Hardware Project: Intelligent Coffee Machine

Osamah Abdullah
Ibrahim Asad

September 2025

Computer Engineering Department

Hardware Graduate Project

Coffee Machine

Students:
Osamah Abdullah
Ibrahim Asad

Supervisor:
Dr. Saed Tarapiah

Acknowledgment

I would like to extend my heartfelt gratitude to everyone who supported and contributed to the development of the Coffee Machine. Special thanks to our academic advisor for invaluable guidance and feedback throughout this project. We are also deeply grateful to our families and friends for their unwavering support and encouragement. Additionally, we appreciate the open-source community and the developers behind the libraries and tools that made this project possible.

Abstract

Coffee Machine is an intelligent, fully automatic coffee machine designed primarily for use in workplaces and institutions. The machine aims to simplify and automate the coffee-making process while maintaining hygiene and consistency. A user initiates a brew via a push button (or companion mobile app). The controller then draws a measured volume of water from an internal tank, heats it to the target temperature, dispenses a measured dose of pre-ground coffee into a reusable filter, automatically places a paper cup, and brews the drink. After dispensing, an automated cleaning cycle uses a small mechanical arm with a water sprayer to remove spent grounds into an internal waste bin, preparing the system for the next user.

Contents

List of Figures

1 Introduction

The Coffee Machine hardware project is an intelligent automated system designed to prepare and serve coffee beverages through a streamlined process. Users activate the machine using a push button or a mobile application to confirm an order. The system draws the required amount of water from the internal tank and heats it using a dedicated heating element. Simultaneously, a measured portion of pre-ground coffee is dispensed into a reusable filter. A mechanical dispensing system automatically places a paper cup beneath the filter and the brewed coffee is poured into the cup. Once serving is complete, the machine initiates a self-cleaning cycle in which a compact arm with a water sprayer removes used coffee grounds and disposes of them in an internal waste bin, ensuring the machine is ready for the next use.

2 Constraints & Limitations

1) Limited time and logistics for sourcing certain mechanical and 3D-printed parts.
2) Selecting simple, reliable mechanisms for each stage to keep costs and complexity low.

3 Literature Review

3.1 Automated Coffee Dispensing Systems

Automated machines for hot beverages are widely used in offices and institutional environments to maximize consistency, speed, and hygiene. Prior work emphasizes microcontroller-based control, flow sensing, and heating regulation to standardize quality while minimizing human error. User interfaces range from push buttons to mobile applications for personalization and accessibility.

3.2 Heating and Brewing Mechanisms

Thermoblocks and boiler elements are commonly used to rapidly achieve and stabilize brewing temperature. Research explores optimal water-to-coffee ratios, pressure/flow control, and timing to improve extraction. Increasingly, reusable filters and pre-dosed dispensing units are used to ensure uniformity and reduce waste.

3.3 Cup Dispensing and Waste Management

Reliable cup-dispensing mechanisms minimize jams and support multiple cup sizes. Waste streams (spent grounds, rinse water) are routed to internal containers to reduce manual intervention and maintain hygiene.

3.4 Self-Cleaning and Maintenance Automation

Self-cleaning cycles using directed water jets and mechanical wiping improve food safety and reduce maintenance. Scheduled cleaning extends component lifespan and improves user satisfaction thanks to consistently clean brewing paths.

4 Methodology

This chapter describes the end-to-end approach for designing and implementing the Coffee Machine, from requirements definition to validation and testing. The process was iterative and modular to reduce risk and allow parallel development of mechanical and electronic subsystems.

4.1 Requirements Analysis

- **Functional**: draw and heat water, dispense coffee dose, place cup, brew, and perform automatic cleaning; optional mobile control.
- **Performance**: brew cycle target 1:47 min per cup; water temperature 88 °C to 96 °C; dosing repeatability ±5%.
- **Usability**: single-button start, clear status indicators on LCD, minimal user steps.

4.2 System Architecture

Figure 1 shows the high-level architecture: a microcontroller coordinates sensors (cup presence, temperature, flow) and actuators (pump, heater, servos/gear motors) to execute a deterministic brew state machine.

