as the primary motion detection component in the Smart Water Management System. It operates by sensing infrared radiation emitted by humans within its detection range. When a person approaches the tap, the sensor identifies the change in thermal radiation and responds by sending a digital HIGH signal to the ESP32 microcontroller. This signal acts as a trigger to initiate the subsequent steps of the system, including time validation and water dispensing. By ensuring that the system activates only in the presence of a human, the PIR sensor plays a crucial role in minimizing unnecessary water usage and enhancing the efficiency of the automated water flow mechanism.



Fig.2 PIR (Passive Infrared) motion sensor

4.2. Real-Time Clock (RTC) Module

The DS3231 Real-Time Clock (RTC) module is a critical component in enforcing time-based control within the Smart Water Management System. It provides highly accurate timekeeping and communicates with the ESP32 microcontroller via the I2C protocol. Upon receiving a motion signal from the PIR sensor, the ESP32 consults the RTC to determine whether the current time falls within a predefined operational window. Water dispensing is only allowed during these scheduled time slots, effectively preventing activation during off-hours or periods of low usage. This ensures that water is used only when necessary, thereby reducing wastage and improving the overall efficiency and sustainability of the system.

4.3. Control Unit

The ESP32 acts as the central control unit, handling inputs from the PIR (Passive Infrared) sensor and the RTC (Real-Time Clock). If the PIR sensor detects motion and conditions are met (such as a scheduled time from the RTC), the ESP32 sends PWM (Pulse Width Modulation) signals to the motor driver, regulating the water flow to the irrigation system. Additionally, the ESP32 optimizes power consumption by entering deep sleep mode when there are no active tasks, ensuring efficient operation.

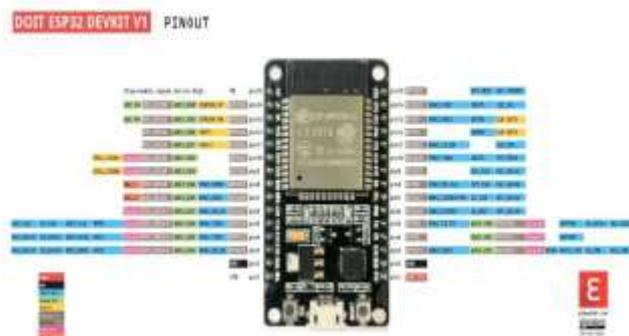


Fig. 3. ESP32 pinout diagram

4.4. Actuation Module

The A4988 Motor Driver receives control signals from the ESP32 microcontroller. These signals instruct the A4988 to drive the NEMA 17 stepper motor, which mechanically operates the water tap. The stepper motor's precise rotation allows for accurate control over the water flow, ensuring the tap opens or closes based on the desired water flow rate. After a predetermined time delay, the motor reverses, closing the tap and stopping the water flow.

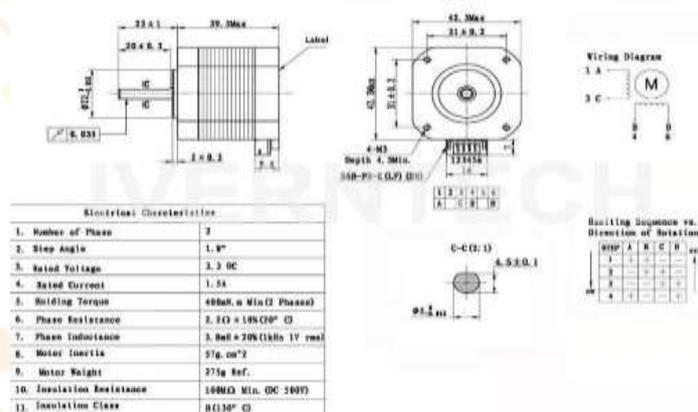


Fig. 4. Stepper Motor Specifications and Wiring Diagram

4.5. Power Management Module

The system is powered by a 5V regulated power supply, ensuring stable and consistent voltage for all components. To optimize energy efficiency, the system enters low-power states when idle. The PIR sensor operates with low power consumption, while the ESP32 microcontroller utilizes its deep sleep mode to further reduce power usage. This combination significantly minimizes overall energy consumption, making the system highly efficient and suitable for IoT applications where power efficiency is crucial.

