ZJU-UIUC Institute

ECE 445 / ME470

SENIOR DESIGN LABORATORY

DESIGN DOCUMENET V1

Intelligent Pour-over Coffee Machine

Team #15

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1 Introduction

Dating back to the early 20th century, the art of pour-over coffee has evolved from Melitta Bentz's simple paper filter to a globally handy craft tide [1]. Although this brewing method is highly praised for the complex flavor and creative experience, it is hard to maintain consistent quality for the public.

Modern consumers demand coffee that is not only good, but also convenient to drink [2]. This project proposes an **intelligent pour-over coffee machine** that employs pre-trained imitation learning algorithms. Our design aims to blend the hand-made art of pour-over with the precision of automation, contributing to the dynamic and expanding coffee machine market [3].

Keywords: pour-over coffee, automated brewing, coffee machine, sensory experience, market opportunity

2 Problem and Solution Overview

2.1 Problem

The art of pour-over coffee brewing, famous for its complex flavor and high quality, is heavily dependent on the skills and experience of a barista. This craftsmanship leads to variability in coffee quality due to human element. Additionally, it is challenging for **common coffee enthusiasts** to replicate professional barista techniques *at home or in non-specialized settings,* particularly in areas where specialty coffee culture is less developed.

2.2 Solution

Imagine a coffee machine that automates the process of pouring water. It can customize each cup according to **the type of coffee bean and the desired flavor**. With the bean grounded and filter in place, the user can start the process with the press of a simple button, after which the machine dynamically adjusts its operations to create a delightful cup of coffee.

This machine should deliver sensory pleasure and the similar taste of hand-poured coffee, while saving time and effort. This machine is designed to mimic the skills of the master and conveniently deliver high quality in-place coffee. Below is a concept diagram of our system, showing the preliminary mechanical design and the feasibility of various details, with special attention to the **brewing** and **control subsystems**.

2.3 User Study

Insights from Professional Coffee Barista

Jie Wang interviewed a series of professional coffee barista in China. Including *MAXPRESSO Coffee*(Suzhou), *Intro Coffee*(Shenzhen), *CoffeeTable&GIF*(Shenzhen) and *Starbucks*(Everywhere) etc. We focused on what is the variance in bean density and its impact on the coffee grind quality. **Specially, *MAXPRESSO* highlighted the importance of customizing the brewing process based on the grind consistency, particularly for beans with different densities**. He donated an Intelligence Pour-Over Coffee Machine to us, the ***Gemilai CRM 4106.*** Under his permission, we did inverse engineering on the machine, disassembled it and

Smart Temperature Profiling

Questions were raised regarding the linear relationship between water temperature and the depth of the roast. This led to discussions on the necessity for the machine to intelligently adjust water temperature rather than simply following a static profile.

Objective of the User Study

The aim of the user study is to validate the intelligent brewing capabilities of the coffee machine. The study will assess:

- The machine's ability to adjust for different bean densities and grind consistencies.

- The effectiveness of the smart temperature control in enhancing the flavor profile of the coffee, particularly for deep-roasted beans.

Criteria for Evaluation

Incorporating the Coffee Ted Lingle Flavor Wheel, we will establish an 'output criterion' for flavor evaluation. This criterion will serve as a professional and persuasive tool in assessing the machine's performance. Sources such as the SCAA flavor wheel and expert videos will be referenced to provide a comprehensive background for our flavor profiling methods [4][5].

