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HydroMate: An IOT Enabled Smart Water Bottle

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***Abstract-** Maintaining adequate hydration is essential for supporting physiological functions, cognitive performance, and overall health. However, individuals often fail to consume sufficient water at regular intervals due to busy lifestyles, irregular routines, and the absence of effective monitoring mechanisms. Conventional water bottles do not provide feedback regarding water consumption, while existing mobile-based hydration applications depend largely on manual user input, which reduces long-term usability and adherence. This paper presents HydroMate, an Internet of Things (IoT)-based smart water bottle designed to facilitate real-time hydration monitoring and automated user assistance. The proposed system employs a non-contact ultrasonic sensor to measure the remaining water level inside the bottle. An ESP32 microcontroller processes the sensor data and determines hydration status, while a Real-Time Clock (RTC) module ensures accurate scheduling of hydration reminders. Audible voice alerts are generated to prompt timely water intake, enhancing user awareness without requiring continuous visual attention. Wireless communication between the smart bottle and a mobile application is achieved using Wi-Fi and the MQTT protocol. A Flutter-based mobile application provides real-time visualization of water levels, reminder notifications, and device connectivity, along with configurable reminder intervals. Experimental evaluation indicates reliable sensing performance, stable communication, and effective reminder delivery under typical usage conditions. The results demonstrate that HydroMate offers a practical, cost-effective, and user-friendly IoT solution for promoting consistent hydration and preventive healthcare. scientific paper or patent application.*

***Index Terms-** Hydration Monitoring, Internet of Things, Smart Water Bottle, Ultrasonic Sensor, Voice Alerts.*

I. INTRODUCTION

Water is a fundamental requirement for sustaining human life and supporting essential physiological processes, including thermoregulation, metabolism, nutrient transportation, and cognitive functioning. Maintaining adequate hydration is closely associated with physical endurance, mental alertness, and overall health. Even mild dehydration has been shown to negatively affect concentration, mood, and energy levels, while prolonged dehydration may lead to serious health complications. Despite the well-established importance of regular water intake, hydration is frequently neglected in daily routines.

In modern society, individuals are increasingly exposed to fast-paced lifestyles characterized by academic pressure, professional workloads, and prolonged screen time. As a result, many people fail to consume sufficient water at regular intervals, relying instead on thirst as a reminder. However, thirst is a delayed physiological response and does not reliably indicate optimal hydration needs. This limitation is particularly evident among students, working professionals, elderly individuals, and athletes, who are more susceptible to dehydration due to irregular schedules or reduced sensitivity to thirst.

Conventional water bottles provide no information regarding water consumption patterns or remaining water levels. Although mobile-based hydration applications have been developed to address this issue, most require manual data entry by users, which reduces convenience and long-term engagement. Over time, users tend to discontinue such applications due to the effort involved in consistent logging. Consequently, existing solutions fail to provide a seamless and automated approach to hydration monitoring.

Recent advancements in the Internet of Things (IoT) have enabled the integration of sensing, computation, and wireless communication into everyday objects. IoT-based healthcare and wellness systems have gained attention for their ability to automate monitoring tasks and provide real-time feedback. Smart water bottles represent a promising application in this domain; however, many commercially available products are either costly or limited in functionality, offering basic visual alerts or short-range connectivity without intelligent monitoring or adaptive reminders.

To address these limitations, this paper presents HydroMate, an IoT-based smart water bottle designed to support consistent hydration through real-time water-level monitoring and automated voice-assisted reminders. The system employs non-contact ultrasonic sensing to measure the remaining water level and utilizes an ESP32 microcontroller for data processing and communication. A Real-Time Clock (RTC) module enables accurate scheduling of reminders, while voice alerts enhance user awareness without requiring continuous visual attention. Wireless data exchange with a mobile application allows users to monitor hydration status and customize reminder intervals.

The primary contribution of this work lies in the design and implementation of an affordable, user-friendly, and automated hydration monitoring system that minimizes user intervention while encouraging healthy hydration behavior. The proposed solution demonstrates the practical application of IoT technologies in preventive healthcare and highlights the potential of smart everyday objects in promoting long-term wellness.

