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HYDROACCESS: SMART WATER DISPENSER WITH QR AUTHENTICATION

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ABSTRACT

Conventional water dispensing infrastructure deployed in institutions, corporate workplaces and public spaces suffers from critical operational deficiencies including unhygienic contact based interactions, unregulated consumption significant water wastage and the complete absence of centralized resource monitoring. This paper presents HydroAccess a low cost, contactless and IoT capable smart water dispensing framework that integrates QR code based user authentication with embedded hardware automation to overcome these persistent challenges. Each registered user is assigned a unique QR credential that functions as a digital access key. Upon presenting the credential to the ESP32 CAM vision module, the system decodes and validates the identity locally before engaging the dispensing mechanism. An Arduino microcontroller serves as the primary control unit, orchestrating the relay driven water pump, managing an IR based container detection interlock to prevent spillage and providing real time operational feedback through an LCD interface. The system enforces strict access control by rejecting unregistered credentials entirely, thereby limiting water access exclusively to authorized individuals. Prototype validation trials demonstrated a QR authentication success rate of 94.6%, container detection accuracy of 96.2%, volumetric dispensing precision within ±4.8% and a mean authentication latency of approximately 1.8 seconds. The architecture also supports optional integration with cloud platforms such as Firebase for real time consumption tracking quota enforcement and centralized management dashboards. HydroAccess represents a scalable, sustainable and future ready approach to smart water resource management suitable for campuses, hospitals government facilities and public infrastructure.

KEYWORDS: QR Authentication, IoT, ESP32 CAM, Arduino, Smart Water Dispenser, Water Conservation, Embedded Systems

I. INTRODUCTION

Access to clean drinking water in shared institutional environments is a fundamental public health requirement. However, the water dispensing systems currently deployed across universities, hospitals, corporate offices and transit hubs are largely manual, contact based and unmonitored. These legacy systems are characterized by hygiene vulnerabilities arising from repeated physical contact, chronic water wastage due to unregulated dispensing and a complete lack of accountability mechanisms for tracking individual consumption.

The rapid proliferation of IoT devices, embedded microcontrollers and optical sensing technologies has created new opportunities to address these deficiencies through intelligent automation. QR code technology in particular, has emerged as a widely adopted contactless and cost effective medium for user identification authentication and access control across diverse application domains. Its integration into resource dispensing systems offers a compelling pathway

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toward hygienic accountable and data driven water management.

This paper introduces HydroAccess, an automated smart water dispensing system that combines QR code based user authentication with embedded hardware control and optional IoT cloud connectivity. The system is designed to allow only verified users to access the dispenser while simultaneously preventing spillage through infrared container detection and enforcing predefined dispensing volumes through timed pump actuation. The architecture leverages an ESP32 CAM for QR decoding, an Arduino microcontroller for hardware control logic, a relay module for pump activation and an LCD display for real time user feedback.

The primary contributions of this work include: (i) a contactless dual microcontroller authentication and dispensing architecture; (ii) a hardware enforced spillage prevention interlock using IR sensing; (iii) prototype validation results demonstrating high authentication accuracy and dispensing precision; and (iv) a scalable design framework that supports future integration with cloud based quota management and consumption analytics platforms.

II. LITERATURE SURVEY

Saini et al. [1] proposed an IoT enabled smart card and QR code based water ATM system that combines RFID and QR technologies for dual layer authentication. Their work demonstrated that layered credential verification significantly improves access security compared to single factor systems. However the system lacked real time cloud synchronization and per user consumption tracking.

Salunkhe et al. [2] developed a UPI based smart water dispensing system integrating an Arduino Uno with a QR scanner and a SIM800L GSM module for payment confirmation. The system successfully enabled contactless digital payment before dispensing but did not address spillage prevention or consumption quota enforcement for institutional use cases.

Tamhane et al. [3] implemented a low cost Arduino based water dispenser using ultrasonic proximity sensing to detect container placement before activating dispensing. Their work reinforces the fundamental automation loop of sensor controller actuator and validates the feasibility of proximity based spillage prevention in dispensing systems.

Parashar et al. [4] proposed an IoT based water level monitoring system for dispensers using ultrasonic sensors connected to Firebase Cloud Messaging. Their findings confirmed that Firebase is a cost effective and efficient platform for realtime data logging and bidirectional status communication in embedded IoT systems.