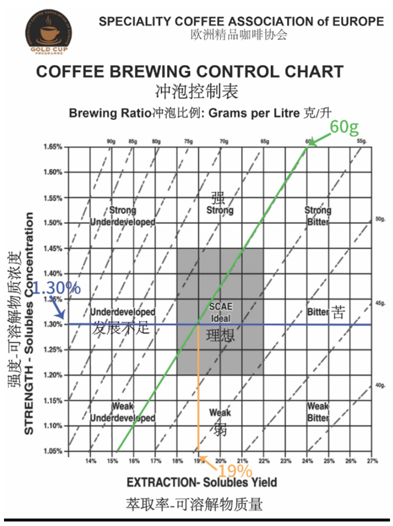

Figure 1: Chemistry Behind Coffee Brewing

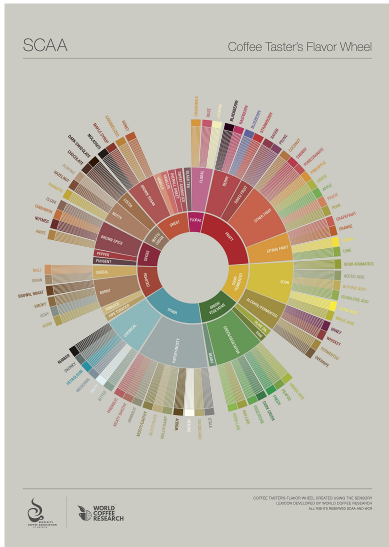

Figure 2: Ted Lingle Flavor Wheel

User Interaction and Feedback

After finishing the senior design, we plan to invite the schoolmates to try our machine, providing feedback on its usability and the quality of the coffee produced. We will evaluate if the machine meets the convenience of automated systems with integrated scales. [6]. This part will strictly follow the **Ethics and Safety** section.

2.4 Visual Aid

2.4.1 Physical Design Diagram

The physical design diagram of our design is shown in Fig 3. As the figure indicates, it consists of several key components and subsystems, each serving a specific function in the brewing process, here I offer an outlined introduction of the system and a more detailed description will be expanded in section 2.2.

First is the Coffee Bean Weighing module, here a piezoresistor placed beneath the coffee bean filter detects the weight of the coffee beans as they're poured into the filter. This weight serves as input for the system's controller, which calculates optimal brewing conditions such as temperature, radius, and waiting time. Then a Cold Reservoir holds the water before it's pumped into the heating system. Once the program is runned, the cold water pump will pump water up into the Heating System, the procedure is controlled by an Arduino or STEM 32-based breadboard. The heating system consists of a container made from thermal insulation material to withstand high temperatures. A heating block, controlled by the STEM 32, heats the water to the desired temperature. Once heated, the water is pumped to a hot water slider. A water rectifier ensures proper velocity at the slider's outlet. The slider, controlled by electromagnetic relays and a reset spring, delivers hot water into three interlayers of the brewing nozzle to achieve different brewing radii.The brewing nozzle has three outlets for different brewing radii. Hot water from the slider is delivered to the nozzle via an intricate spur gear set,

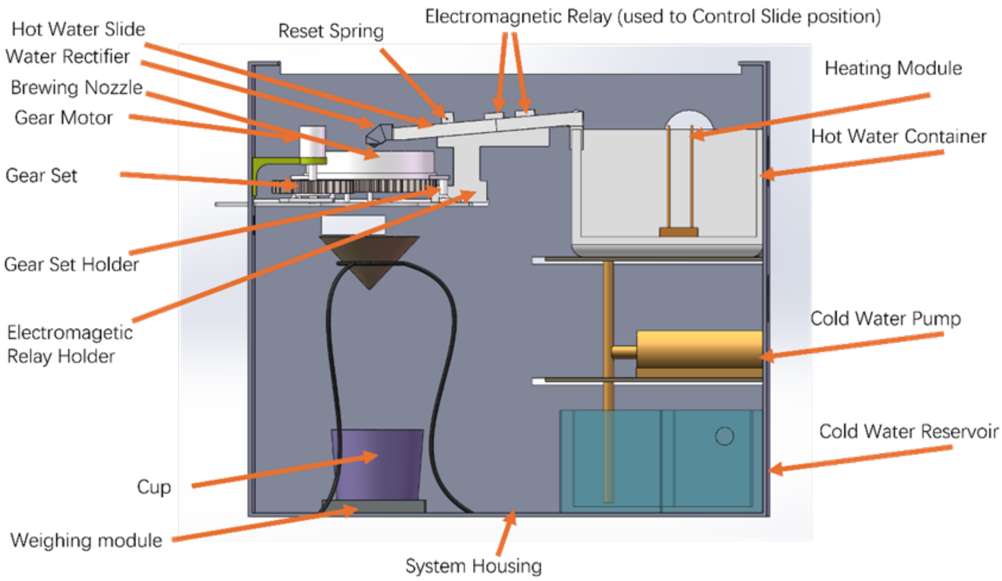

Figure 3: Physical Design of the Coffee Machine

ensuring precise control over the brewing process. Finally, the hot water from the brewing outlet reaches the coffee bean filter, where it brews the coffee. The brewed coffee is collected in a cup, ready to be enjoyed.