II. LITERATURE REVIEW

Recent years have witnessed significant growth in the application of Internet of Things (IoT) technologies within the healthcare and wellness domain. IoT-based systems have been widely explored for monitoring physiological parameters such as heart rate, physical activity, sleep patterns, and dietary habits. These systems aim to promote preventive healthcare by enabling continuous monitoring and timely feedback. However, compared to other health indicators, hydration monitoring has received relatively limited research attention, despite its critical role in maintaining overall health.

Several studies have investigated liquid-level measurement techniques suitable for compact containers. Among these, ultrasonic sensing has emerged as a reliable and widely adopted approach due to its non-contact operation, low cost, and ease of integration with embedded systems. Ultrasonic sensors operate based on time-of-flight principles, where the distance to the liquid surface is estimated using reflected sound waves. Prior research demonstrates that ultrasonic sensors can achieve accurate measurements when factors such as sensor placement, container geometry, and environmental conditions are carefully considered. These characteristics make ultrasonic sensing particularly suitable for smart bottle applications.

Alternative hydration monitoring approaches have also been explored. Weight-based methods using load cells estimate water consumption by measuring changes in bottle weight. Although this technique can provide reasonable accuracy, it is sensitive to bottle orientation, external vibrations, and handling variations. Pressure-based sensors have been proposed for detecting liquid levels, but they often require complex calibration and may be affected by temperature and pressure fluctuations. Vision-based approaches using cameras and image processing techniques have shown high precision under controlled conditions; however, their dependency on stable lighting, higher computational requirements, and increased power consumption limits their practicality for portable, battery-operated devices.

From a user interaction perspective, existing studies highlight that manual hydration tracking methods are ineffective for long-term use. Many mobile applications require users to input water intake data manually, which leads to reduced compliance over time. Research on behavioral assistance systems indicates that automated reminders significantly improve adherence to routine-based activities. In particular, auditory notifications have been shown to be more effective than visual cues, as they capture user attention even when the user is not actively engaging with a display.

Commercial smart water bottles currently available in the market often rely on simple visual indicators such as LEDs or smartphone notifications delivered via short-range communication technologies. While these solutions offer basic functionality, they lack intelligent monitoring, real-

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time sensing, and adaptive reminder mechanisms. Additionally, high cost and limited customization further restrict their adoption among general users.

The reviewed literature suggests that an effective hydration monitoring solution should integrate real-time sensing, automated reminders, minimal user interaction, low power consumption, and affordability. These insights form the foundation for the proposed HydroMate system, which combines ultrasonic sensing, embedded processing, voice-assisted alerts, and mobile application support to address the limitations identified in existing hydration monitoring approaches.

III. PROPOSED SYSTEM

The proposed system, HydroMate, is an Internet of Things (IoT)-based smart water bottle designed to monitor hydration levels in real time and encourage regular water consumption through automated assistance. The system integrates sensing, processing, communication, and user interaction components into a unified architecture that operates with minimal user intervention. The primary objective of the proposed system is to provide accurate hydration monitoring while ensuring usability, affordability, and reliability for daily use.

HydroMate continuously monitors the water level inside the bottle using non-contact sensing techniques and delivers timely reminders through voice-based alerts. The system is supported by wireless communication with a mobile application, enabling users to visualize hydration status and configure reminder preferences. The overall design emphasizes modularity and scalability, allowing future enhancements without significant changes to the core architecture.

A. System Architecture

The system architecture of HydroMate follows a layered design approach consisting of three major components: the sensing layer, the processing and communication layer, and the application layer. This structured architecture ensures efficient data flow, clear separation of responsibilities, and ease of system maintenance.

The sensing layer is responsible for acquiring real-time information about the water level inside the bottle. An ultrasonic sensor is mounted at the inner side of the bottle cap and oriented toward the water surface. The sensor periodically emits ultrasonic pulses and receives the reflected echoes. Based on the time-of-flight of these signals, the distance between the sensor and the water surface is calculated. This distance is mapped to the predefined internal dimensions of the bottle to estimate the remaining water quantity. The use of ultrasonic sensing enables accurate, hygienic, and non-invasive measurement of water levels.

