An-Najah National University

Faculty of Engineering & Information Technology Computer

Engineering

Hot Drinks machine

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Disclaimer statement

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Abstract

The main idea of our project is to build a fully-automated **Hot Drinks Machine** to be working instead of depending on human resources in the making hot drinks such as coffee, cappuccino, and Nescafé, the machine we built is controlled by a main controller built in the machine and a mobile application; it also includes features that were not included in some coffee machines. We tried our best, and we used sensors and electronic pieces to guarantee the efficiency and accuracy of the project. Generally, the main features like automated cup dispensing mechanism, Dedicated powder containers corresponding to different beverage types dispense precise quantities of powder Each container is equipped with an ultrasonic sensor to monitor powder levels and generate refill alerts when necessary, A heated water tank maintains the required water temperature through continuous monitoring using a temperature sensor while a pump regulates the controlled delivery of hot water into the cup, and a mechanical stirring mechanism ensures proper mixing to achieve uniform beverage quality.

The integration of sensors, actuators, and embedded control logic results in an efficient, consistent, and user-friendly automated solution, illustrating the effectiveness of automation technologies in modern beverage production lines.

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Chapter 1: Introduction

The global food and beverage service industry is increasingly embracing automation technologies to enhance efficiency, ensure product consistency, and improve customer experience. Within this domain, the preparation of hot beverages—a daily ritual for millions—remains an area ripe for innovation Traditional methods often rely on manual intervention, leading to potential inconsistencies in taste, strength, and temperature, while also incurring significant labor costs and wait times. Even existing vending solutions can be limited, often offering pre-mixed selections with little customization and lacking real-time operational feedback.

This project addresses these challenges by designing and implementing a fully-automated Hot Drinks Machine. The core objective is to eliminate dependence on human resources for the preparation of specific hot beverages—such as coffee, cappuccino, and Nescafé—while introducing advanced features for reliability and user control. The proposed system moves beyond simple button-operated dispensers by integrating a centralized embedded controller with a companion mobile application, allowing for both on-demand service and remote system management.

Key operational challenges in automated beverage preparation include precise ingredient dispensing, maintaining optimal water temperature, and ensuring homogeneous mixing. Our solution incorporates dedicated subsystems to address each of these requirements: an automated cup dispensing mechanism; dedicated, sensor-monitored powder containers for accurate and tracked ingredient delivery; a dynamically heated and regulated water tank; and an integrated stirring mechanism. This synthesis of mechatronic components is governed by embedded control logic to coordinate the entire preparation cycle.

The following report details the design, implementation, and functionality of this automated Hot Drinks Machine. It begins with a review of relevant literature and existing technologies, followed by a comprehensive explanation of the system's design methodology, including its architectural overview, hardware components (sensors and actuators), and software control structure. Subsequent sections cover the system integration, operational workflow, and a discussion of the results achieved. The report concludes by evaluating the project's success in meeting its objectives, considering its limitations, and suggesting potential avenues for future enhancement. This project demonstrates a practical application of automation principles, illustrating their effectiveness in creating efficient, consistent, and user-centric solutions for modern beverage production.

Objectives of this project include:

1. To design a fully-automated machine for preparing select hot beverages without manual intervention.
2. To ensure beverage consistency through precise, sensor-controlled ingredient dispensing and mixing.
3. To provide dual user control via an onboard main controller and a mobile application.
4. To incorporate advanced features for system reliability, including real-time ingredient monitoring and automated alerts.

Finally, this report is structured as follows: Chapter 2 presents the constrains, Chapter 3 reviews relevant literature; Chapter 4 outlines the methodology; Chapter 5 discusses constraints, standards, and earlier coursework; Chapter 6 presents the results and analysis; Chapter 7 provides discussion and interpretation; and Chapter 8 concludes the study with recommendations for future work.

Chapter 2: Constraints, Standards/ Codes and Earlier course work

2.1 Constraints:

- **Design Complexity:**
  - ***Cup Compatibility*:** The mechanical design, particularly the cup dispenser and stirring mechanism, was constrained by the physical dimensions (height and diameter) of commercially available, low-cost disposable cups. This necessitated iterative adjustment of component heights and gripper designs to ensure reliable operation.
  - **Dual Control Interface Requirement:** The system was required to provide two distinct control pathways: a primary, built-in controller for direct operation and a secondary, wireless interface via a mobile application for remote selection and monitoring, increasing design complexity.

- **Sensors Accuracy:**
  As mentioned before, the project is sensitive for its job, and the sensors we were using in our project have an error margin that we must be committed to (temp sensor, IR sensor, limit switch and ultrasonic sensors).
- **Lack of Knowledge and Guidance:**
  We are students of engineering field and have we don't have a knowledge how to optimize the mixing and temperature control to be efficient in power and the type of Pipes and pumps to give the highest quality.

2.2 Earlier Coursework:

- Microcontrollers and Embedded Systems: Programming Arduino and ESP32 modules.
- Control Systems: Designing automated feedback loops for temperature, humidity, and ventilation.
- Computer Networks: Integrating IoT and web-based monitoring systems.
- Power Electronics: Managing DC motors, relays, and power supply distribution.
- Software Engineering: Supporting user interface development and systematic design documentation.

Chapter 3: Literature Review

3.1 Introduction and Evolution of Automated Beverage Systems

The automation of beverage preparation represents a significant intersection of consumer convenience, operational efficiency, and mechatronic engineering. Traditional vending machines have historically offered limited, pre-packaged selections with minimal sensory feedback and no quality assurance during the dispensing process. The contemporary shift, as evidenced in commercial and research domains, is toward smart, connected, and sensor-rich systems that guarantee consistency, enable remote management, and provide a customizable user experience. This project contributes to this evolution by implementing a fully-integrated Hot Drink Machine that synthesizes precision dispensing, real-time process control, and dual-mode user interaction—features often siloed in existing solutions. The transition from simple electromechanical switches to microcontroller-driven systems with feedback loops marks the current state of the art. This review contextualizes the implemented system's architecture by examining the core technologies for ingredient handling, thermal management, fluid dynamics, and system control, thereby framing the project's technical contributions within the broader landscape of automated food service technology.