2.4.2 FSM Diagram

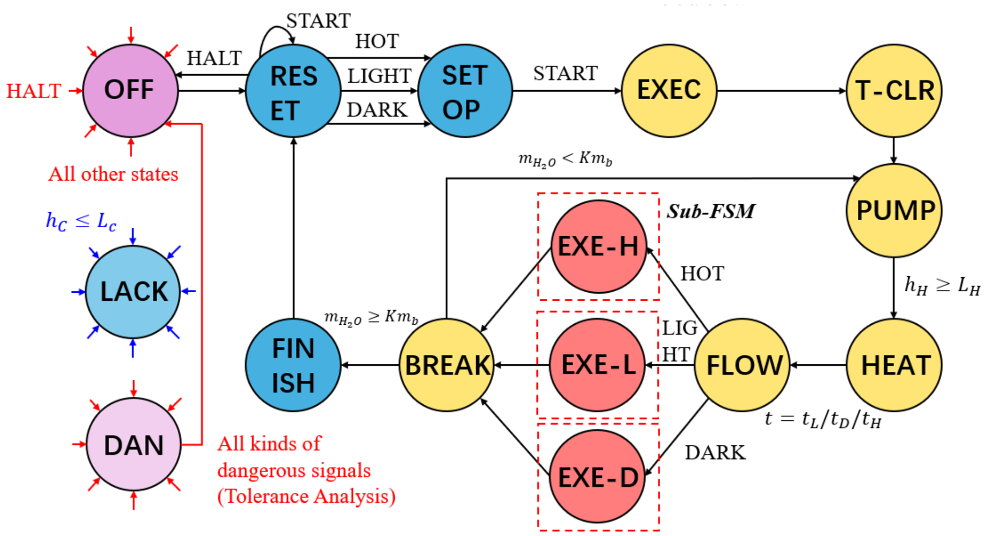

Figure 4: Finite State Machine Diagram.

We are figuring out a simple way to describe the control logic of this coffee machine. [7] provided a finite state machine (FSM) paradigm that abstracts the story of how a laundry machine washes clothes well. FSMs are also abstracts for other control systems, like cooking machines [8], robots [9], and vending machines [10]. In this project, we tried to use FSM to describe our coffee machine.

As shown in Figure 4, the FSM includes the states of setup, brewing, heating, and pumping, and set the execution order according to different input commands.

FSM Summary. The FSM describes the entire coffee brewing process. After setting the brewing method, the coffee machine starts by moving water from the cold tank to the hot tank. Once the hot water tank is fully filled, the heating element kicks in, heating the water to about 95 degrees Celsius. At this point, water is distributed through the hot water outlet. Depending on the chosen brewing method, the machine then activates a gear motor to perform a specific movement, such as a direct or rotating drop mode. If the weight sensor shows that the coffee concentration meets the set standard, the brewing cycle ends, and further water addition is stopped. If not, the process is repeated for another cycle. A more detailed explanation of FSM is provided in section 2.3.

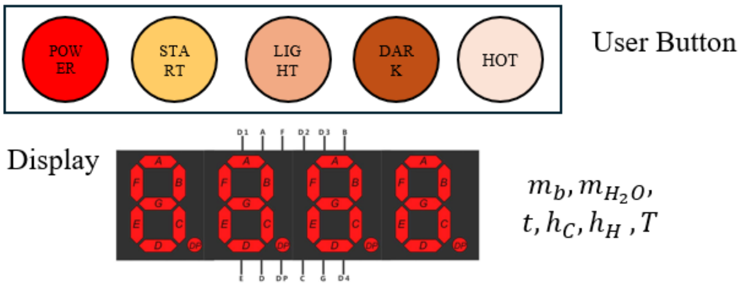

Figure 5: Coffee Machine Dashboard.

Dashboard. As shown in Figure 5, we designed 5 buttons on the console for the user's convenience. We also used LED digital tubes to display physical quantities such as water temperature, time, water weight, water height, and so on. The user interface has five buttons, indicating that five signals can be sent.

POWER stands for power and can be pressed to switch the coffee machine on or off. In the event of an emergency situation with the coffee maker (power short circuit, system damage, water temperature malfunction, etc.), the POWER button can be pressed to switch off the power in an emergency. START stands for start, press it to let the coffee maker brew coffee according to the programme. It is necessary to have the coffee maker record the type of brewing (light coffee, espresso, hot water cleaning) before pressing START. LIGHT stands for Light Roasted Coffee, this type of brewing simulates the process of a human hand brewing light roasted coffee. DARK stands for Dark Roasted Coffee. This brew type simulates the process of human hand brewing dark roasted coffee. HOT stands for Hot Water Cleaning. This brewing type uses only hot water to clean the pumping system, arm, nozzle, and wash.