The processing and communication layer forms the core of the system and is implemented using an ESP32 microcontroller. The ESP32 processes raw sensor data, performs water-level computation, and manages the system's control logic. A Real-Time Clock (RTC) module is integrated to maintain accurate timekeeping and to schedule hydration reminders at predefined intervals. This ensures consistent reminder delivery regardless of power interruptions or system restarts. The ESP32 also controls the voice playback module, which generates audible alerts to prompt users to drink water or refill the bottle when necessary.

Wireless communication is established through the built-in Wi-Fi capability of the ESP32 using the MQTT protocol. MQTT is selected due to its lightweight nature and suitability for low-power IoT applications. Sensor data, reminder status, and system updates are published to designated topics, enabling efficient and reliable data exchange between the smart bottle and the mobile application.

The application layer consists of a mobile application developed using the Flutter framework. This application serves as the primary user interface for the system. It displays real-time water-level information, reminder notifications, and device connectivity status. The application also allows users to configure reminder intervals and monitor hydration trends. By offloading visualization and configuration tasks to the mobile application, the system reduces the processing burden on the hardware while enhancing user experience.

Overall, the proposed system architecture enables seamless integration of hardware and software components, ensuring accurate hydration monitoring, timely reminders, and intuitive user interaction. The modular design of HydroMate provides a strong foundation for future enhancements such as cloud-based analytics, personalized hydration recommendations, and integration with wearable devices.

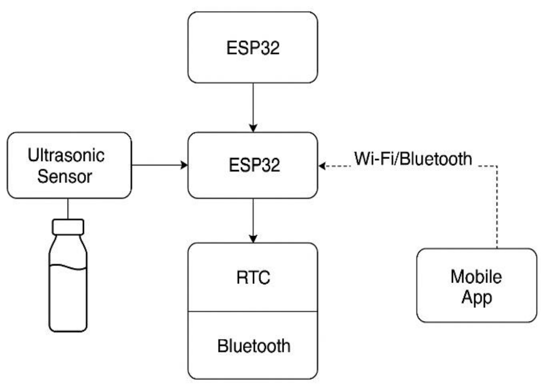

Fig 1: System Architecture of Hydromate

B. Working Principle

The working principle of the proposed HydroMate system is based on continuous water-level sensing, intelligent data processing, and automated user notification through voice-assisted reminders. The system operates in a cyclic manner, ensuring real-time monitoring of hydration status with minimal user intervention.

At the initial stage, when the system is powered on, the ESP32 microcontroller initializes all connected peripherals, including the ultrasonic sensor, Real-Time Clock (RTC) module, voice playback unit, and wireless communication interface. Predefined parameters such as bottle dimensions and user-configured reminder intervals are loaded into the system memory. Once initialization is complete, the system enters its normal operational mode.

The ultrasonic sensor periodically emits ultrasonic pulses toward the water surface inside the bottle. These pulses are reflected back to the sensor after striking the water surface. The time interval between pulse transmission and echo reception is measured and used to calculate the distance between the sensor and the water surface using time-of-flight principles. This measured distance is then mapped to the known internal height of the bottle to determine the remaining water level. To improve measurement reliability, multiple readings are sampled and averaged, reducing the effects of minor disturbances such as surface ripples or bottle movement.

The ESP32 continuously processes the computed water-level data and monitors changes over time. Based on this information, the system determines the hydration status and checks whether predefined conditions for alerts are met. The RTC module plays a critical role by maintaining accurate timekeeping and triggering reminder events at scheduled intervals. When a reminder condition is satisfied, the microcontroller activates the voice playback module to deliver an audible hydration prompt. Additional alerts are generated when the water level falls below a specified threshold or when the bottle requires refilling.

Simultaneously, the processed water-level data and system status information are transmitted wirelessly to the mobile application using the MQTT protocol over Wi-Fi. The mobile application receives these updates in real time and displays the current water level, reminder notifications, and device connectivity status. Users can modify reminder intervals and preferences through the application, and updated configurations are sent back to the smart bottle, ensuring synchronized operation.

Through this integrated sequence of sensing, processing, alert generation, and wireless communication, the HydroMate system effectively supports continuous hydration monitoring. The working principle emphasizes automation, accuracy, and user convenience, enabling the system to function as a practical and reliable hydration assistance solution for daily use.