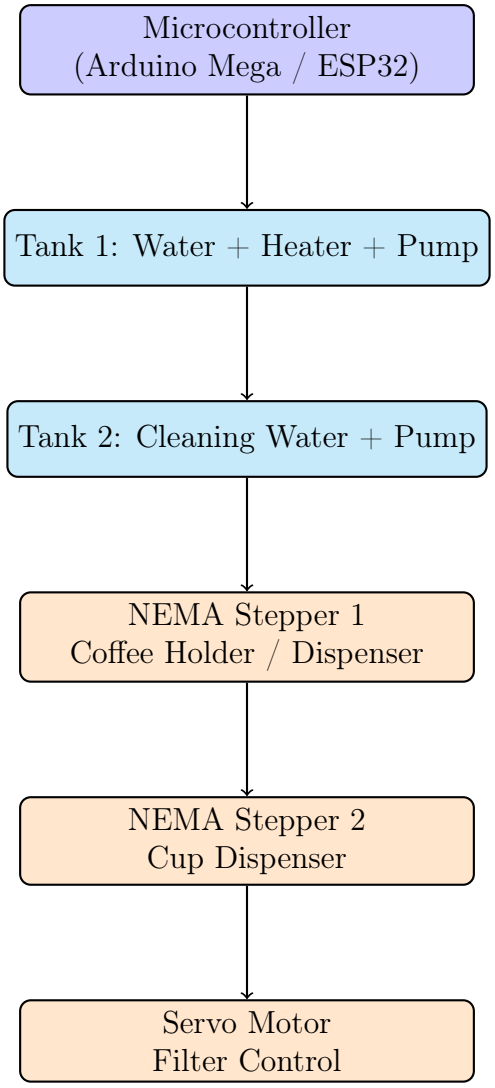

Figure 1: Vertical block diagram of the Coffee Machine showing controller, tanks with pumps, and actuators.

4.3 Hardware Modules

4.3.1 Controller (Arduino Mega 2560 or ESP32)

Provides sufficient I/O for multiple sensors/actuators and supports serial diagnostics.

4.3.2 Water Path: Pump, Flow Sensor, Heating Element

A 5 V or 12 V food-safe pump moves water from the tank through a flow sensor for metering. A heating element (thermoblock/boiler) brings water to target temperature. A thermistor/thermocouple feeds back temperature for PID control.

4.3.3 Coffee Dosing Mechanism

A geared DC motor or stepper drives a dispenser to deliver a repeatable mass of pre-ground coffee into a reusable filter. An optional load cell can close the loop on dose mass.

4.3.4 Cup Dispenser

A servo-driven gate or spiral mechanism advances a single paper cup into position.

4.3.5 Self-Cleaning Module

A miniature arm with spray nozzle rinses the filter, and a wiper guides spent grounds to a sealed bin. A drain line collects rinse water.

4.4 Electronics and Power

- **Motor Drivers**: L298N (for DC/gear motors) and dedicated drivers for servos/steppers.
- **Relays/MOSFETs**: switching of heater and pump with flyback protection.
- **Power**: 12 V 6 A supply for motors/heater and regulated 5 V rail for logic and sensors.

4.5 Control Software

State Machine The firmware implements a deterministic state machine: `IDLE` → `PREHEAT` → `CUP_CHECK` → `DOSE` → `BREW` → `CLEAN` → `READY`. Transitions are guarded by sensor confirmations and timeouts.

Sensing and Control PID temperature regulation, debounced digital inputs for IR sensors, pulse measurement for flow sensor (mL via pulses), and safety interlocks. The UI (push button and 16x2 LCD) shows status and error codes.

4.6 Bill of Materials (excerpt)

Component	Model/Spec	Qty	Notes
Controller	Arduino Mega 2560 / ESP32	1	Main MCU
Pump	5–12 V food-safe	3	–
Heater	Thermoblock/Boiler	1	With thermal fuse

L298N Driver	Dual H-bridge	2	For gear/DC motors
Stepper Motor	NEMA 17	2	Cup gate / arm
Servo Gear Motor	High torque	1	Doser / wiper
16x4 LCD	I2C preferred	1	Status UI
Power Supply	12,5,3.3 V, 500 W	1	Shared power

5 Tools and Technologies

5.1 Arduino Mega 2560

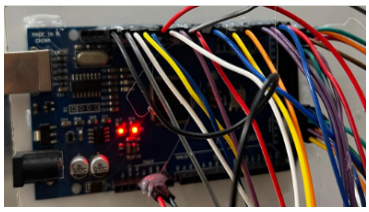

Figure 2: Arduino Mega 2560

At the core of the project is the Arduino Mega, providing abundant I/O (54 digital, 16 analog) and 256 KB flash. Development was done in the Arduino IDE, enabling rapid iteration and serial diagnostics.

5.2 Power Supply

Figure 3: 12,5,3.3 V, 500 W Power Supply

A 12 V, 6 A supply powers motors and the heater; a regulated 5 V rail feeds logic and sensors.

5.3 L298N Motor Driver

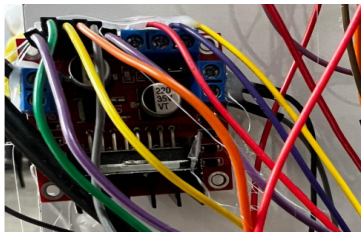

Figure 4: L298N Motor Driver

The L298N dual H-bridge drives DC/gear motors with bidirectional control and PWM speed modulation.