Motor Movement. The nozzle dispenses water using both straight and rotary drip, alternating between the two. The timing of the drip is also very delicate. We hardcore the nozzle control code for the different brewing modes into the circuit chip of the control system during the coffee machine's production. Figure 13 in 3.3.3 illustrates an example for the movement.

2.5 High-level Requirements List

- **Precision and Consistency:** The machine should replicate the pour-over skill of human. It should precisely control water temperature, water-bean ratio and flow.
- **Affordability and Accessibility:** The product should offer a more cost-effective solution than existing commercial product without sacrificing flexibility and quality.
- **Easy User Experience:** The design should be intuitive, easy to use for the specialty coffee beginner.
- **Durability and Maintenance:** The machine should be built to last, requiring minimal maintenance while operating efficiently.
- **Quality of Brew:** The coffee produced must be consistently high in quality, with taste tests confirming its superiority or equivalence to manually brewed pour-over coffee.
- **Coffee Roast Degree Difference**: The machine should be able to distinguish light roast and dark roast coffee, taking different brewing strategy on them.

3 System Design

3.1 Block Diagram

Figure 6 shows the system block diagram of our design.

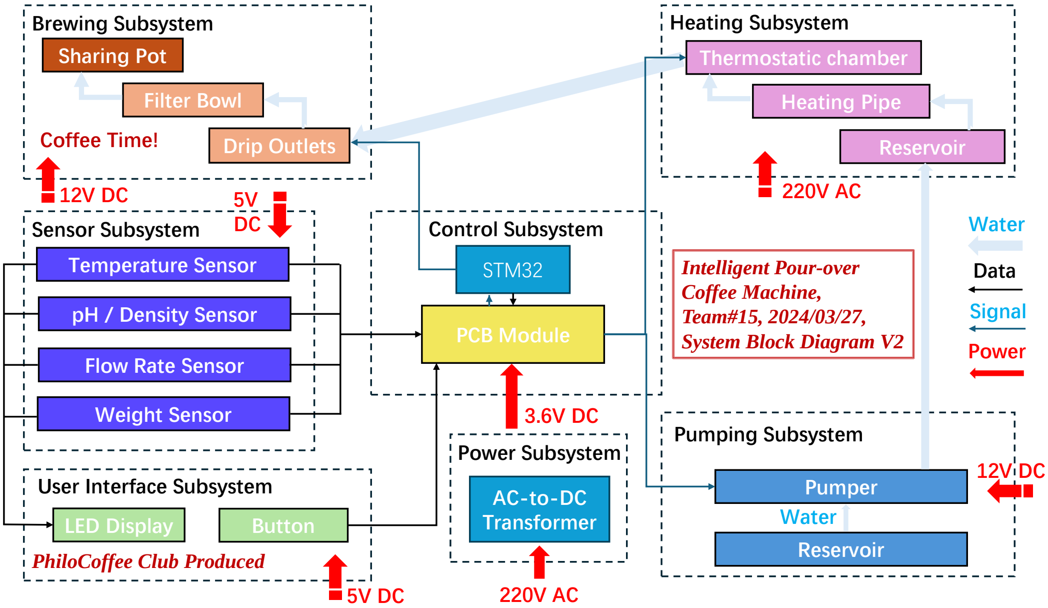

Figure 6: System Architecture of Our Design

3.2 Physical Design

Table 1: summarizes all 18 components included in our coffee machine

Cold water reservoir	Hot water slide	Gear set(two spur gear)
Cold water pump	Electromagnetic relay	Gear set holder
Hot water tank	Reset spring	Coffee machine housing
Heating module	Water rectifier	Electromagetic Relay Holder
Temperature sensor	Brewing Nozzle	Cup
Hot water pump	Gear Motor	Weighing module

As shown in the Fig 3, our physical design consists of the following sub-systems including a coffee beam weighing system, a cold reservoir, a pump, a heating system and a brewing nozzle which is able to squeeze hot water from three different outlets.

Fig 3 displays a coffee beam weighing system. The weight of the coffee beam serves as the input of our system. We planned to use a piezoresistor to achieve this function. We place the piezoresistor underneath the coffee beam filter, once the user poured the coffee beam in to the filter, the piezoresistor is going to be able to generate a signal as an input to the controller, then the controller will calculate the optimum brewing condition including brewing temperature, brewing radius, waiting time and so on.

Fig 8 shows a zoomed-out view of the cold water tank. To reduce the cost, we decide to use an aluminum food box considering there is no specific material danger to contain water at room temperature.

