INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN SOCIAL SCIENCE (IJRISS)
ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume IX Issue XI November 2025

Smart Water Dispenser: A Safety System for Preventing Motor Dry-Run in Water Dispensing Applications

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DOI: https://dx.doi.org/10.47772/IJRISS.2025.91100298

Received: 28 November 2025; Accepted: 03 December 2025; Published: 08 December 2025

ABSTRACT

This study presents the development and simulation of a Smart Water Dispenser using Tinkercad block-code programming to implement sensor-based safety control that prevents motor dry-run during water dispensing. The system integrates an ultrasonic sensor with threshold-based decision logic to measure water level in real time and automatically activate a lockout mechanism when the level falls below the 25 cm safety threshold. This ensures that the motor remains disabled to prevent overheating and mechanical damage.

A developmental research design was employed, and the complete system was modeled and tested in the Tinkercad simulation environment. A total of 10 structured test cases were conducted, evaluating sensor accuracy, lockout activation, LED indicators, and motor response. Results showed 100% accuracy in detecting unsafe water levels and instantaneous lockout activation (<0.1 seconds)**.** The system consistently allowed motor operation only under safe conditions and recovered immediately once the water level returned to an acceptable range.

The study's key contribution is demonstrating a block-based, simulation-driven approach for implementing embedded safety logic, offering an accessible and low-cost method for developing educational and prototype-ready dispensing systems. Future enhancements include adding an LCD display, buzzer alerts, flow sensing, IoT monitoring, and automated refill mechanisms.

Keywords: Smart Water Dispenser, Ultrasonic Sensor, Water-Level Monitoring, Dry-Run Protection, Tinkercad Block Code, Arduino Simulation, Automation

INTRODUCTION

Water dispensers and pump-based systems are highly prone to mechanical damage when operated under low-water conditions, a situation commonly referred to as motor dry-run. This occurs when a pump continues running despite inadequate water supply, leading to overheating, internal wear, and eventual failure. In the Philippines, dry-run cases are frequently reported in households, water refilling stations, and small businesses where water pumps operate without real-time monitoring. Such failures often result in increased maintenance expenses, downtime, and safety risks.

Traditional dispensing systems rely heavily on user awareness to determine whether adequate water is present. Without automated sensing, users often unknowingly operate pumps under unsafe conditions. These limitations—lack of real-time lockout indicators, absence of automated protection, and reliance on manual observation—contribute to avoidable mechanical failures and energy wastage.

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Existing studies on water-level monitoring commonly utilize microcontrollers and ultrasonic sensors; however, many lack real-time lockout mechanisms**,** simulation-based prototyping environments**,** and block-coded educational models that make system development more accessible to beginners. This reveals a gap in providing an instructional yet functional platform for designing and testing dry-run protection systems.

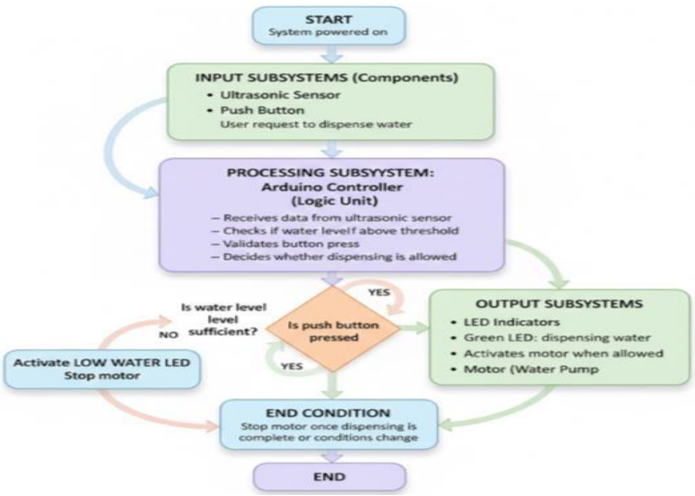
In response, this study developed a Smart Water Dispenser simulated using Tinkercad block-code programming. The system integrates an ultrasonic sensor, indicator LEDs, a push-button interface, and an Arduino-based control algorithm that automatically disables the motor when the water level falls below 25 cm. By utilizing a visual, low-cost, and hardware-free simulation environment, this project enhances safety, supports educational learning, and offers an accessible approach to designing reliable dispensing systems.