IV. IMPLEMENTATION

A. Hardware Implementation

The hardware implementation of the proposed HydroMate system focuses on integrating accurate sensing, reliable processing, effective alert mechanisms, and efficient power management within a compact and user-safe smart water bottle structure. The design emphasizes non-contact measurement, low power consumption, portability, and long-term usability, making the system suitable for continuous daily operation.

The primary sensing component of the system is an ultrasonic sensor, which is positioned at the inner surface of the bottle cap and oriented toward the water surface. This configuration enables non-invasive measurement of the water level, thereby maintaining hygiene and eliminating direct contact with the liquid. The ultrasonic sensor operates based on the time-of-flight principle, where sound pulses emitted toward the water surface are reflected back to the sensor. The measured echo time is used to compute the distance between the sensor and the water surface. This distance value is mapped to the predefined internal height of the bottle to estimate the remaining water quantity accurately.

An ESP32 microcontroller serves as the central processing and control unit of the system. The ESP32 interfaces with the ultrasonic sensor to acquire distance measurements and performs the necessary computations to determine water-level percentage. The microcontroller was selected due to its integrated Wi-Fi capability, sufficient processing power, low energy consumption, and compatibility with IoT communication protocols. In addition to sensor processing, the ESP32 manages reminder scheduling, controls the voice alert module, and handles wireless data transmission to the mobile application.

To ensure accurate and consistent reminder scheduling, a Real-Time Clock (RTC) module is incorporated into the hardware design. The RTC maintains precise time information independently of the microcontroller's internal clock and continues to operate during power interruptions. This ensures that hydration reminders are delivered at correct intervals throughout the day without drift or inconsistency.

User notifications are provided through a voice playback module connected to a compact speaker. The module stores pre-recorded audio messages corresponding to hydration reminders, low-water alerts, and refill notifications. Voice-based alerts were chosen to enhance user engagement and accessibility, ensuring that notifications are clearly perceived even when users are not actively interacting with the mobile application or viewing the bottle.

The system is powered using a regulated external power source, providing a stable and reliable voltage supply to all hardware components. Voltage regulation circuitry is employed to protect the microcontroller and peripheral modules from fluctuations and electrical noise. The ESP32 utilizes low-power operating modes during idle periods to reduce overall power consumption and enhance system efficiency.

Overall, the hardware implementation of HydroMate achieves a balance between accuracy, safety, compactness, and energy efficiency. The integrated design supports reliable hydration monitoring and forms a robust foundation for real-world deployment and future system enhancements.

B. Software Implementation

The software implementation of the HydroMate system is designed to ensure accurate sensing, reliable data processing, timely alert generation, and seamless communication between the smart bottle and the mobile application. The software architecture consists of embedded firmware running on the ESP32 microcontroller and a mobile application developed using the Flutter framework. The overall design emphasizes modularity, robustness, and real-time responsiveness.

The embedded firmware was developed using the Arduino development environment and programmed in Embedded C. At system initialization, the firmware configures the microcontroller's input/output pins, timers, communication interfaces, and network parameters. Essential system variables, including bottle dimensions and user-defined reminder intervals, are loaded into memory. Following initialization, the system enters a continuous execution cycle that manages sensing, processing, and communication tasks.

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Sensor data acquisition is performed periodically by triggering the ultrasonic sensor to emit sound pulses toward the water surface. The firmware measures the echo return time using high-resolution timers available on the ESP32. These time measurements are converted into distance values using the speed of sound. To enhance reliability, multiple samples are collected during each sensing cycle and averaged to reduce the effects of surface disturbances and minor bottle movements. The computed distance values are then mapped to predefined bottle dimensions to determine the remaining water level as a percentage.

The firmware continuously monitors the calculated water-level values and evaluates them against predefined conditions. The Real-Time Clock (RTC) module is used to manage time-based operations, ensuring accurate scheduling of hydration reminders. When a scheduled reminder interval is reached, the firmware triggers the voice playback module to deliver an audible hydration alert. In addition to periodic reminders, event-based alerts are generated when the water level falls below specified thresholds, such as low-water or empty-bottle conditions.