Then the water will be pumped up into the heating system as shown in Fig. 9, the pump will be controlled using a STM 32 based breadboard. When the water level in the heating system reaches the designed value, which will be measured by a separate water level measurement device (not shown in the design), the pump will stop working.

The heating system starts working then, the container is designed to be made by a thermal insulation material, ensure it could sustain temperature up to boiling point of water. The orange component in Figure 9

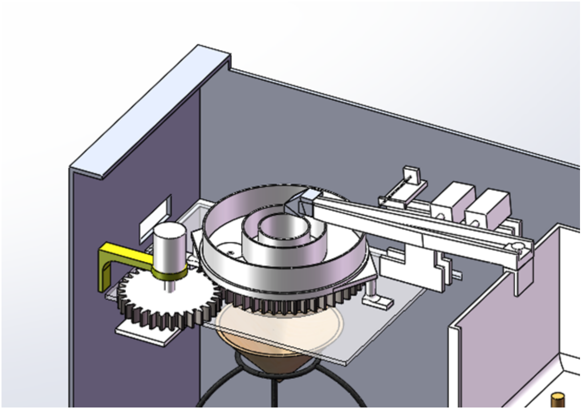

Figure 7: Brewing System

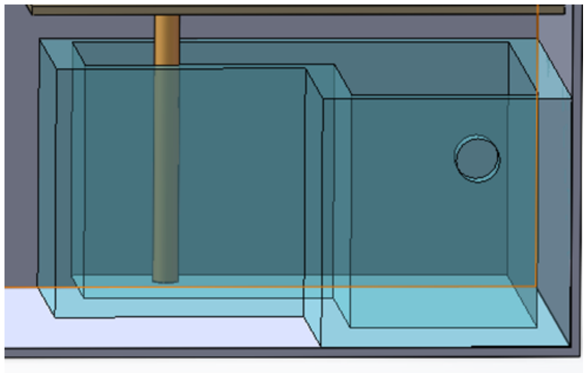

Figure 8: Cold Reservoir

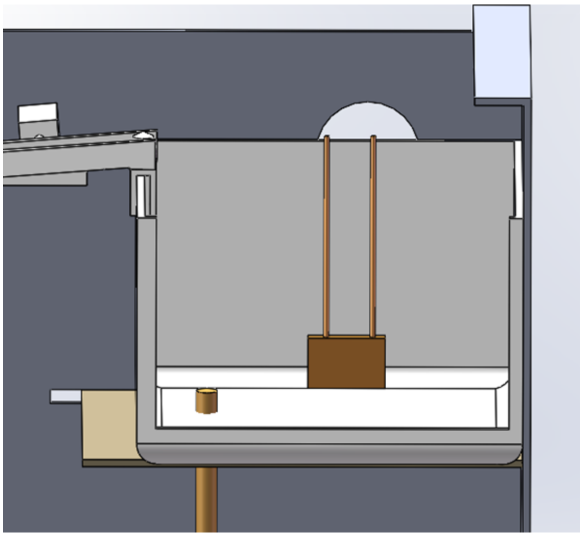

Figure 9: Heating System

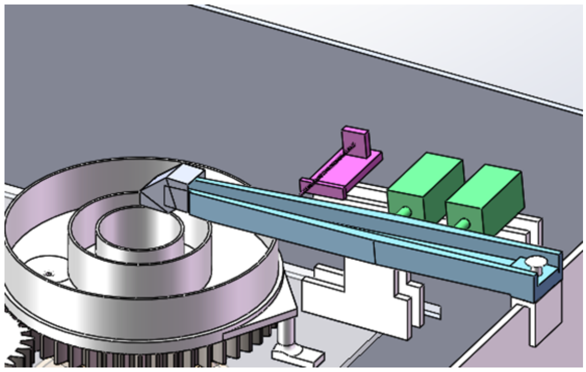

Figure 10: Hot Water Slider

indicates a heating block, and our group has already bought it from web. It can be controlled by linking it with the STEM 32, where the control signal comes from.

After heating to the designated temperature, the hot water will again be pumped to a hot water slider shown in Fig 10 in blue color. A water rectifier is used to impel the horizontal velocity of the hot water at the outlet of the slider. The hot water slider is pin-fixed at left end and its right end position is controlled by two separate Electromagnetic Relay (used to Control Slide position) and a reset spring shown in green and purple in the picture. With the help of such design, the hot water slider could deliver hot water into three different interlayers of the brewing nozzle to achieve three different brewing radius.