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3.2 System Architecture and Control Paradigms

Modern automated systems require robust architectural patterns to manage complexity. A prevalent and effective design is the **multi-layer control architecture**, which separates high-level user interface logic from low-level hardware actuation. This project implements a distributed model:

- **Primary Controller (Arduino Mega):** Functions as a real-time **state machine**, directly managing sensors, actuators, and the sequential logic of the preparation cycle. This pattern, as described in embedded systems design literature, ensures deterministic timing and reliable hardware interaction.
- **Secondary Controller/Interface (ESP32):** Operates as a **networked co-processor**, hosting a web server to provide a remote graphical user interface (GUI) and acting as a communication bridge. This decouples the resource-intensive tasks of networking and web serving from time-critical motor and sensor control, enhancing overall system stability.

This architecture directly addresses a common gap in integrated systems: maintaining responsive, real-time control while offering rich user connectivity. The use of serial communication (UART) between the two microcontrollers exemplifies a standard industry practice for creating modular, maintainable systems.

3.3 Analysis of Core Subsystems & Implemented Technologies

The machine's functionality is decomposed into interdependent subsystems, each leveraging established engineering principles.:

1. Ingredient Storage and Precision Dispensing

Accurate dry ingredient dispensing is fundamental. This system employs dedicated auger mechanisms for each powder (Coffee, Nescafé, Cappuccino), driven by stepper motors (TB6600 drivers). The use of stepper motors allows for open-loop positional control, dispensing precise volumes per beverage. The code implements runDrinkMotor () with defined step counts, ensuring repeatability. While ultrasonic sensors for powder level monitoring (mentioned in the abstract) are a recognized method for non-contact measurement, the current code base focuses on the dispensing actuation. Future integration of such sensors would follow the common practice of time-of-flight measurement to track inventory.

2. Thermal Management and Fluid Delivery

Maintaining water at an optimal temperature is critical for beverage quality. The system implements a closed-loop temperature control system:

- Sensor: A DS18B20 digital temperature sensor provides accurate feedback.
- Actuator: A relay-controlled immersion heater.
- Control Logic: A simple but effective hysteresis controller (maintaining temperature between TEMP_LOW and TEMP_HIGH). This avoids the rapid cycling associated with a simple on/off thermostat and is a common, robust solution for such thermal masses.
- Delivery: A timed pump (CUP_PUMP_RELAY) dispenses the hot water. The inclusion of an automated tank refill system (with a separate pump and solenoid valve sequenced in handleTankRefill ()) is an advanced feature that enhances autonomy, addressing a notable operational gap in many machines.

3. Cup Handling and Spatial Manipulation

A multi-axis cartesian slider system, powered by stepper motors, transports the cup between stations (Dispense, Powder, Water, Mix, Delivery). The use of infrared (IR) sensors and limit switches for positional feedback (moveSliderUntilSensor1(), homeSlider ()) is a standard and cost-effective method for achieving semi-closed loop control in linear motion, ensuring the cup is correctly aligned at each stage.

4. Homogenization (Mixing) Mechanism

Achieving a consistent mixture is a known challenge. This system implements a dedicated two-stage mechanical stirring process:

- A linear actuator (DC motor with limit switches) inserts the cup into the mixing station (runMixingMotor2()).
- A separate stirring motor (runMixingMotor1()) operates for a fixed duration. This active mechanical mixing is superior to relying solely on fluid turbulence from water pouring and directly addresses the quality gap of "powder clumping" common in simpler machines.

5. User Interaction and System Interface

The system provides a multi-modal user interface, a significant advancement over single-method control:

- Local Interface: A 4x3 keypad and 20x4 LCD offer direct selection and status feedback (showMenu()).
- Contactless Payment/Access: An MFRC522 RFID reader enables card-based initiation, adding a layer of access control or payment simulation.
- Remote Web Dashboard: The ESP32 hosts a sophisticated, reactive web application providing real-time monitoring (simulated ingredient levels, live temperature/water level via API), manual testing controls, and system logs. This fulfills the modern demand for IoT connectivity and remote management.

System Architecture Diagram:

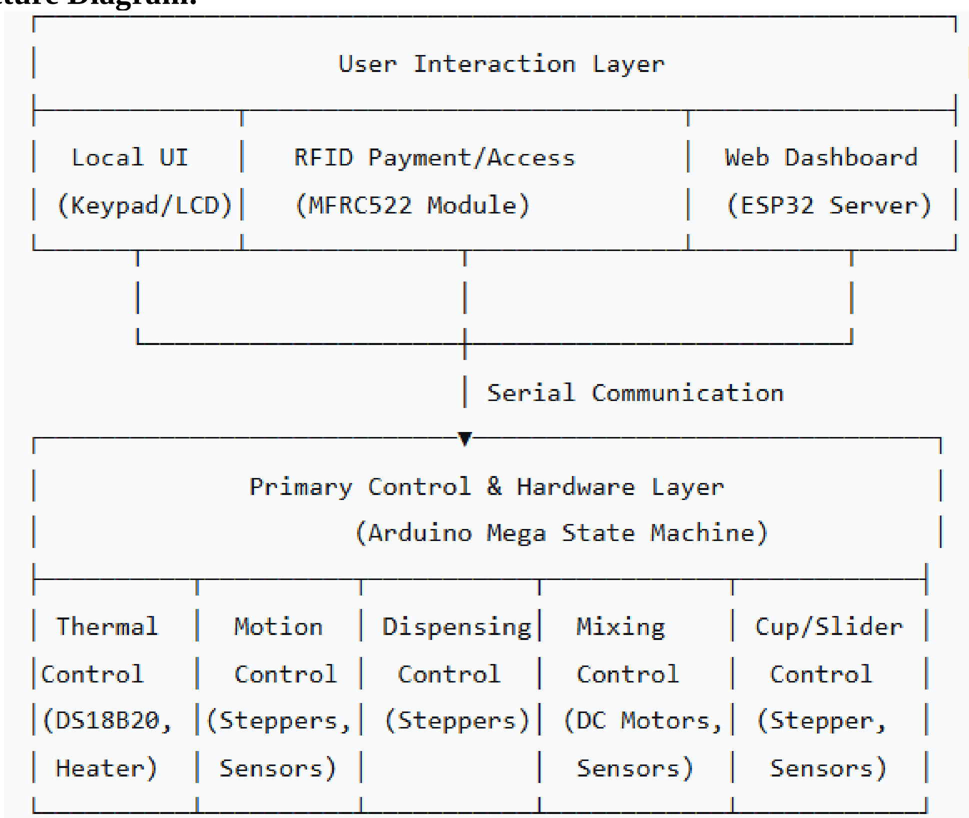


Figure 1:system overview.