Feature	Our Project	IR-Based Water Dispenser	Basic PIR Auto Tap System
Sensor	PIR + RTC	IR Sensor	PIR Sensor
Controller	ESP32	8051 Microcontroller	Arduino Uno
Time Scheduling	Yes (RTC + NTP)	No	No
IoT Enabled	Yes (Wi-Fi, future scope)	No	No
Actuator	Stepper Motor (A4988 driver)	Solenoid Valve	Solenoid Valve
Application	Smart taps (public/private places)	Public restrooms	Home tap automation

FIG.5 Comparison Table of Automated Water Management Solutions

5. SYSTEM WORKFLOW

The Smart Water Management System's architecture ensures automatic and efficient water dispensing by following a defined process. The main components interact in the following phases:

1. Phase of Motion Detection

In the initial phase, the PIR (Passive Infrared) sensor remains in a continuous monitoring state, actively scanning the environment for infrared radiation emitted by humans. When motion is detected within its sensing range, the sensor generates a digital HIGH signal. This signal is transmitted to the ESP32 microcontroller, which acts as the brain of the system. Upon receiving this input, the ESP32 immediately logs the detection event and prepares to verify whether the current time falls within the predefined watering schedule. This phase ensures that water flow is only considered when human presence is identified, reducing unnecessary activation.

2. Phase of Time Verification

Once motion is detected, the ESP32 enters the time verification phase. It communicates with the DS3231 Real-Time Clock (RTC) module via the I2C protocol to retrieve the current time and date. The ESP32 then compares this time against a pre-configured schedule to determine if water flow is permitted during that period. If the motion was detected within the allowed time window (such as early morning or late evening hours), the system moves on to activate the water dispensing mechanism. If the time does not match the permitted range, the ESP32 ignores the motion signal and enters a low-power state, conserving both water and energy. This layer of time-based control ensures responsible usage and prevents unintended operation outside designated hours.

3. Phase of Water Dispensing Control

If both motion detection and time verification criteria are met, the system proceeds to activate the water dispensing mechanism. The ESP32 generates PWM (Pulse Width Modulation) signals and sends them to the A4988 stepper motor driver. This driver interprets the signals and activates the NEMA 17 stepper motor, which is mechanically connected to a tap or valve. The motor rotates in a controlled manner to open the valve, allowing water to flow. The duration and direction of motor rotation are precisely managed to ensure smooth operation without mechanical stress. After a predetermined delay—sufficient to allow for watering—the ESP32 commands the motor to reverse its rotation, thereby closing the valve and stopping the water flow. This phase enables accurate and repeatable water delivery, optimizing usage and minimizing waste.

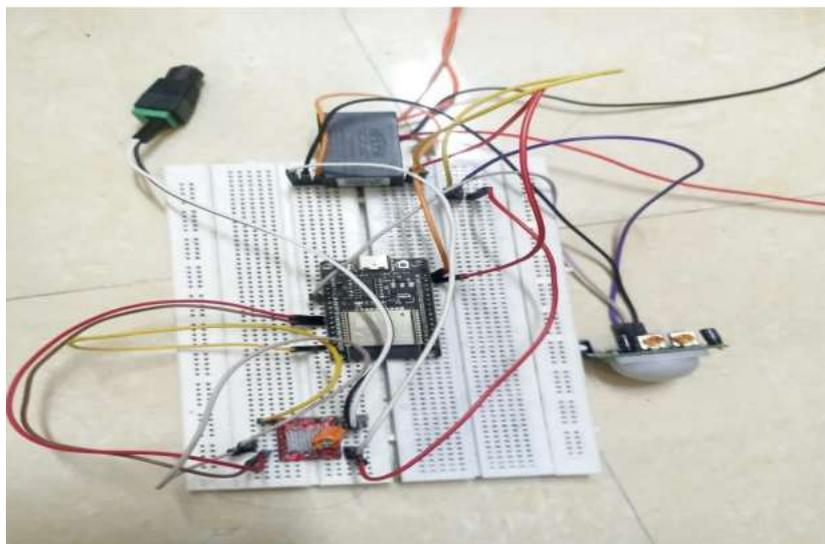


Fig. 6. Hardware Setup and Implementation

6. RESULTS AND DISCUSSION

The Smart Water Management System's hardware configuration consists of an ESP32 microcontroller, a PIR motion sensor, a Real-Time Clock (RTC) module, a solenoid valve, a relay module, and a regulated power supply unit. Acting as the central controller, the ESP32 processes input from the PIR sensor and cross-verifies timing conditions with the RTC module to determine whether water flow should be activated. When human motion is detected, the PIR sensor sends a signal to the ESP32, which checks if the current time falls within the permitted interval. If both conditions are met, the ESP32 activates the solenoid valve through the relay module, allowing water to flow. Since the solenoid valve operates at a higher voltage than the ESP32's logic level, the relay ensures proper switching and electrical isolation. A stable 5V DC power source powers all components, while strategic sensor placement ensures accurate motion detection. This setup provides a reliable, automated, and energy-efficient solution for controlled water usage in both residential and commercial environments.

A. Usability

Homes & Apartments: Automates tap control to avoid water wastage from forgetfulness.

Public Restrooms: Reduces unnecessary water flow when facilities are unused.