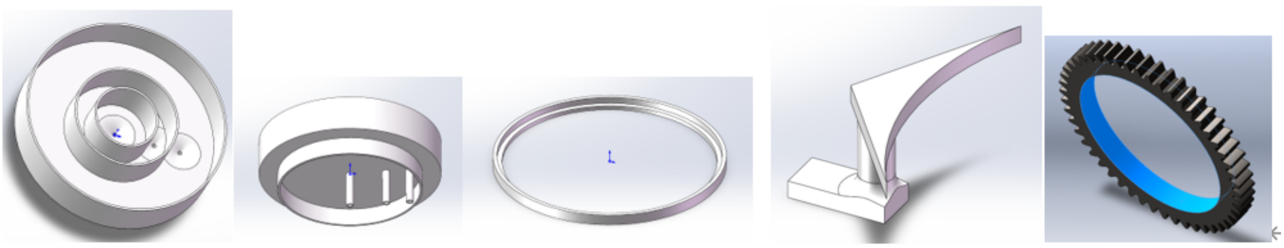

Figure 11: Brewing Nozzle (from top & bottom), Nozzle Holder, Holder Support, Spur Gear Ring

Table 2: Key Parameters

Grind Size	Medium-fine grind
Coffee-to-Water Ratio	1:15
Water Temperature	Boiling (approximately 92°C)
Brewing Time	About 1 minute and 30 seconds
Raw Material	15 grams of fresh coffee beans, brewing into 225 grams of coffee

The brewing nozzle has three different outlets corresponding to different brewing radii, hot water comes from the slider controlled by Electromagnetic Relay and spring as discussed before. The brewing nozzle is driven by another spur gear in intimate contact as shown in Fig 12.

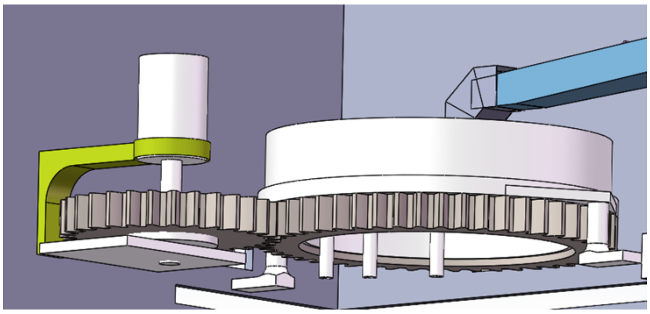

Figure 12: The spur gear set

Finally, the hot water coming from the brewing outlet reaches the coffee beam filter, and after that, a cup of fragrant coffee will be there waiting for you.

3.3 Finite State Machine Design

3.3.1 Key Parameter for Brewing

Table 2 outlines the key parameters for brewing.

Brewing Method:

1. Heat water in a kettle to 92°C and prepare the grind.
2. Pre-wet the filter and set up the brewing station with a scale.
3. Start with a 20-30 gram bloom pour, ensuring all grounds are saturated.
4. Continue with a slow pour to 100 grams, then quickly pour around the edges.
5. Finish the pour to reach a total weight of 225 grams without disturbing the flow.
6. Allow the coffee to drip through, and clean equipment with remaining hot water.

3.3.2 State Description

Here's a breakdown of how the coffee machine works, using 15 different states. Think of these states as steps or conditions the machine can be in, based on what button you press:
OFF: The coffee machine is not powered on.
RESET: The coffee maker is not working.
SET-OP: This sets up the operation The coffee machine knows the brewing method chosen by the user.

EXEC: to execute. The coffee machine starts the brewing process.
T-CLR: Clears the timer. The timer is set to 0. Used to record the brewing time.
PUMP: Water is pumped to a hot water reservoir.
HEATING: The coffee maker is heating the water in the hot water reservoir.
FLOW: Water flows from the hot pool to the brewing nozzle through the slider.
EXE-H/L/D: The gear motor starts to rotate in various ways, controlled by the code in Arduino or STEM 32. H is the hot water mode, and L/D is the light/deep roast coffee mode.
BREAK: After completing an execution cycle, the coffee machine stops for a while. Here, the machine waits for the weighing module to judge whether the water is sufficient.
FINISH: After washing the coffee beans with enough hot water, the machine finishes its brewing process.
LACK: Once the water in the cold reservoir is below the threshold, the signal is printed on the display LED on the instrument panel.
DAN: It's a dangerous situation. Once the machine works abnormally, it will stop the machine to ensure people's safety.