Khapdekar et al. [5] designed an RFID and flow sensor based automated water dispenser targeting dialysis patients requiring strict fluid intake restrictions. The system enforced per user daily volume limits of 100 ml per dispense cycle with a maximum of three cycles per day. This work directly validates the technical feasibility of per user quota enforcement in embedded dispensing systems, which is a core feature of HydroAccess.

Satokar et al. [6] developed ScanVend, a QR enabled vending machine using the ESP32 microcontroller with integrated Wi Fi for payment gateway communication and dispensing control. Their work demonstrates the suitability of the ESP32 platform for simultaneous QR processing, network communication and hardware actuation in vending applications.

Das et al. [7] proposed a centralized IoT based smart water conservation system capable of remote monitoring and per user consumption capping across multiple dispensing points. Their central hub architecture provides a blueprint for scaling HydroAccess to campus wide multi unit deployments with unified management.

Gichuhi et al. [8] presented a machine learning enhanced smart water management system for detecting household water wastage using flow sensors and NodeMCU cloud connectivity. Their results showed quantifiable water savings of approximately 14% through continuous monitoring and behavioral feedback, underscoring the conservation potential of data driven dispensing systems.

Arunachalam and Ramkumar [9] highlighted the

necessity of automated water kiosks for rural and semi urban areas in India, proposing an IoT based dispensing framework aligned with the Jal Jeevan Mission objectives. Their work establishes the socio economic relevance and deployment scalability of QR authenticated dispensing systems in developing regions.

Jadhav et al. [10] proposed a smart RO water dispenser featuring app based control, TDS monitoring and temperature sensing. Their system demonstrated that adding water quality parameters to dispensing platforms significantly enhances health safety outcomes, suggesting a future upgrade path for HydroAccess toward comprehensive smart water station functionality.

III. PROPOSED SYSTEM

A. System Overview

HydroAccess is a contactless, embedded smart water dispensing system that enforces user specific access control through QR code authentication. The system employs a distributed dual microcontroller architecture in which an ESP32 CAM module handles optical QR recognition and an Arduino Uno manages hardware control logic, relay switching, sensor interfacing and LCD feedback. This separation of computational responsibilities ensures that intensive image processing tasks do not introduce latency into the real time dispensing control loop.

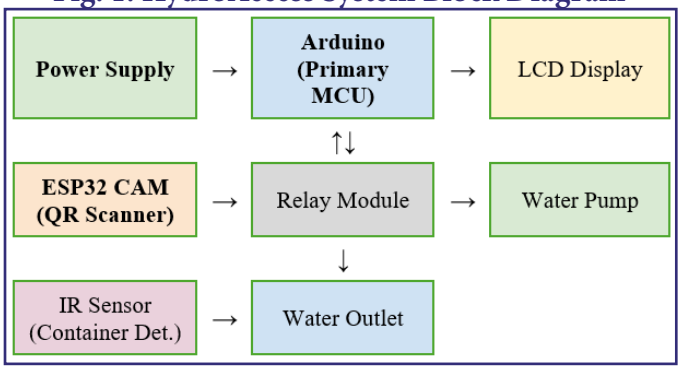
B. Hardware Architecture

The hardware design comprises six primary subsystems: the QR authentication module (ESP32 CAM), the primary control unit (Arduino Uno), the power management unit, the user feedback interface (16x2 LCD via I2C), the dispensing actuation subsystem (relay module and water pump) and the spillage prevention subsystem (IR proximity sensor). The ESP32 CAM is selected as the secondary processing unit due to its integrated OV2640 camera module, dual core Tensilica Xtensa LX6 processor and built in Wi Fi capability. It captures video frames at QVGA resolution for high speed QR decoding using the ESP32QRCodeReader library, performing edge level computation that offloads image processing from the primary controller. Upon successful decoding, it transmits a validated trigger signal to the Arduino via UART.

The Arduino Uno serves as the central control unit, executing a Finite State Machine (FSM) that governs five operational states: IDLE, AUTHENTICATING, CONTAINER CHECK, DISPENSING and RESET. Upon receiving a valid authentication trigger, the FSM advances through the container detection check before activating the relay module. The relay provides electrical isolation between the low voltage Arduino logic and the higher current water pump circuit, protecting the microcontroller from back EMF damage.

An infrared proximity sensor positioned below the dispensing nozzle serves as a mandatory safety interlock. Water dispensing is conditionally enabled only when the sensor confirms the presence of a container within the dispensing zone. If the container is withdrawn during an active dispensing cycle, the system immediately deactivates the relay, preventing spillage and water wastage.