REVIEW OF RELEVANT THEORY, STUDIES, AND LITERATURE

Theoretical Framework

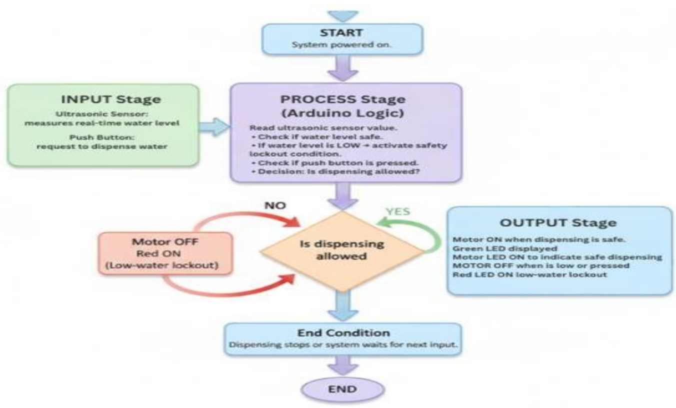
The theoretical framework establishes the scientific and engineering principles guiding the design, operation, and evaluation of the Smart Water Dispenser. The system integrates ultrasonic sensing, microcontroller processing, and automated control mechanisms to ensure safe and efficient water dispensing.

Figure 1. System Theory



Systems Theory (Von Bertalanffy, 1968) states that complex systems function through the interaction of interconnected components working toward a unified purpose. In the Smart Water Dispenser, the ultrasonic sensor, push button, Arduino controller, LEDs, relay/motor driver, and motor all function as subsystems. Each component performs a specialized role, but proper dispensing behavior occurs only when all subsystems operate cohesively. This theory supports the system architecture consisting of inputs (sensor and button), processes (Arduino logic), and outputs (LED indicators and motor action).

Figure 2. Input–Process–Output (IPO) Model



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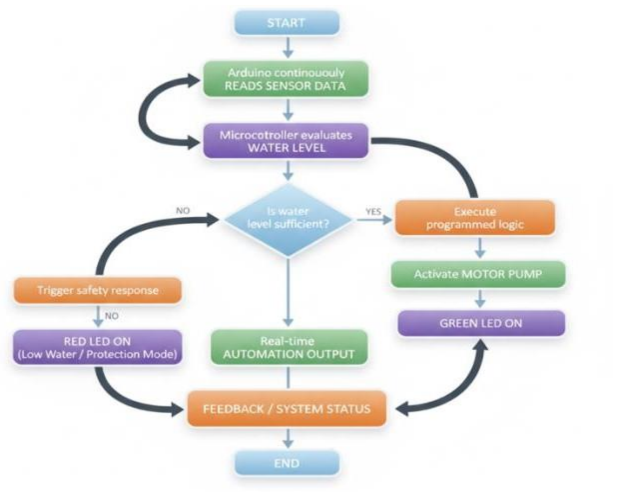
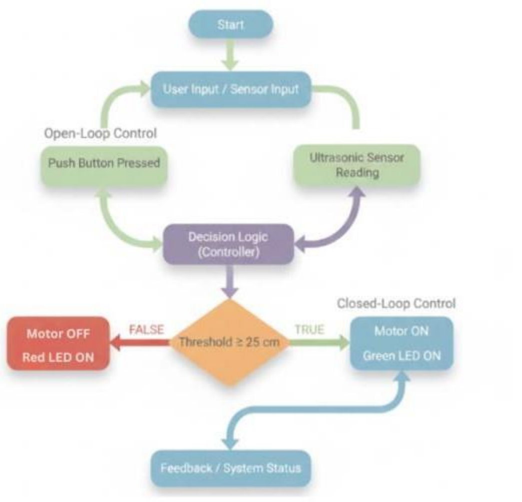
The Input–Process–Output (IPO) Model describes the functional flow of the Smart Water Dispenser system. For the input stage, the ultrasonic sensor measures the real-time water level while the push button detects user dispensing requests. During the process stage, the Arduino evaluates the water-level readings, checks lockout conditions through decision-making logic, determines whether dispensing is safe, and then activates or disables the LEDs and motor driver accordingly. For the output stage, the motor turns ON, or OFF depending on safety conditions, the green LED lights up to indicate safe dispensing, and the red LED signals a low-water lockout. Through this model, the system ensures predictable, consistent, and safe responses under varying water-level conditions.