3.4 **Identified Gaps and Technical Positioning of the Project**

Based on the analysis of common commercial systems and research prototypes, this project is designed to bridge several specific gaps, as implemented in the provided code check table1:

Table 1: gap

Gap in Conventional Systems	Implementation in This Project	Technical Method / Code Reference
Single control modality	Dual local & remote control	RFID/Keypad (Arduino) + Web UI (ESP32 via /api/command).
No process feedback/assurance	Full sensor-guided state machine	Limit switches, IR sensors guide startSequence(); temp feedback controls heater.
Incomplete automation (e.g., no mixing)	End-to-end automation cycle	Integrated stirring sequence (runMixingSequence()) post water dispensing.
Manual refill monitoring	Automated tank refill system	Timed pump/valve sequence (handleTankRefill()) and water level sensor (ESP32 ultrasonic).
"Black box" operation, no remote diagnostics	Real-time monitoring dashboard	Web API (/api/temperature, /api/waterlevel) feeding live data to GUI.
Lack of maintenance/testing interface	Integrated hardware test suite	Web dashboard buttons trigger diagnostic routines via Arduino commands.

3.5 **Synthesis and Contribution**

This Hot Drink Machine project demonstrates a **practical synthesis of mechatronics, embedded systems design, and IoT principles**. By implementing a distributed control architecture (Arduino+ESP32), a robust state machine for process coordination, and multiple feedback mechanisms, it moves beyond the capabilities of basic vending machines. It explicitly addresses key operational challenges—consistent mixing, temperature stability, water level management, and user access—through integrated hardware solutions and intelligent software control.

The provided code base reveals a system that is not merely conceptual but functionally detailed, covering error handling (sensor disconnect, timeout), safe motor control (enable/disable logic), and multi-stage sequential processes. It stands as a case study in integrating commercial off-the-shelf (COTS) components like stepper drivers, RFID readers, and temperature sensors into a coherent, automated whole, providing a blueprint for similar consumer or light-commercial automated preparation systems.

Chapter 4: Theoretical Background and Previous Work

1. **Theoretical Foundations:**

   The machine's design applies established engineering principles to ensure reliable automation.

- Finite State Machine (FSM) Control: The Arduino implements a finite state machine, a fundamental model for managing sequential processes. The system exists in defined states (MENU, PROCESSING, etc.) and transitions based on inputs (keypress, RFID scan, sensor). This ensures a deterministic, error-resistant workflow for the multi-stage beverage preparation.
- Sensor-Actuator Feedback Loops: The system employs hybrid control schemes. Water temperature is regulated by a hysteresis controller, using the DS18B20 sensor for feedback to toggle the heater within a set band. Motor positioning uses open-loop control with endpoint verification; steppers execute pre-defined steps, while IR sensors and limit switches provide closed-loop confirmation of correct arrival at key positions (e.g., homeSlider ()).
- Networked Systems Architecture: The design follows a distributed control architecture. The Arduino Mega handles real-time, sensor-critical tasks. The ESP32 acts as a networked co-processor, hosting a web server (Wi-Fi AP) and providing a remote GUI. They communicate via a serial (UART) protocol, cleanly separating real-time hardware control from network connectivity and user interface logic.

2. **Analysis Of previous work:**

   This project synthesizes and advances concepts from three key domains: commercial systems, academic research, and DIY maker projects.

   Commercial Vending Machines are robust but closed, using proprietary controllers and often pre-packaged ingredients (pods/syrups), offering limited user interaction and no remote access.

   Academic Prototypes explore advanced concepts like robotic arms or AI but often prioritize novelty over cost-effective reliability, resulting in complex, impractical systems for a fixed, repetitive task.

   DIY/Maker Projects demonstrate accessibility and modularity using platforms like Arduino. However, they frequently offer only partial automation, lack comprehensive sensor feedback, and have monolithic, non-robust code structures.

3. **Project Positioning and innovation:**

   This project fills the gap between these domains. It adopts the reliability focus of commercial machines but implements it with an open, modular architecture using standard microcontrollers. It embraces the innovative spirit of academic work but grounds it in practical, cost-effective mechatronics (e.g., a linear slider versus a robotic arm). It leverages the accessibility and component-level knowledge of the maker community while advancing toward a professional system with robust state-machine code, full sensor integration, and a dual-layer control scheme.

Table 2: Project Positioning and innovation

Aspect	**Commercial Machines**	**Academic Prototypes**	**DIY Projects**	**This Project**
Architecture	Closed, Proprietary	Often Overly Complex	Ad-hoc, Monolithic	**Open, Modular, Dual-Controller**
Control	PLC Logic	Varies, Often PC-based	Simple Scripts	**Finite State Machine with Sensors**
UI/UX	Basic Buttons	Touchscreen/Gestures	Basic LCD/Buttons	**Multi-modal: Local + Web Dashboard**
Key Value	Reliability at Scale	Novelty/Research	Low-Cost Accessibility	**Complete, Practical Automation with IoT**

Chapter 5: Methodology

First of all, let us mention the features one by one to understand how it was done from the beginning.

1. **Centralized Control Using Arduino Mega (Main Controller)**: The hot drinks vending machine is centrally controlled using an Arduino Mega, which acts as the main processing and decision-making unit. The Arduino Mega was selected due to its high number of digital and analog I/O pins, allowing seamless integration of multiple subsystems such as motors, sensors, relays, RFID module, keypad, and LCD display.
   The controller executes a **state-based control algorithm** that manages the entire operation flow, starting from drink selection, payment verification, drink preparation, mixing, and finally system reset. By using a finite state machine (FSM), the system ensures safe transitions between operational states such as menu display, payment waiting, processing, tank refilling, and testing mode. This structured approach improves

2. **User Interaction via LCD Display and Keypad Interface**: The system provides a user-friendly interface using a 20×4 I2C LCD and a 4×3 matrix keypad. The LCD continuously displays system status information such as available drink options, real-time water temperature, payment instructions, and processing feedback. The keypad allows the user to select the desired drink (Coffee, Nescafe, or Cappuccino) in an intuitive manner.