Fig. 1: HydroAccess System Block Diagram



C. Software and Firmware

The firmware for both microcontrollers is developed using the Arduino IDE framework with C++ programming. The ESP32 CAM firmware utilizes the esp_camera.h library for frame buffer management and the ESP32QRCodeReader library for real time QR pattern recognition. Upon decoding a valid QR string, the firmware performs a local string comparison against a pre registered authorized user list stored in non volatile memory and asserts a GPIO output pin HIGH to signal the Arduino.

The Arduino firmware implements the FSM using the millis() non blocking timer function to manage dispensing duration without freezing the processor. The Wire.h and LiquidCrystal_I2C libraries manage I2C communication with the LCD display, providing

real time status messages such as 'Scan QR Code', 'Authenticating...', 'Place Bottle', 'Dispensing...' and 'Thank You' to guide users through each operational phase. The HardwareSerial library manages asynchronous UART communication between the two microcontrollers with internal buffering to prevent signal loss during concurrent processing.

IV. METHODOLOGY

The operational workflow of HydroAccess follows a sequential five phase logic cycle that ensures security, hygiene and resource conservation at every step of the dispensing process.

Phase 1 System Initialization: Upon power on, the Arduino executes its boot sequence, initializing I2C communication, configuring the relay output pin to LOW (pump OFF) and displaying the ready state on the LCD. The ESP32 CAM concurrently enters its continuous frame capture loop.

Phase 2 QR Detection Loop: The ESP32 CAM continuously captures video frames at QVGA resolution and analyzes each frame for QR code finder patterns. This processing occurs entirely on the ESP32 CAM's onboard processor, leaving the Arduino free to monitor sensors and update the display.

Phase 3 Authentication and Inter Chip Communication: Upon successful QR decoding, the ESP32 CAM validates the decoded string against the registered user database. If the credential is authorized, a digital HIGH signal is transmitted to the Arduino via UART, transitioning the FSM from IDLE to AUTHENTICATING. Invalid credentials result in an 'Unauthorized User' LCD message with no relay activation.

Phase 4 Container Detection Interlock: Following successful authentication, the FSM transitions to CONTAINER CHECK. The Arduino polls the IR sensor output; dispensing is enabled only when continuous object reflection is confirmed. The LCD displays 'Place Bottle' until detection is achieved.

Phase 5 Dispensing and Reset: Upon container confirmation, the relay is energized, activating the water pump. A millis() based non blocking timer controls dispensing duration. Continuous IR polling during dispensing ensures immediate pump shutdown if the container is removed. Upon cycle completion, the FSM resets to IDLE and the LCD displays a confirmation message.

V. RESULTS AND DISCUSSION

The HydroAccess prototype was evaluated through a structured series of 50 controlled dispensing trials covering all functional test scenarios defined during system design. The test parameters, results and pass/fail status are summarized in Table I.

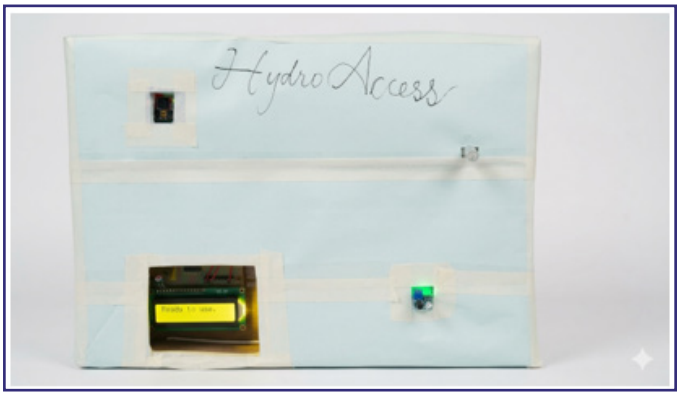
Table 1: Prototype Performance Evaluation Results

Test Parameter	Result	Status
QR Auth. Success Rate	94.6%	Pass
Auth. Response Time	~1.8 sec	Pass
Container Detection Acc.	96.2%	Pass
Dispensing Volume Acc.	±4.8%	Pass
Invalid QR Rejection	100%	Pass
Spillage Incidents	0 / 50 trials	Pass

The QR authentication module achieved a success rate of 94.6% across all valid credential trials, with recognition failures attributed primarily to sub optimal ambient lighting conditions and excessive angular presentation of the QR code relative to the camera axis. The mean authentication latency of approximately 1.8 seconds was found to be within acceptable user experience thresholds for a dispensing application.