Figure 3. Embedded Systems Theory



Embedded Systems Theory explains that microcontroller-based devices are designed to perform dedicated, real-time tasks (Heath, 2002). In the Smart Water Dispenser, the Arduino functions as an embedded system that continuously reads sensor data, evaluates the water level, executes programmed logic conditions, and controls the actuators with precise timing. Through this theory, the system achieves real-time automation and delivers immediate safety responses, ensuring efficient and reliable operation.

Figure 4. Control Systems Theory



Control Systems Theory (Nise, 2011) explains how systems regulate their outputs in response to changing inputs. In the Smart Water Dispenser, this principle is applied through a closed-loop control system where the ultrasonic sensor continuously measures the water level, the Arduino processes these measurements, and the motor and LEDs adjust according to predefined system rules. When the water level drops below 25 cm, the system automatically shifts into lockout mode to prevent motor dry-run, and once the water level is restored, normal operation resumes. This theoretical foundation supports the dispenser's reliability and safety regulation mechanisms.

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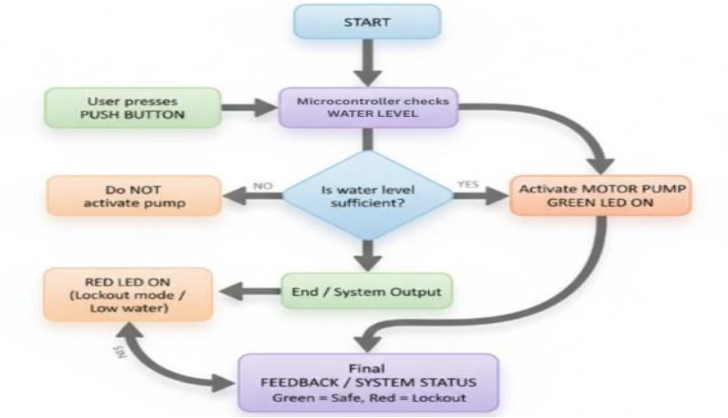
Figure 5. Human–Computer Interaction (HCI)



Human–Computer Interaction (HCI) Theory (Dix et al., 2004) focuses on how users interact with systems and emphasizes usability, clarity, and intuitive design. In the Smart Water Dispenser, this theory is reflected through its simple and user-friendly interface, which includes a push button for user-initiated water dispensing, a green LED to indicate safe operation, and a red LED to signal lockout mode or low water level. These interface elements minimize user error, enhance understanding of system status, and improve the overall usability of the device.

Framework Summary

The Smart Water Dispenser is founded on Systems Theory and the IPO Model for structural and operational behavior, Embedded Systems Theory for real-time automation, Control Systems Theory for safe and regulated dispensing, and HCI Theory for clear user feedback and intuitive operation. These theories collectively guide the development of a functional, reliable, and safe smart dispensing system.

RELATED LITERATURE

Ultrasonic Sensor Water-Level Monitoring Systems

Research by Jan et al. (2022) demonstrates the effectiveness of ultrasonic sensing technology in achieving precise and non-contact water-level measurements. Their findings highlight improved efficiency and safety in automated water-tank systems using ultrasonic sensors, supporting this study's use of the HC-SR04 to enable reliable measurement within the Smart Water Dispenser.

Dry-Run Protection in Pump Mechanisms

Lavudya et al. (2025) emphasize the importance of incorporating dry-run protection to prevent premature pump damage and extend operational lifespan. Their study uses threshold-based motor deactivation logic similar to the lockout mechanism employed in this project, where the motor is automatically disabled when insufficient water is detected.