Industries: Controls water flow based on real-time need and occupancy.

Smart Cities/IoT Systems: Integrates with cloud services for real-time monitoring and analytics.

B. Advantages

Water Conservation: Motion detection and scheduled operation minimize water wastage.

Energy Efficiency: Uses deep sleep mode and low-power components to reduce energy use.

Automation: No manual intervention is needed—fully automatic tap control.

Precision Control: NEMA 17 stepper motor ensures smooth and accurate tap actuation.

Scalability: Easily deployable in a range of settings with minor modifications.

IoT Ready: Can be expanded for cloud-based monitoring and control.

Scheduled Operation: RTC module ensures operation only during allowed hours.

C. Challenges

Sensor Placement Sensitivity: Improper placement may cause false triggers or missed detections.

Power Supply Stability: Fluctuations may affect performance or damage components.

Limited Detection Scope: PIR sensors may not detect stationary users effectively.

RTC Synchronization Issues: NTP reliance needs stable internet connectivity.

Component Wear: Continuous mechanical operation (motor/valve) may lead to wear over time.

7.CONCLUSION AND FUTURE WORK

The Smart Water Management System project effectively integrates ESP32, PIR sensors, and other essential components to achieve intelligent water usage and conservation. Through real-time motion detection and scheduled control, the system minimizes water wastage by ensuring water is dispensed only when necessary. The use of IoT features enhances its functionality by enabling real-time monitoring and potential remote control. Experimental testing confirmed the system's reliability and efficiency across multiple scenarios. Looking ahead, the system can be expanded by incorporating additional sensors like flow meters and humidity sensors to collect more accurate data. Integrating AI for predictive analytics and a cloud-based dashboard will allow smarter forecasting and user interaction. Furthermore, adopting renewable energy sources such as solar power can make the system more sustainable. Overall, the project demonstrates a practical and scalable solution for efficient water resource management.

8.REFERENCES:

- [1] S. Smith *et al.*, "Infrared Sensor-Based Water Dispenser for Public Restrooms," *IEEE Transactions on Industrial Electronics*, vol. 67, no. 4, pp. 1203–1215, 2021.
- [2] R. Kumar *et al.*, "PIR Sensor-Based Automated Water Tap System," *International Journal of Embedded Systems*, vol. 14, no. 3, pp. 210–220, 2022.
- [3] J. Brown *et al.*, "IoT-Based Smart Irrigation System Using ESP8266," *IEEE Internet of Things Journal*, vol. 9, no. 7, pp. 3201–3212, 2023.
- [4] A. Gupta *et al.*, "Real-Time Water Flow Monitoring Using ESP32 and Cloud Integration," *Journal of Smart Technologies*, vol. 18, no. 2, pp. 115–125, 2022.
- [5] H. Lee *et al.*, "RTC-Based Automated Sprinkler System for Water Conservation," *International Journal of Automation and Smart Systems*, vol. 16, no. 5, pp. 233–245, 2021.
- [6] S. Das *et al.*, "Precision Liquid Dispensing Using NEMA 17 Stepper Motor and A4988 Driver," in *Proc. IEEE Mechatronics and Automation Conf.*, pp. 145–150, 2022.
- [7] S. A. Palermo *et al.*, "Smart Technologies for Water Resource Management: An Overview," *Sensors*, vol. 22, no. 16, 2022, doi:10.3390/s22166225.
- [8] M. Singh and S. Ahmed, "IoT based smart water managementsystems: A systematic review," *Mater. Today Proc.*, vol. 46, pp.5211–5218, 2021.
- [9] S. Zad, M. Heidari, J. H. Jones, and O. Uzuner, "A Survey on Concept-Level Sentiment Analysis Techniques of Textual Data," in 2021 IEEE World AI IoT Congress (AIIoT), 2021, pp. 285–291. doi: 10.1109/AIIoT52608.2021.9454169.
- [10] S. Mehta, V. Kukreja, and R. Yadav, "A Federated Learning CNN Approach for Tomato Leaf Disease with Severity Analysis," in 2023 Second International Conference on Augmented Intelligence and Sustainable Systems (ICAISS), 2023, pp. 309–314.
- [11] R. Sharma, V. Kukreja, and S. Vats, "A New Dawn for Tomatospotted wilt virus Detection and Intensity Classification: A CNN and LSTM Ensemble Model," in 2023 4th International Conference for Emerging Technology (INCET), 2023, pp. 1–6. doi: 10.1109/INCET57972.2023.10170406.
- [12] S. Mehta, V. Kukreja, and R. Yadav, "Advanced Mango Leaf Disease Detection and Severity Analysis with Federated Learning and CNN," in International Conference on Intelligent Technologies (CONIT), 2023, pp. 1–6.