Voice alerts are managed through serial communication between the ESP32 and the voice playback module. Pre-recorded audio messages are stored within the module and are selected dynamically based on system conditions. This approach provides intuitive feedback and enhances user awareness without requiring constant visual attention.

Wireless communication between the smart bottle and the mobile application is achieved using Wi-Fi and the MQTT protocol. The ESP32 functions as an MQTT client and publishes water-level data, reminder status, and system information to predefined topics. The firmware also subscribes to control topics, allowing the mobile application to transmit configuration updates such as reminder interval adjustments. This bidirectional communication ensures real-time synchronization between the hardware and software components.

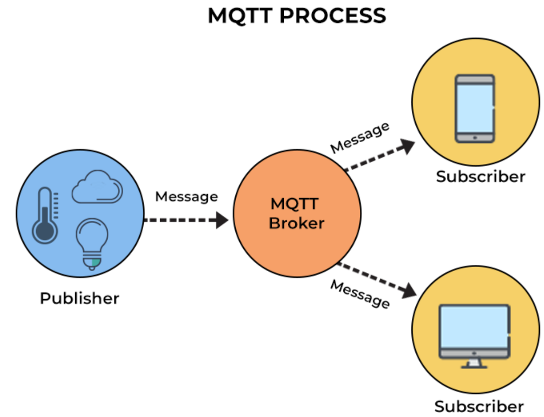

Fig 2 : MQTT Process

The mobile application was developed using the Flutter framework, enabling cross-platform compatibility and a consistent user interface. The application receives MQTT messages and dynamically updates the user interface to display current water levels, reminder notifications, and device connectivity status. Users can configure reminder preferences and monitor hydration information through an intuitive dashboard. Error-handling mechanisms are incorporated to manage temporary network disruptions and maintain a stable user experience.

Overall, the software implementation integrates embedded firmware and mobile application logic into a cohesive system that supports real-time hydration monitoring, automated voice-assisted reminders, and user-friendly interaction. The modular design of the software facilitates future enhancements such as cloud-based analytics, personalized hydration recommendations, and integration with wearable devices.

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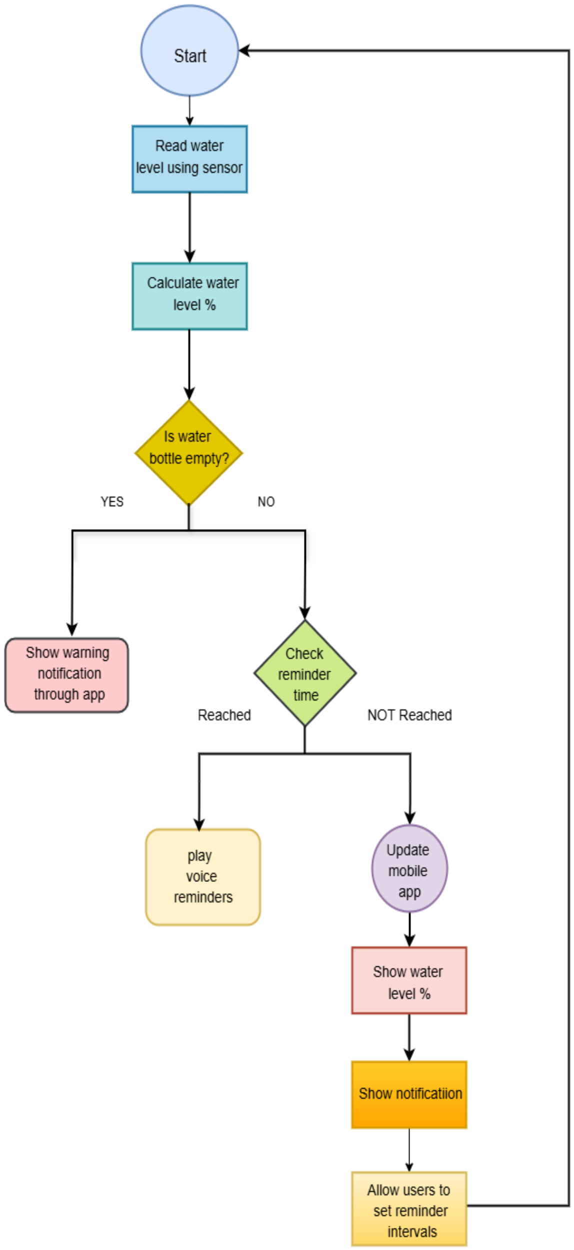

Fig 3 : Data Flow of HydroMate

V. RESULTS AND DISCUSSION

The performance of the proposed HydroMate system was evaluated to assess its accuracy, reliability, and usability under typical operating conditions. Experimental testing focused on validating water-level measurement accuracy, reminder functionality, wireless communication stability, and overall user interaction. The system was tested across multiple refill cycles and daily usage scenarios to ensure consistent operation.