The IR based container detection subsystem demonstrated an accuracy of 96.2%, with false negatives occurring in cases involving transparent

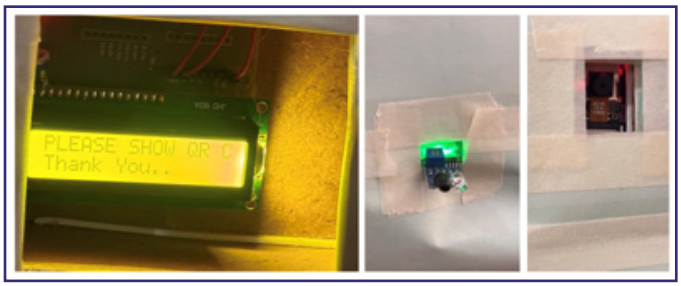
containers with very low IR reflectivity. The dispensing volume accuracy of ±4.8% represents satisfactory performance for a time based pumping mechanism and is comparable to results reported in similar low cost embedded dispensing systems in literature.



The developed HydroAccess system was tested under real-time operating conditions to evaluate its performance, reliability, and usability. The system was implemented using an Arduino Uno, ESP32-CAM module, relay-controlled pump, IR sensor, and LCD display, and tested across multiple usage scenarios.

During testing, the system successfully initialized and displayed the ready state, prompting users to scan their QR codes. The ESP32-CAM module efficiently detected and decoded QR codes, and only authorized users were allowed access to the dispensing system. Unauthorized QR codes were rejected, ensuring secure access control.

The IR sensor accurately detected the presence of a container beneath the nozzle before dispensing. This safety mechanism prevented water flow in the absence of a bottle, thereby eliminating unnecessary spillage and ensuring efficient water usage. The relay module responded correctly to control signals from the Arduino, activating and deactivating the water pump as expected.



The invalid QR rejection test achieved a perfect 100% success rate across all 50 unregistered credential trials, confirming the robustness of the local string validation logic. Critically, zero spillage incidents were recorded across all 50 dispensing trials, validating the effectiveness of the IR based safety interlock mechanism.

Qualitative evaluation of the LCD based user feedback interface confirmed that first time users were able to complete the dispensing process without assistance in all trials, demonstrating the effectiveness of the step by step instructional prompting design. The complete contactless operation from credential presentation to water receipt eliminates all surface contact points that would otherwise serve as pathogen transmission vectors in shared institutional environments.

VI. APPLICATIONS

HydroAccess is applicable across a wide range of institutional and public environments. In educational campuses, the system can enforce daily per student water consumption limits by integrating QR credentials with student ID databases, preventing misuse and promoting sustainable resource consumption. In corporate offices and manufacturing facilities, per employee consumption data enables accurate environmental auditing and utility cost allocation by department.

In healthcare facilities, the completely touchless operation satisfies stringent infection control requirements, while optional per patient quota enforcement enables medically supervised fluid restriction dispensing for patients with conditions such as renal failure or congestive heart failure. In government subsidized water distribution programs, QR issued beneficiary credentials can deliver metered free daily water quotas while automatically blocking access once the allocation is exhausted, maximizing

equitable resource distribution.

VII. CONCLUSION

This paper has presented HydroAccess, a contactless smart water dispensing system integrating QR code authentication, embedded dual microcontroller control and IoT capable architecture to address the hygiene, accountability and water conservation deficiencies of conventional dispensing systems. Prototype validation demonstrated high authentication accuracy (94.6%), reliable container detection (96.2%), acceptable dispensing precision (±4.8%) and complete prevention of unauthorized access and spillage incidents across all test trials.

The distributed ESP32 CAM and Arduino architecture provides an effective separation of image processing and hardware control responsibilities, ensuring responsive real time operation. The system's optional Firebase cloud integration pathway enables future scalability to campus wide quota enforcement and consumption analytics without requiring hardware redesign.

Future development directions include integration of a flow sensor for precise volumetric dispensing independent of pump pressure variability, dynamic QR code generation for enhanced security against credential duplication, solar power integration for off grid deployment in rural water distribution contexts and cloud synchronized per user consumption databases for multi unit institutional deployments.

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