This list explains all the steps your coffee machine takes to get your coffee just right, from starting up to ensuring everything's safe.

3.3.3 Spatial-Temporal Diagram

Figure 14 uses a space-time chart to show the sequence of steps (pumping, heating, brewing) in the coffee machine's operation. This chart lays out the order in which things happen during a cycle, with time points labeled from t_0 to t_6 marking the stages. Each stage happens one after the other, in order. It's a simple way to explain how the coffee machine works step by step.

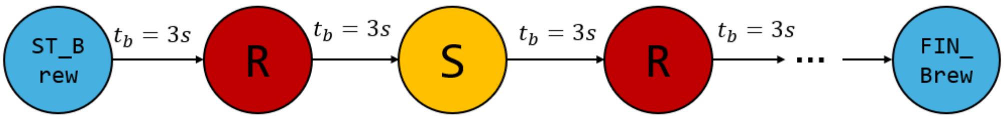

Figure 13: Sub-FSM for the dripping ways of a certain brewing type.

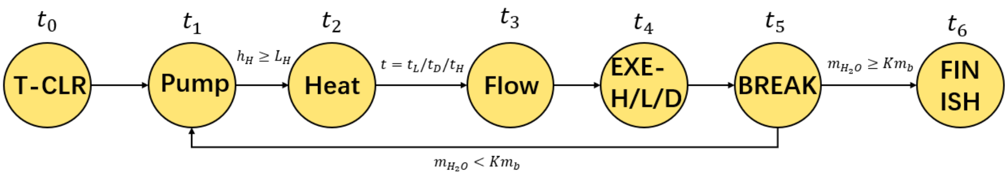

Figure 14: Sub-FSM for the dripping ways of a certain brewing type.

3.4 Subsystem Functions & Requirements

3.4.1 Brewing System

- **Function**: This subsystem is responsible for the physical aspects of coffee brewing, including the holding and dispensing of water and coffee grounds. It mimics the actions of a barista in a pour-over coffee-making process.
- **Requirements**:
  - Must accommodate varying amounts of coffee grounds and water.
  - Must achieve a water dispensing accuracy of +/- 5ml.
  - Compatible with standard pour-over coffee filters and holders.
- **Contribution**: Enables the physical brewing of coffee, essential for the product's core functionality.

Table 3: All Sensor Modules and Functions in Design

Sensors	Sensor Position	Sensor Function
Weight sensor	Placed under coffee beam filter	Weigh the coffee beam weight as the input of the system for further calculation and implementation
Cold Reservoir Water Level Sensor	Inside the cold reservoir	Measure the water level to judge whether the user has added enough cold water
Cold water pump sensor	In series with the cold water pump	Measure the working condition of the pump avoiding overload
Hot reservoir water level sensor	Inside the Hot reservoir	Measure the water level in the hot water reservoir, with the result of how much hot water is needed, judge how when should the hot water pump stop pumping.
Hot water pump sensor	In series with the hot water pump	Measure the working condition of the pump avoiding overload
Brewing nozzle outlet temperature sensor	At the outlet of the brewing nozzle	Give feedback of the outlet water temperature at the nozzle end

- **Interfaces**: Receives control signals from the Control System; mechanical feedback to Sensing System.

Table 4: Requirements and Verifications for Brewing Subsystem

Requirement	**Verification Procedure**	**Notes**
Simulate pour-over technique accurately.	Observe and compare the technique with a standard manual pour-over.	Imitate professional barista techniques.
Allow for adjustment of brewing parameters.	Verify through UI that parameters can be adjusted and take effect.	Customization for users.

3.4.2 Sensing System

- **Function**: Our design contains a lot of sensors in order to produce a cup of well-controlled and tasty pour-over coffee. Table 3. tabulated all sensor module and their functions included in the design.
- **Requirements**:
  - Temperature sensor with accuracy of +/- 1°C.
  - Weight sensor with accuracy of +/- 1g.
  - Optical sensors for monitoring coffee flow and color.
- **Contribution**: Ensures optimal brewing conditions and provides necessary data for the Control System.
- **Interfaces**: Provides real-time data to the Control System; receives user preference data from the User Interface.

Table 5: Requirements and Verifications for Sensor Subsystem

Requirement	Verification Procedure	Notes
Accurately measure water temperature.	Compare sensor readings with a calibrated thermometer.	Critical for brewing quality.
Detect water level in the reservoir.	Verify sensor triggers at predefined water levels.	Prevents overflow and dry run.