The ultrasonic sensing module demonstrated reliable performance in measuring the remaining water level inside the bottle. When the bottle was placed on a stable surface, the measured water-level values closely matched the actual water volume. Minor variations were observed during rapid bottle movement or shaking; however, these fluctuations were significantly reduced through averaging and filtering techniques implemented in the firmware. The results indicate that non-contact ultrasonic sensing is effective for real-time hydration monitoring in portable applications.

The accuracy of reminder scheduling was evaluated using the Real-Time Clock (RTC) module. Time-based reminders were triggered consistently at predefined intervals without observable drift over extended periods of operation. This confirms the effectiveness of RTC-based scheduling in maintaining reliable hydration reminders independent of system restarts or temporary power interruptions.

Voice-assisted alerts played a crucial role in improving user awareness and engagement. Compared to silent or visual notifications, audible reminders were more noticeable and ensured that users were prompted even when not actively interacting with the mobile application. Users reported improved adherence to hydration routines due to the presence of voice alerts, particularly during busy activities or extended work sessions.

Wireless communication between the smart bottle and the mobile application was evaluated using the MQTT protocol over Wi-Fi. Data transmission remained stable with low latency under normal network conditions. Real-time updates of water-level information and reminder status were accurately reflected on the mobile application interface. Occasional network disruptions did not affect system reliability, as the firmware was able to reconnect automatically and resume data transmission without manual intervention.

The mobile application interface was assessed for usability and responsiveness. The application provided clear visualization of water levels, reminder notifications, and connectivity status. The ability to customize reminder intervals enhanced user flexibility and allowed adaptation to individual hydration needs. Feedback from users indicated that the application was intuitive and easy to navigate.

Overall, the experimental results demonstrate that HydroMate effectively integrates sensing, processing, communication, and user interaction to provide a reliable hydration monitoring solution. The system successfully addresses the limitations of traditional hydration tracking methods by offering automation, real-time feedback, and minimal user involvement. These results validate the feasibility of the proposed system for practical deployment in daily hydration management.

VI. CONCLUSION

This paper presented HydroMate, an Internet of Things (IoT)-based smart water bottle designed to promote consistent hydration through real-time monitoring and automated voice-assisted reminders. The proposed system addresses the limitations of conventional hydration practices and manual tracking applications by offering an integrated solution that combines non-contact sensing, embedded processing, and wireless communication.

The system utilizes ultrasonic sensing to accurately measure the remaining water level inside the bottle without direct contact, ensuring hygienic operation and reliable performance. An ESP32 microcontroller manages data processing, reminder scheduling, and wireless communication, while a Real-Time Clock (RTC) module ensures accurate and consistent delivery of hydration reminders. Voice-based alerts enhance user engagement by providing intuitive notifications that do not require continuous visual attention. The integration of a mobile application enables real-time visualization of hydration status and allows users to customize reminder preferences according to individual needs.

Experimental evaluation demonstrated that the proposed system operates reliably under typical usage conditions, with accurate water-level estimation, stable communication, and effective reminder delivery. The results indicate that HydroMate offers a cost-effective and user-friendly approach to hydration monitoring, making it suitable for daily use by students, working professionals, athletes, and elderly individuals.

Overall, the proposed solution highlights the practical application of IoT technologies in preventive healthcare and wellness monitoring. By reducing user intervention and automating hydration assistance, HydroMate has the potential to encourage healthier hydration habits and contribute to long-term personal well-being. Future enhancements may include cloud-based data analytics, personalized hydration recommendations, and integration with wearable health devices to further extend the system's functionality.

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