5.4 Servo Gear Motors

Figure 5: DC Gear Motors

Geared DC motors provide high torque at low speed for dosing and mechanism actuation.

5.5 Water Pump and Flow Sensor

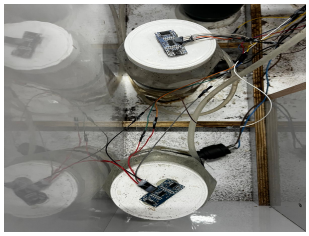

Figure 6: 5V Water Pump and Hall Flow Sensor

A compact pump moves water; a hall-effect flow sensor outputs pulses proportional to volumetric flow, enabling accurate dosing.

5.6 Cup Dispenser

Figure 7: Cup Dispenser Mechanism

The cup dispenser is driven by a NEMA stepper motor that reliably releases one paper cup at a time. This ensures accurate and jam-free cup placement during each brewing cycle.

5.7 Coffee Dispenser

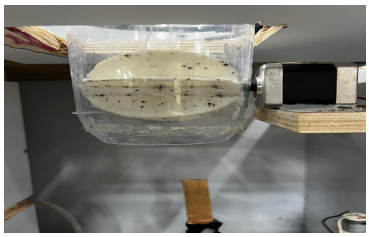

Figure 8: Coffee Dispenser with Stepper Motor

The coffee dispenser uses a stepper motor mechanism to release a measured dose of pre-ground coffee into the filter. This guarantees repeatability and consistency for every cup brewed.

5.8 Ultrasonic Sensor (for Tank Monitoring)

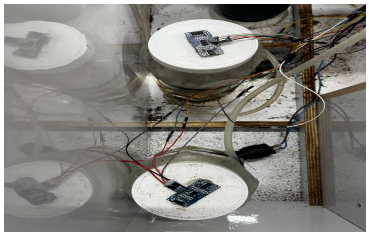

Figure 9: Ultrasonic Sensor HC-SR04

An ultrasonic sensor (e.g., HC-SR04) is placed at the top of the tanks to monitor water levels. This ensures that the heater tank and cleaning tank always have sufficient water, and prevents the heater from running dry.

5.9 Relay

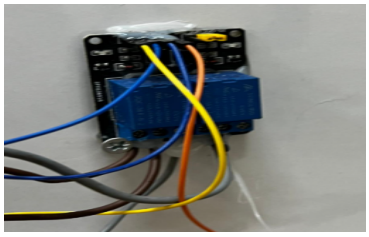

Figure 10: two-Channel Relay

A relay or MOSFET module safely switches higher-current loads such as the heater and pump, with proper isolation and flyback protection.

6 Project Operation

6.1 Brew Sequence

1) **Start**: user presses the start button.
2) **Preheat**: heater ramps to setpoin.
3) **Cup Placement**: cup dispenser advances one cup.
4) **Dosing**: coffee dispenser delivers the configured dose to the filter.
5) **Brew**: pump deliver the target.
6) **Dispense**: coffee flows into the cup.
7) **Clean**: spray/wipe removes grounds to waste; rinse line drains.
8) **Ready**: machine returns to `IDLE` state.

7 Results

During testing, the prototype consistently brewed single cups within the 100–110 s window. Flow calibration reduced volumetric error to under 5% and temperature was maintained within the 90(2) °C range at the brew head. The self-cleaning cycle removed visible residues and prepared the filter for subsequent use without manual intervention.

8 Conclusion

The Coffee Machine demonstrates how mechanical, electronic, and embedded software components can integrate into a hygienic, fully automated brewing system. Accurate dosing, reliable cup handling, temperature control, and automated cleaning were achieved with off-the-shelf components controlled by Arduino Mega (or ESP32). Future enhancements include stronger UI customization (cup size, strength), improved energy efficiency, and deeper app integration.

9 Future Work

1) Multi-size cups with automatic detection and adaptive dosing.
2) Smart sugar/milk dispensing modules for personalization.
3) Wireless/mobile application control with telemetry and maintenance alerts.
4) Load-cell feedback for precise coffee mass dosing.
5) Modular waste management with fill-level sensing.

10 References

1. Arduino. "Arduino Mega 2560." https://www.arduino.cc/ (accessed September 2025).
2. Instructables. "Coffee/Drink Machine Builds." https://www.instructables.com/.
3. YouTube. "Embedded Systems Coffee Machine Prototypes." https://www.youtube.com/.
4. ChatGPT (for drafting/structuring technical text).