   This interaction layer ensures clarity for the user and reduces operational errors by guiding the user step-by-step through the drink selection and payment process.

Figure 2:user interface

3. **RFID-Based Payment and Authentication System**: To enable secure and contactless payment, the system integrates an MFRC522 RFID module. Each user is required to scan an RFID card after selecting a drink. The Arduino reads the unique identifier (UID) of the card and confirms payment before allowing the drink preparation sequence to start.

   A timeout mechanism is implemented to automatically return the system to the main menu if no valid RFID card is detected within a predefined time window, enhancing usability and preventing system blocking.

Figure 3:RFID SENSOR

4. **Temperature Monitoring and Heater Control System**: The water heating system is monitored using a DS18B20 digital temperature sensor, which provides accurate and stable temperature readings. The Arduino continuously monitors the water temperature and controls the heater through a relay using a hysteresis-based control logic.
   The heater is automatically turned OFF when the temperature exceeds a predefined upper threshold and turned back ON when the temperature drops below a lower threshold. This prevents overheating, improves energy efficiency, and ensures consistent drink quality.

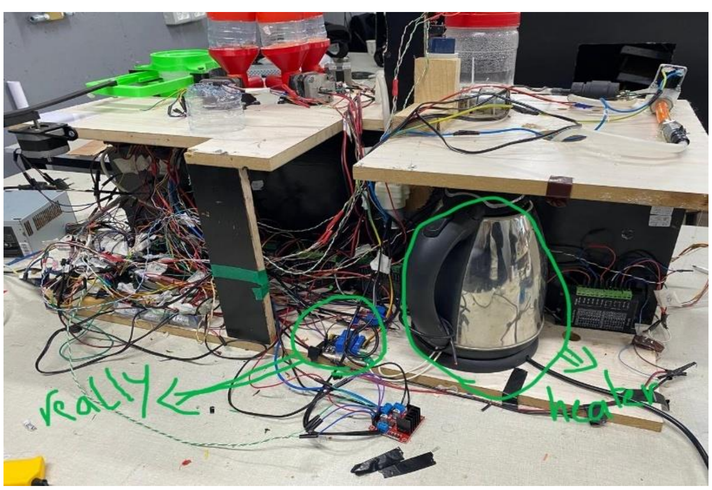


Figure 4:intrernal system wiring

5. **Slider Homing and Position Calibration System:** At system startup and before initiating the drink preparation sequence, the slider motor is activated in the reverse direction until the home limit switch is triggered. This limit switch defines the mechanical zero reference of the slider system. Once the switch is detected, the motor is immediately stopped, and the slider position is considered calibrated.

   After successful homing, the system proceeds to dispense the cup at the correct starting position. This approach ensures that all subsequent movements—such as powder dispensing, water filling, and mixing—are spatially aligned with high precision. The homing routine is fully automated and does not require user intervention, enhancing system reliability and repeatability.

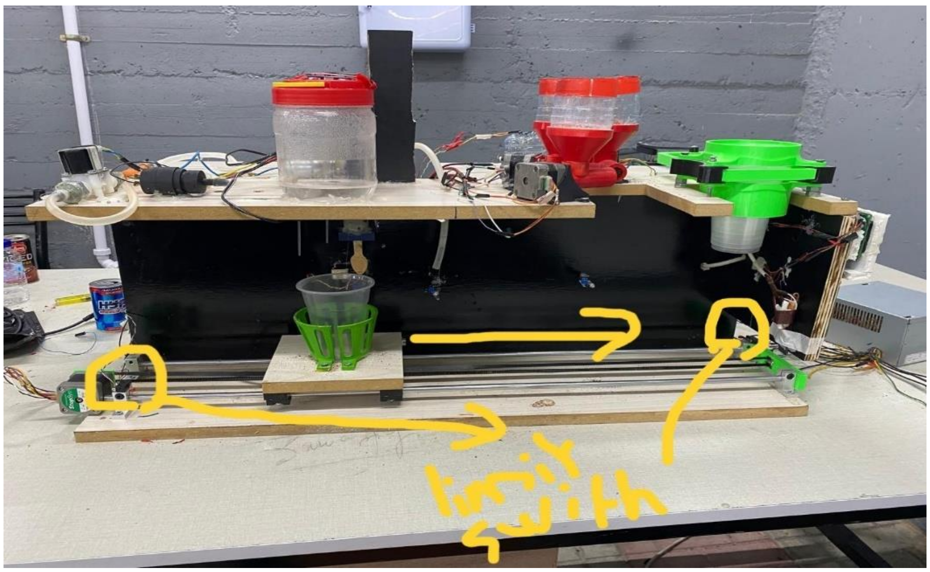


Figure 5: slider at homing stage

Importance

- Prevents cumulative positioning errors
- Ensures mechanical safety
- Improves drink preparation accuracy
- Enables reliable multi-stage automation

6. **Automated Cup Dispensing and Slider Mechanism**: The machine uses multiple stepper motors driven by TB6600 drivers to control cup dispensing and horizontal slider movement. Limit switches and infrared sensors (IR sensor) are employed to accurately detect positions such as home, drink dispensing points, mixing station, and final delivery location.

   This sensor-based positioning system ensures precise alignment of the cup during all stages, minimizes mechanical errors, and enhances repeatability of operations.

Figure 6:dispensing cups

7. **Automated Powder Dispensing System**: Separate stepper motors are assigned for dispensing Coffee, Nescafe, and Cappuccino powder. The amount dispensed is controlled by precise motor stepping and timing, ensuring consistent drink concentration.

   This modular design allows easy calibration and future expansion to additional drink types without altering the core system architecture.

Figure 7:dispensing powdra

8. **Hot Water Delivery Control Using Solenoid Valve**: The system continuously monitors the water temperature inside the heater tank using a digital temperature sensor. When the temperature reaches the safe operating threshold, the heater is disabled, and the system authorizes hot water dispensing.

   During the drink preparation sequence, once the slider reaches the water dispensing position, the solenoid valve is activated via a relay for a predefined duration. This allows a controlled amount of hot water to flow into the cup. If the temperature is below the required level, the valve remains closed, and water dispensing is blocked to prevent serving under-heated drinks.