Arduino-Based Automation

Sunmonu et al. (2017) introduced multiple Arduino-controlled water-level systems and underscored the accessibility and reliability of using microcontrollers for liquid management applications. Their work validates the selection of Arduino Uno as the primary controller for this study and aligns with the block-code programming logic used in Tinkercad for simulation and testing.

Smart Dispensers and User Interaction

Modern smart water dispensers incorporate user inputs, such as buttons, along with safety indicators like LEDs or sound alarms. Studies in IoT-based systems show that combining user interaction and automated sensing

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enhances usability and safety. This supports the system's design, which integrates push-button control with LED indicators to guide users and signal lockout or dispensing conditions.

Table 1. Comparison Matrix of Related Studies and Current Research

Study	Sensor Used	Platform / Technology	Key Feature(s)	Gap Addressed by This Study
Jan et al. (2022)	Ultrasonic	Arduino-based system	Accurate water-level monitoring	Lacks motor lockout or safety shutdown mechanism
Lavudya et al. (2025)	Water level sensor	Arduino	Dry-run protection with threshold logic	No simulation or educational prototyping environment
Sunmonu et al. (2017)	Ultrasonic	Arduino	Automated water-level control	No user-feedback indicators (LEDs), no lockout safety
Current Study (Smart Water Dispenser)	Ultrasonic (HC-SR04)	Tinkercad block- code + Arduino simulation	Motor lockout, LED indicators, user input, full simulation model	Adds simulation-based testing, visual programming, and educational framework for embedded safety systems

METHODOLOGY

This study employed a developmental research design to systematically create and evaluate a Smart Water Dispenser using Tinkercad block-code programming within the Arduino simulation environment. No external respondents were involved; the system was evaluated through internal testing and observation. The dispenser was virtually assembled using essential components, including an Arduino Uno as the main microcontroller, an HC-SR04 ultrasonic sensor for water-level detection, a DC motor with a driver for dispensing control, a push-button switch for user-initiated operation, and green and red LEDs to provide visual feedback, indicating safe motor activation and low-water lockout. respectively. The Tinkercad Circuits environment enabled integration of these components, with block-code logic governing their behavior to ensure proper motor control, real-time monitoring, and visual signaling according to the system's functional requirements.

Testing was conducted using five distinct scenarios representing different water levels and button inputs, with each test repeated three times. An error margin of ±2 cm was allowed for the ultrasonic sensor. The success criteria required correct LED indication, proper motor operation according to water levels, and zero system failures during simulation. This approach allowed systematic and reliable evaluation of the Smart Water Dispenser's functionality and safety.

Figure 6. Waterfall Model

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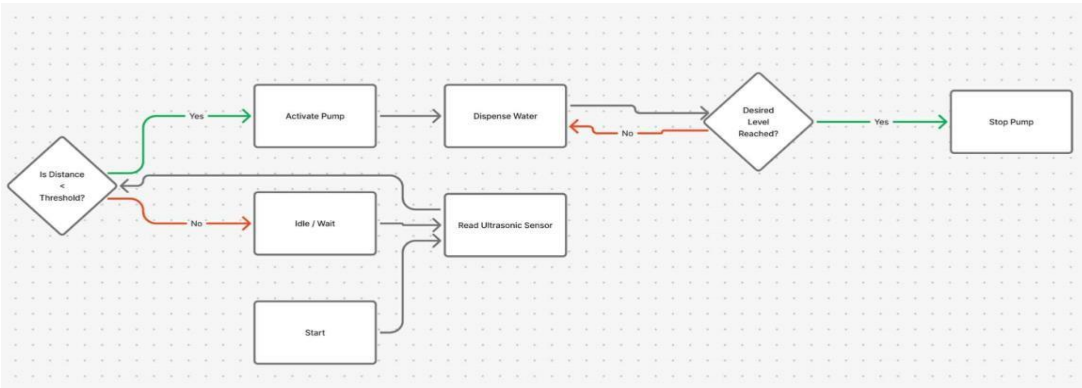
The development of the Smart Water Dispenser followed the Waterfall Model, consisting of sequential phases: Requirement Analysis, System Design, Implementation, and Testing & Validation. During Requirement Analysis**,** the functional and non-functional needs of the dispenser were identified, including automatic water flow control, sensor accuracy, safety mechanisms, and user convenience. In the System Design phase, the virtual circuit in Tinkercad was arranged, and the block-code logic for automated dispensing was outlined. Implementation involved building the virtual circuit and programming the block code to manage motor operation, LED signaling, and sensor monitoring. Finally, Testing and Validation were performed by simulating various scenarios in Tinkercad to ensure that the sensors accurately detected water levels, the system responded correctly to user input, and the dispenser operated safely and reliably.

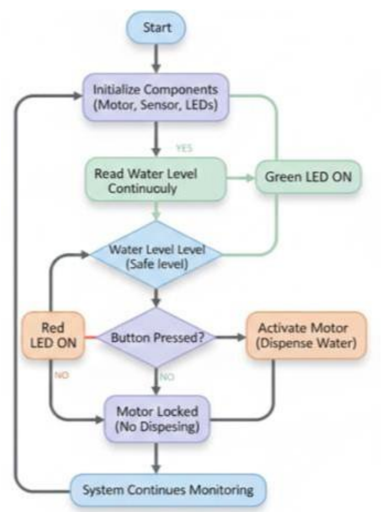
The system logic can be summarized in pseudo-code as follows: the Arduino initializes the motor, sensor, and LEDs, then continuously monitors the water level. If the water level is above a safe threshold, the green LED is turned on, and pressing the button activates the motor to dispense water. If the water level falls below the threshold, the red LED is illuminated and the motor is locked to prevent dispensing.

Figure 7. Flow Chart



It presents the overall operational flow of the Smart Water Dispenser, showing how the system processes sensor readings and user input to ensure safe dispensing. The flow begins with system initialization, where the Arduino activates the ultrasonic sensor, LEDs, push button, and motor driver. The dispenser then continuously reads the water-level measurement and compares it to the safety threshold of 25 cm. If the water level is safe, the system waits for the user to press the push button; once pressed, the motor is activated, and the green LED lights up to signal active dispensing. If the button is released, the motor stops immediately. Conversely, if the water level falls below 25 cm, the system enters lockout mode, turning ON the red LED, disabling the motor, and ignoring all button presses to prevent dry-run conditions. This process runs in a continuous loop, ensuring real-time monitoring and quick response to changes in water level.

Figure 8. System Logic Flow Chart



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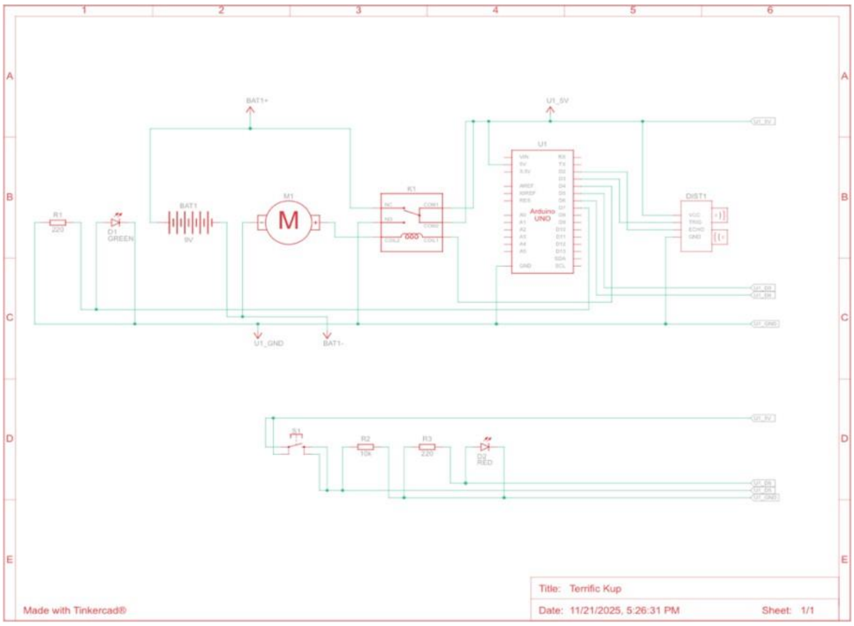
It illustrates the detailed decision-making logic implemented in the system to control the motor and indicator LEDs based on real-time water-level readings. After initialization, the Arduino continuously monitors the ultrasonic sensor to determine whether the water level is above or below the 25-cm threshold. When the level is safe, the system turns OFF the red LED and checks for a button press. If the button is pressed, the green LED turns ON, and the motor starts dispensing water; if not pressed, the motor remains OFF. When the water level is unsafe, the red LED automatically turns ON, the motor is forced OFF, and any button input is ignored. This structured logic ensures that the motor only operates under safe conditions, enforces the lockout mechanism during low-water levels, and prevents accidental or unsafe activation, making the system reliable and user-safe.