   This logic ensures both user safety and drink quality by preventing accidental hot water flow or incomplete heating cycles.

9. **Mixing System for Homogeneous Drink Preparation**: The mixing system consists of two DC motors controlled through PWM signals. One motor positions the cup inside the mixing chamber, while the second motor performs the mixing operation for a fixed duration to ensure homogeneous blending of powder and hot water.

   Limit switches are used to verify cup positioning, guaranteeing mechanical safety and consistent mixing quality.

Figure 8: mixing stage

10. **Automatic Water Tank Refill System:** The system includes an automated water tank refill mechanism using a solenoid valve and pump, controlled via timed sequences. This ensures that the heating tank maintains sufficient water levels without manual intervention.
    The refill process is safely sequenced using delays and system states to prevent dry running or overflow conditions.

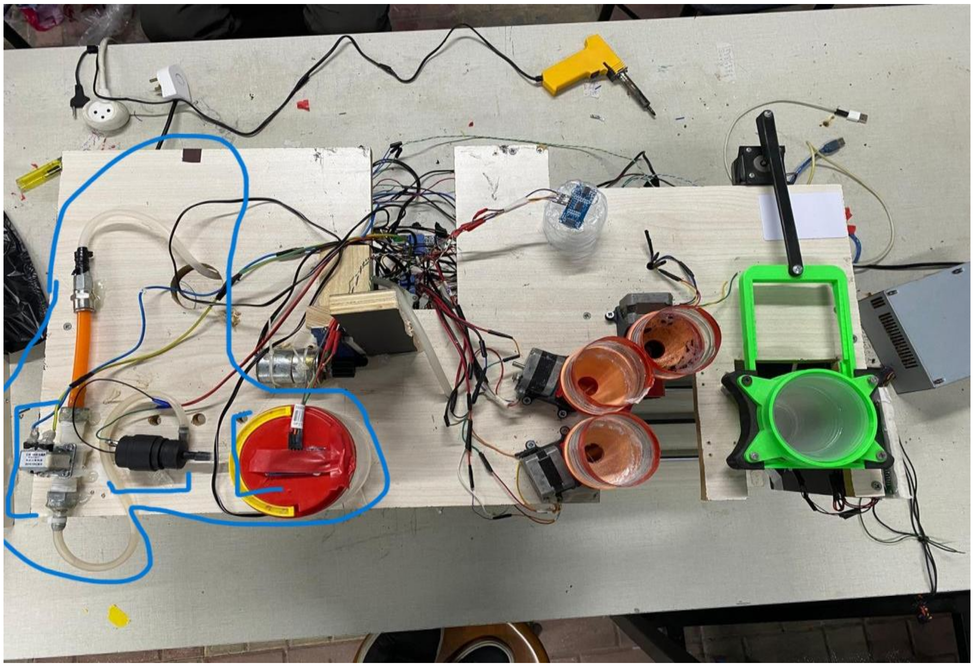


Figure 9: refill tank stage

11. **ESP32-Based Web Dashboard and Remote Monitoring:**An ESP32 microcontroller is integrated to provide wireless monitoring and control via a web-based dashboard. The ESP32 operates as a Wi-Fi access point and hosts a responsive web interface displaying real-time system parameters such as water temperature and tank levels.
    Communication between the Arduino Mega and ESP32 is achieved through UART serial communication, enabling remote testing, diagnostics, and system monitoring without interrupting normal operation.

Login:

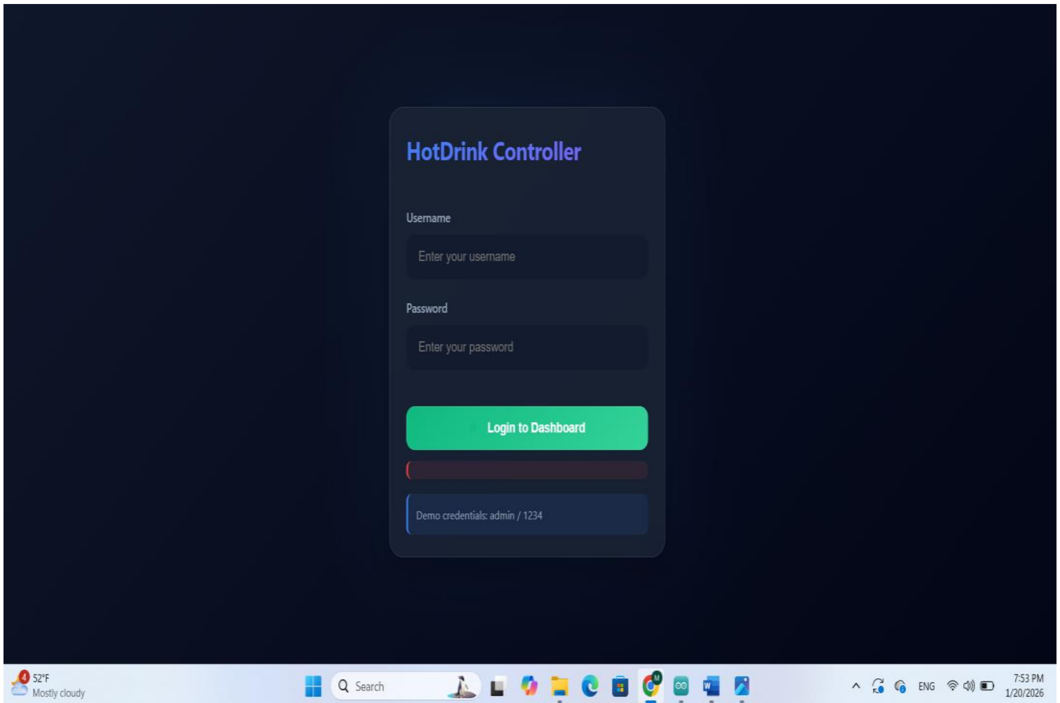


Figure 10: login page

Dashboard:

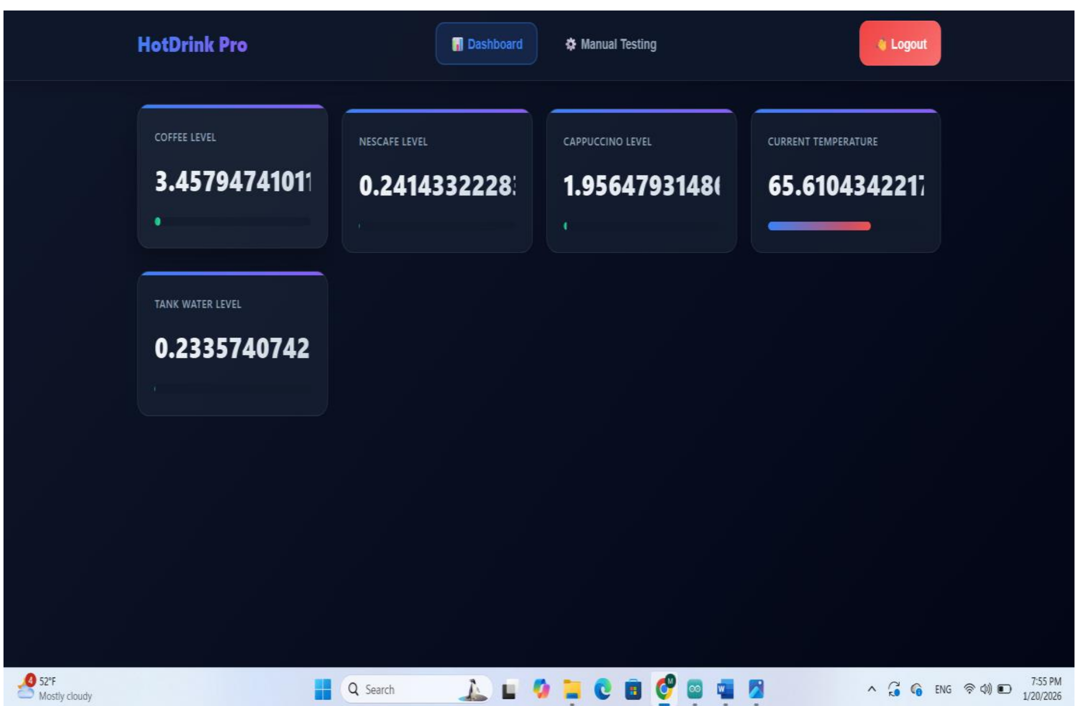


Figure 11: admin dashboard

Testing and Maintenance Mode:A dedicated testing mode is implemented to allow individual subsystem verification, including motors, pumps, mixing system, and dispensing mechanisms. This feature significantly simplifies maintenance, debugging, and calibration during development and future servicing.

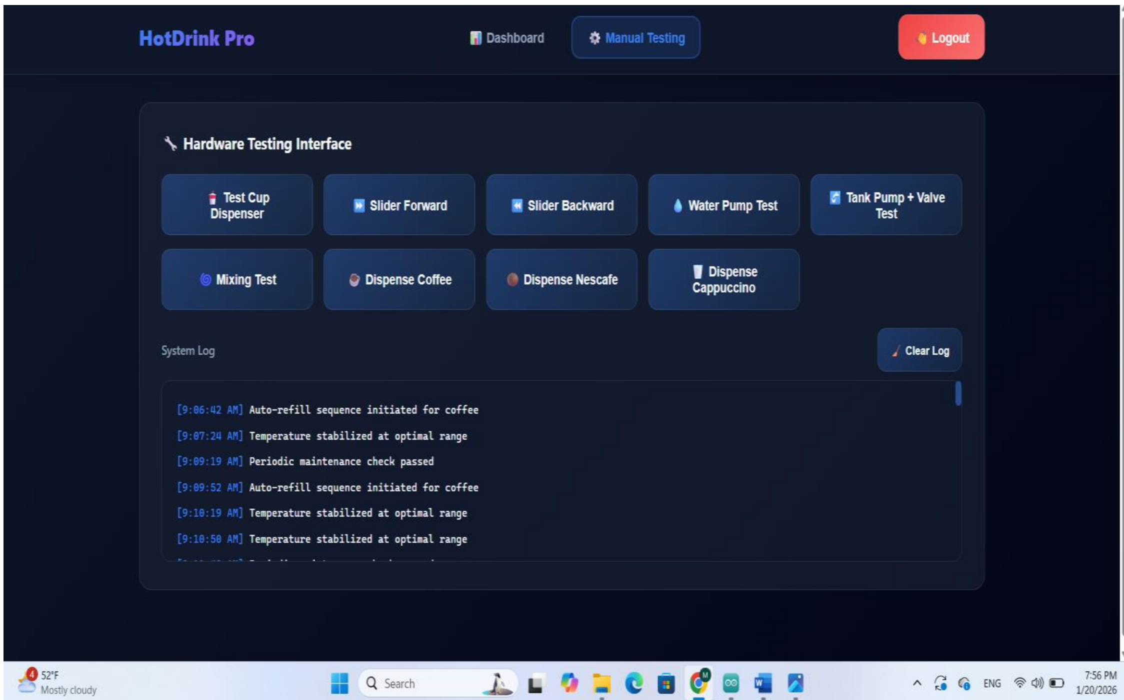


Figure 12: admin testing page

12. **Power**: We have used a power supply source that provides 12V and 5V and separated it as required for each component.

The project was built from the scratch, its outside structure is made of wood which was cut and gathered by our hands, this figures shows an upper and front views of the project:

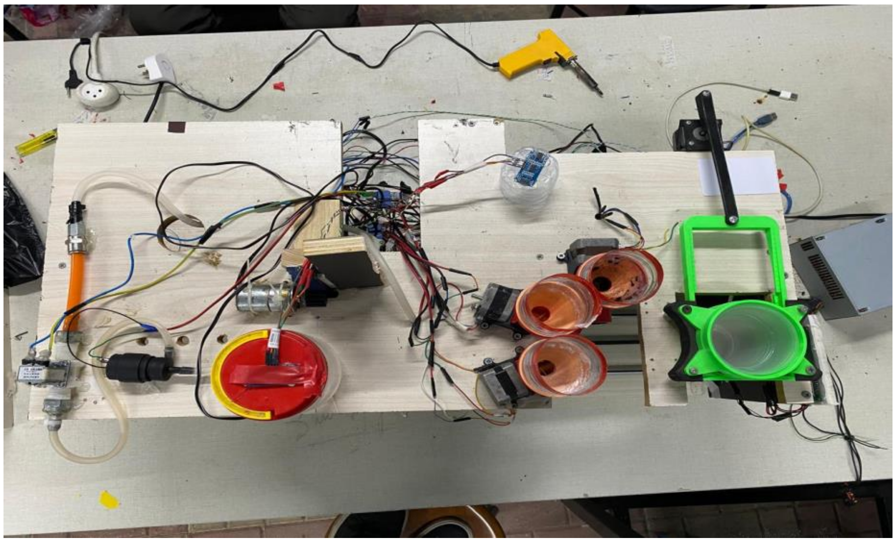


Figure 13: machine from above view

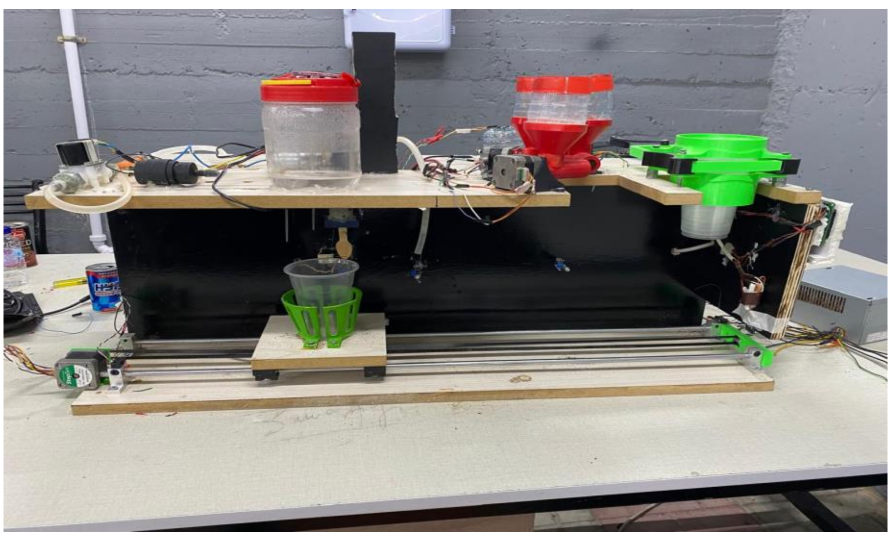


Figure 14: machine from front view

Chapter 6: Tools and Technologies

1. **Microcontroller & Processing**

Arduino Mega 2560

Figure 15:Adruino mega 2560

Definition: The main system microcontroller. It executes the control program, reads all sensors, and operates all actuators.
Requirement: Its high number of digital and analog I/O pins is essential for interfacing with the vast array of sensors, relays, and servos in this project simultaneously.

ESP32 Module

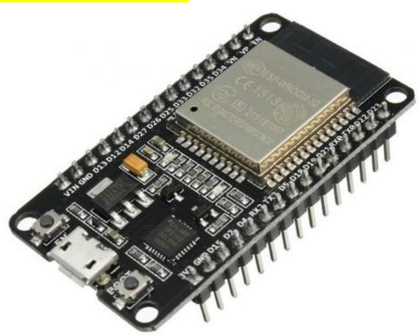


Figure 16: ESP32 DEVKIT v1

Definition: A Wi-Fi and Bluetooth-enabled microcontroller. It receives data from the Arduino Mega via serial communication.
Requirement: It is responsible for connecting the system to the local network and hosting the web server for remote monitoring and control via a website.

2. Sensors

ds18b20(waterproof temperature sensor)

Figure 17:ds18b20 waterproof temperature sensor

Definition: Digital sensor that provides temperature. Witch is placed inside the header

Requirement: to measure the current water heating degree.

HC-SR04 Ultrasonic Sensor (x4)

Figure 18: HC-SR04 Ultrasonic Sensor

Definition: Measures distance by emitting ultrasonic waves and calculating the time for the echo to return.

Requirement: four are used to measure drink powder levels in three powder containers and one for water tank level.

IR (Infrared) sensor

Figure 19:IR Infrared sensor

Definition: detects infrared (IR) radiation, a form of light invisible to humans, emitted by all objects as heat.
Requirement: We used four IR sensor to detect the current stage of the FSM in beverages preparing sequence.

Limit switch (4x):

Definition: an electromechanical device that uses an actuator to detect the physical presence, absence, or position of an object and convert that mechanical motion into an electrical signal

Used for stop the slider at home position and end also for the mixing arm

Figure 20: limit switch

rfid rc522 sensor

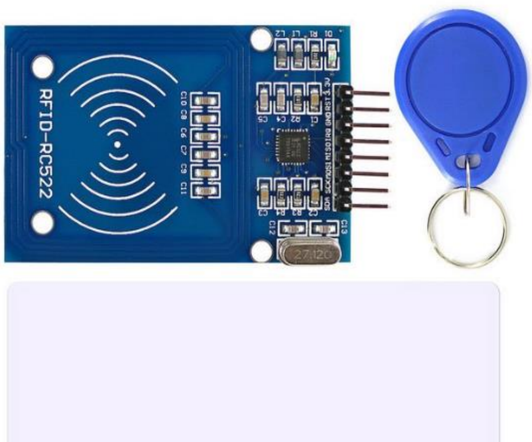


Figure 21: RFID-RC522

Definition: a popular, low-cost reader/writer that operates at **13.56 MHz** and is widely used in hobbyist electronics projects like access control systems
Requirement: simulate the real payment feature in the machine

3. Actuators & Output Devices

Stepper motor + TB6600 driver(3.5Am) (x5)

Figure 22: stepper motor

Figure 23:TB6600 driver

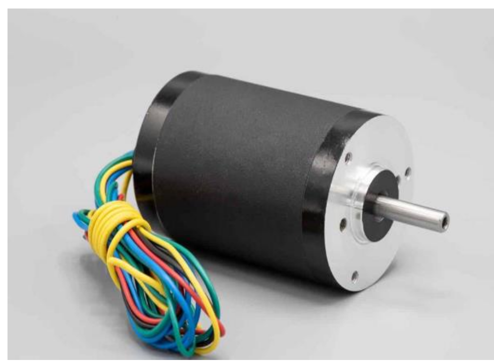
Definition: widely used stepper motor known for its balance of compact size and

reliable torque rotate full 360 degree clockwise and counter clockwise,
Requirement: Used five motor the first one is for control the cup dispenser by rotating 360 degree to dispense a cup, three for control the drink powder and dispense them in the cup and the last one for the slider movement between stages.