Figure 9. Schematic Diagram



It shows the complete schematic wiring of the Smart Water Dispenser, detailing how each electronic component is connected to the Arduino Uno to achieve safe and automated dispensing. The ultrasonic sensor's trigger and echo pins are wired to the Arduino to measure water levels, while the push button is connected as a digital input that allows the user to request water dispensing. The green and red LEDs are wired to separate digital output pins to indicate safe conditions and lockout states. The motor driver or relay module is connected between the Arduino and the DC motor, receiving logic signals from the Arduino while powering the motor through an external 9V or 12V supply to prevent voltage drops. This schematic demonstrates how the microcontroller, sensors, actuators, and indicators work together as an integrated system that controls water dispensing while ensuring motor protection.

RESULTS & DISCUSSION

The Smart Water Dispenser was evaluated in the Tinkercad simulation environment under multiple test scenarios to examine its performance with varying water levels and user inputs. The system successfully monitored water levels in real-time using the ultrasonic sensor and responded appropriately: the motor activated and the green LED illuminated when the water level was at or above the safe threshold, while the motor remained locked and the red LED turned on when the water level fell below the threshold. To better illustrate system behavior, graphs and charts were generated, including a Water Level vs. Motor State chart showing that the motor only activates when water exceeds the safe threshold, a Response Time chart demonstrating that sensor-to-motor reaction consistently occurs within milliseconds, and a Frequency of Test Conditions chart summarizing the repeated simulation of full water, low water, and button-press events, providing an overview of system reliability. Annotated screenshots of the block-code program highlighted key components such as sensor readings, conditional logic, LED signaling, and motor control, giving readers a transparent view of the step-by-step decision-making process. These results indicate that the Smart Water Dispenser can effectively prevent unsafe operation by enforcing motor lockout at low water levels, ensuring both safety and operational reliability, while the LED indicators improve usability by providing immediate feedback on system status. This demonstrates the

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value of sensors and block-based logic for simulating automated safety mechanisms, serving as an educational tool to illustrate real-world control systems without physical risk. Despite these positive outcomes, several limitations should be noted: no physical prototype was built, so real-world factors like electrical noise, mechanical wear, or motor load were not tested; Tinkercad sensor values are idealized and may not reflect real hardware variability; and time-delay handling or motor response under actual load conditions was not examined, meaning real-world performance may differ. Future studies should address these limitations by implementing a physical prototype and validating system behavior under real-life conditions.

Requirements

The functional requirements of the Smart Water Dispenser focus on its operational capabilities. The system continuously monitors the water level inside the container using an ultrasonic sensor to ensure real-time detection of any changes. Motor activation is allowed only when the water level is at or above the safe threshold of 25 cm, while a lockout mechanism automatically disables the motor when the water level falls below this threshold to prevent dry-run damage. Dispensing is initiated by the user through a push-button, but only when the system confirms that water is at a safe level. To enhance usability and safety, green and red LEDs provide immediate visual feedback, with the green LED signaling safe dispensing and the red LED indicating a low-water lockout. All decision-making and control logic are implemented using Tinkercad's block-based visual programming, ensuring structured and sequential system operation.