DC motor(2x) + H-bridge

Definition: an electrical machine that **converts electrical energy from direct current into mechanical energy** (rotational motion) using electromagnetic principles.

Requirement: for mixing stage control the arm and the Stirring hand

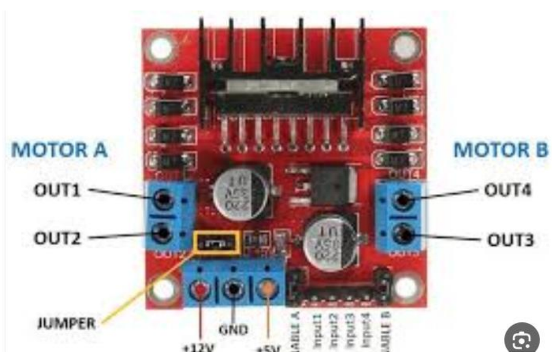


Figure 24: h-bridge

5V Relay Module (x4)

Figure 25: tow channel relay

Definition: An electrically operated switch. It allows a low-voltage Arduino to control a high-voltage/high-current circuit.
Requirement: Essential for safely turning on/off high-power equipment like water pumps, heater, valve.

16x4 I2C LCD Display with I2C

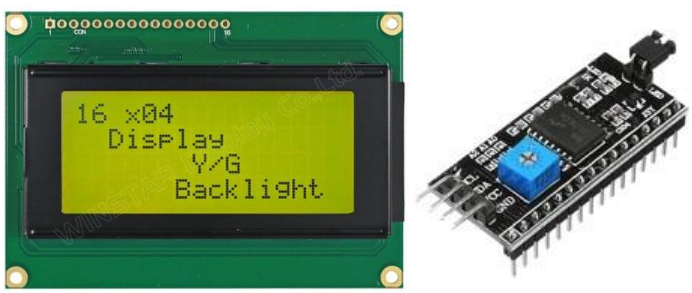


Figure 26: LCD dipaly with I2C

Definition: A liquid crystal display with 4 rows of 16 characters each. It uses an I2C interface to minimize wiring.
Requirement: Provides the primary local user interface for displaying sensor readings, system status, menus, and warnings without needing a computer.

12V DC Water Pump

Definition: A submersible or inline electromechanical device that uses a small DC motor to impel water through a system.

Figure 27: PUMP1

Requirement: for refill the heater from a water tank when take a drink to keep the heater full of hot water

Figure 28: PUMP2

Requirement: for pull the hot water from the heater to the cup.

12V one direction valve:

Figure 29:one direction valve

Definition: are low-voltage flow control devices, commonly found as **solenoid valves** or **motorized ball valves**, used in automotive, irrigation, and safety systems.

Description: control the flow of water from tank to heater.

4x4 Matrix Membrane Keypad

Figure 30: lcd

Definition: A keypad with 16 buttons arranged in a grid, requiring only 8 digital pins to read.

Requirement: Allows for user input to navigate menus, enter passwords, change settings, and trigger manual operations directly on the system.

4. **Power & Connectivity**

12V, 5V Power Supply &

Figure 31: power source

Definition: A power adapter provides 12V to the system, which is then stepped down to 5V for the Arduino and most components.

Requirement: Provides stable and sufficient power to the entire system.

Chapter 7: Evaluation and Analysis

The Hot Drinks Machine was successfully built and tested under Key outcomes include:

1. **Homing Slider:** ensures the system always starts from a known reference position and use limit switches to perform this.

2. **Hot Water always:** provides precise control of hot water delivery.

3. **Sequential operation:** improves overall system accuracy.

4. **Independent control (manual testing) and dashboard:** increases operational safety and easy to debug stages, Real-time alerts and full remote control via mobile/web interface improved usability.

5. **Modular design:** allows future system expansion.

Overall, the system met its objectives, though limitations include sensor accuracy (~90%) and relatively high energy consumption.

Chapter 8: Discussion

This project demonstrates the successful integration of **mechanical motion control, fluid control, and embedded system logic** into a single automated system. By combining sensors, actuators, and microcontroller-based control, the system achieves reliable and repeatable operation suitable for practical applications.

The **sequencing of operations**—homing, positioning, hot water dispensing, and mixing—ensures that mechanical and fluid actions do not interfere with each other. Proper sequencing minimizes mechanical stress, prevents mis operation, and improves overall system efficiency.

From a system design perspective, the **modular architecture** of the project enhances scalability and maintainability. Each subsystem (motion control, valve control, sensing, and user interaction) can be modified or expanded independently, making the design suitable for future upgrades.

Overall, the project reflects sound embedded system design principles by emphasizing accuracy, safety, and expandability. The integration strategy and control logic align with widely accepted engineering practices, demonstrating the system's potential for real-world automation applications.

Chapter 9: Conclusions and Recommendation

9.1 Conclusion:

To conclude what we have accomplished, this project successfully achieved the design and implementation of an automated embedded system that integrates motion control, fluid control, and sensor-based decision making. The use of a homing slider mechanism ensured accurate and repeatable positioning, while controlled hot water delivery through a dedicated solenoid valve improved process precision and safety. Proper sequencing and timing of system operations resulted in stable and reliable performance across multiple operating cycles. Overall, the project demonstrates effective application of embedded system design principles and provides a solid foundation for practical automation solutions.

All in all, we have taken advantage of our major to convert electricity into a modern system and used programming techniques to convert it to a smart system, we have done what we have prepared and planned to do using all time and resources we could use.

9.2 Recommendations:

Based on the outcomes and challenges encountered, the following recommendations are proposed:

- Implement non-blocking timing techniques to further improve system responsiveness.
- Use industrial-grade limit switches to increase mechanical reliability.
- Add flow sensors to improve water volume accuracy.
- Improve electrical isolation between control and power circuits.
- Enhance documentation for easier system maintenance and troubleshooting.

9.3 Future Work:

- Expand the system to support additional drink types or processes.
- Add more than one cup size.
- Integrate a real payment method.
- Add a sensor in the final stage to detect that the cup in removed from the cup holder.

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