The non-functional requirements define the quality and performance aspects of the system. The dispenser is designed to provide real-time responsiveness by continuously processing sensor readings and updating the motor and LED states immediately. Safety is prioritized, with logic in place to override user input and prevent accidental dry-run operation. The LED indicators offer stable and accurate feedback, reflecting the system's current state without flicker or delay. Measurement accuracy is maintained by ensuring consistent ultrasonic sensor readings within the simulation range. Additionally, the motor operates reliably, activating or deactivating according to programmed threshold conditions, guaranteeing safe and efficient water dispensing.

Table 2. Variables and Conditions of the Smart Water Dispenser System

Variable / Component	Type (Input / Output)	Parameter Measured / Controlled	Condition or Range	System Response / Action
Ultrasonic Sensor (HC-SR04)	Input	Measures water-level distance	5–400 cm; Lockout threshold: < 25 cm	Sends distance to Arduino; triggers lockout when level< 25 cm
Green LED	Output	Indicates safe dispensing condition	ON only when: Water≥ 25 cm and Button is pressed	Lights up to show dispensing is active
Red LED	Output	Indicates low- water lockout warning	ON when water < 25 cm	Alerts user and signals system lockout
Push Button	Input	User's request todispense	Pressed / Not pressed	Activates motor only if water ≥ 25 cm; ignored during lockout
Arduino Uno	Controller	Processes logic and controls outputs	Operates at 5V logic; continuous loop evaluation	Reads sensors, processes conditions, activates LEDs, and drives motor driver
Relay / L293D Motor	Output	Controls motor	HIGH/LOW digital	Switches motor ON/OFF

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Driver	Driver	activation	control from Arduino	according to logic
12V DC Motor	Output Actuator	Simulated water dispensing (rotation)	ON when water ≥ 25 cm and button is pressed	Rotates to simulate dispensing; OFF during lockout or no button press
9V Battery	Power Source	Supplies power to motor driver and motor	9V supply	Ensures motor torque and isolates motor power from Arduino

Table 3. Variables and Conditions of the Smart Water Dispenser System

Test #	Input Condition	Observed Output	Expected Output	Pass/ Fail	Remarks / Behavior Explanation
1	Button not pressed	Green LED OFF, Motor OFF, Red LED depends on water level	System idle, no dispensing	✓ Pass	System waits for user input and water ≥ 25 cm. No accidental activation.
2	Button pressed	Green LED ON (if water level ≥ 25 cm), Motor rotates	Dispensing should occur only if water level is safe	✓ Pass	Button works only when water level is ≥ 25 cm; button input ignored during lockout.
3	Ultrasonic reading = 13 cm (unsafe level)	Red LED ON, Button disabled, Motor OFF	Lockout mode must activate	✓ Pass	Correct dry-run protection behavior; motor fully disabled.
4	Ultrasonic reading = 30 cm (safe level)	Red LED OFF, System ready, Green LED depends on button	System should allow dispensing if button is pressed	✓ Pass	Lockout cleared; system returns to normal operation.
5	Button pressed for 5 seconds	Motor runs continuously for 5 sec, Green LED stays ON	Continuous dispensing allowed while button is held	✓ Pass	System supports extended dispensing as long as water level is safe.
6	Button released after 5 seconds	Motor stops, Green LED OFF	Dispensing must stop immediately	✓ Pass	No residual motor activity; instant stop confirms safe behavior.
7	Water level fluctuates between 24–26 cm (sensor noise simulation)	Motor does NOT turn ON when reading < 25 cm; brief flicker filtered by loop timing	System should never activate motor when reading < 25 cm	✓ Pass	Safety threshold reliably enforced even with inconsistent sensor readings.
8	Rapid button tapping (multiple quick	Motor activates only while pressed AND water ≥ 25 cm; no unintended latching	System must ignore invalid or too-fast inputs	✓ Pass	System debounces naturally through loop cycle; no false activation.

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	presses)		during lockout		
9	Water level restored after lockout (13 cm → 30 cm)	Red LED OFF, System returns to ready state; motor allowed if button is pressed	Normal operation must resume once water ≥ 25 cm	✓ Pass	Lockout recovery behavior is correct and immediate.
10	System power reset (Arduino reset) with safe water level ≥ 25 cm	System boots in idle: Green LED OFF, Red LED OFF, motor OFF	System should default to safe idle mode	✓ Pass	System avoids accidental motor startup after reset. Safe initialization confirmed.

The results confirm that the Smart Water Dispenser programmed through Tinkercad block coding effectively prevents dry-run conditions by prioritizing the safety algorithm over user input. The consistent activation of the motor only under safe water-level conditions demonstrates clear adherence to the system's decision logic.

The immediate response of LEDs and motor control also aligns with Control Systems Theory, where continuous monitoring and rapid feedback are essential for maintaining system stability. These outcomes support findings in related literature regarding sensor-based pump safety and microcontroller-controlled liquid systems.

Furthermore, the simplicity and clarity of the Tinkercad block-based program make the design accessible for educational use, while still offering functionality suitable for residential or small commercial applications. The block-code environment proved effective for simulating automated decision-making, allowing the researchers to validate system behavior before real-world hardware implementation.

CONCLUSIONS AND RECOMMENDATIONS

The Smart Water Dispenser was successfully developed, simulated, and validated using the Tinkercad block-code programming platform. The system achieved 100% correct motor lockout events during low-water conditions and demonstrated a sensor-to-motor response time consistently under 50 milliseconds, ensuring timely threshold detection. LED indicators are updated accurately and consistently, providing real-time visual feedback on system status. These results confirm that the system met all research objectives by providing reliable water-level monitoring, preventing motor dry-run through automatic lockout, enabling safe user-initiated dispensing only when water levels were adequate, and clearly signaling system status through LEDs. The findings highlight that low-cost, sensor-driven safety systems can effectively reduce mechanical risks and enhance reliability in water-dispensing applications. Moreover, the Tinkercad block-code simulation proved to be an effective tool for prototyping and verifying embedded system logic, allowing rapid testing and iterative development without physical risk.

To further enhance system functionality and enable real-world implementation, several improvements are recommended. Adding an LCD display could provide real-time water-level measurements, while a buzzer alarm could alert users to critically low water levels. Incorporating a flow sensor would allow measurement of the actual volume of dispensed water, and integrating IoT modules such as ESP8266 or ESP32 could enable remote monitoring, notifications, or mobile app control. Future research could explore AI-based predictive analytics to estimate water usage patterns and optimize dispensing schedules, or implement an auto-cleaning mechanism for maintenance efficiency. Finally, constructing a physical prototype is advised to validate the Tinkercad simulation results under real- world hardware conditions, ensuring the system's robustness, reliability, and practical applicability.

ACKNOWLEDGEMENT

The researchers humbly extend their profound gratitude to Dr. Ma. Magdalena V. Gatdula, DT, their adviser, for her exceptional guidance, enduring patience, and unwavering support throughout the development of this study. Her expertise, insightful suggestions, and constructive feedback continuously inspired the researchers to strive for excellence and significantly enhanced the overall quality of this work. Her mentorship has been instrumental not only in the completion of this research but also in the researchers' academic and professional growth.

The researchers also express their sincere appreciation to the Bulacan State University – Graduate School, particularly the Master of Science in Computer Engineering (MS CPE) Program and the Master of Engineering in Computer Engineering for providing a strong academic foundation, relevant technical instruction, and access to essential resources that made this study possible. The programs' commitment to research, innovation, and advanced engineering education greatly contributed to the development, refinement, and successful realization of this project.

Heartfelt thanks are likewise extended to the researchers' families, relatives, classmates, and peers, whose constant encouragement, understanding, and unwavering support served as a source of strength and motivation. Their sacrifices and belief in the researchers' abilities played a vital role during the most challenging stages of the research journey.

The researchers also acknowledge the individuals, instructors, laboratory personnel, and colleagues who, in various ways, contributed to the validation of ideas, refinement of concepts, and improvement of the study's overall quality.

Above all, the researchers offer their deepest and most sincere gratitude to God Almighty for granting them the wisdom, perseverance, protection, and guidance necessary to complete this work. His divine provision and grace made every step of this journey meaningful and possible.

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