3.4.3 Control System

- **Function**: The Control System interprets sensor data and controls the Mechanical Coffee Brewing System. It utilizes pre-trained imitation learning algorithms to replicate professional barista techniques.
- **Requirements**:
  - Must process sensor data in real-time.
  - Must apply 3.6V direct current for STM 32. [11]
  - Capable of executing complex imitation learning algorithms.
  - Interface for receiving user input and sensor data.
- **Contribution**: Acts as the brain of the machine, controlling the brewing process based on sensor inputs and learned barista techniques.
- **Interfaces**: Receives data from Sensing System and User Interface; sends commands to Mechanical Coffee Brewing System.

Table 6: Requirements and Verifications for Control Subsystem

Requirement	Verification Procedure	Notes
Execute the brewing cycle based on user input.	Test with different user inputs and verify correct cycle execution.	Flexibility in brewing.
Respond to error conditions with safety shutdown.	Simulate error conditions (e.g., overheating) and check for shutdown.	Safety critical.

3.4.4 Heating Subsystem

- **Function**: The Heating Subsystem is tasked with heating water to the optimal temperature range for brewing coffee, typically between 85°Cand 95°C. This precise temperature control is essential for the extraction of the full flavor spectrum from the coffee grounds. The subsystem utilizes a heating element, such as a thermo-coil or a boiler, to achieve the desired water temperature.
- **Requirements**:
  - Heat water to a temperature range of 85°Cto 95°Cwithin 2 minutes.
  - Maintain temperature accuracy of +/- 2°Cduring the brewing process.
  - Implement safety features to prevent overheating and ensure user safety.
- **Contribution**: The Heating Subsystem is critical for optimizing the extraction of flavors from coffee grounds, directly influencing the quality of the brewed coffee.
- **Interfaces**: The Heating Subsystem interfaces with the Control Subsystem to receive temperature settings based on user input or predefined brewing profiles. It also communicates with the Pumping Subsystem to ensure water is heated before being pumped over the coffee grounds.

Table 7: Requirements and Verifications for Heating Subsystem

Requirement	**Verification Procedure**	**Notes**
Heat water to 90°C within 2 minutes.	Use a thermometer to check water temperature after heating.	Essential for optimal extraction.
Maintain temperature within +/- 2°C.	Monitor temperature stability over 10 minutes of operation.	Temperature consistency is key.

3.4.5 Pumping Subsystem

- **Function**: The Pumping Subsystem is engineered to transport water from the reservoir to the Heating Subsystem and subsequently onto the coffee grounds. It consists of a water pump, which may be a diaphragm or peristaltic type, chosen for its capability for precise control over the water flow rate, which is crucial for replicating the pour-over brewing technique.
- **Requirements**:
  - Deliver water at a controlled flow rate of 250 to 500 ml per minute to simulate the pour-over process.
  - Include fail-safes to prevent pump operation in the absence of water to avoid damage to the pump.
- **Contribution**: The Pumping Subsystem plays a vital role in the automation of the pour-over coffee brewing process, ensuring consistency and precision in water delivery.
- **Interfaces**: This subsystem interfaces with the Heating Subsystem to supply water for heating and with the Control Subsystem to adjust the flow rate according to the selected brewing profile. It also interacts with the Sensing Subsystem to monitor the water level and prevent dry runs.

Table 8: Requirements and Verifications for Pumping Subsystem

Requirement	**Verification Procedure**	**Notes**
Deliver water at 250 ml per minute flow rate.	Measure the output over a minute. Repeat three times for consistency.	Adequate for brewing.
Operate without failure for 500 cycles.	Run the pump for 500 cycles, checking for performance issues.	Ensures durability.

3.4.6 User Interface

- **Function**: This subsystem allows user interaction with the machine, enabling selection of coffee preferences and providing feedback on the brewing process.
- **Requirements**:
  - Intuitive, easy-to-use interface.
  - Display for showing brewing status and feedback.
  - Inputs for user preferences (e.g., coffee strength, temperature, sourness level).
- **Contribution**: Enables user interaction and customization of the brewing process.
- **Interfaces**: Collects user input for the Control System; displays data from the Sensing System.

Table 9: Requirements and Verifications for User Interface

Requirement	Verification Procedure	Notes
Intuitive interface for all user interactions.	Conduct a user study with at least 10 participants to gather feedback on interface usability.	Simplify user interaction.
Display real-time brewing status.	Verify by performing a brewing cycle and observing displayed information.	Critical for user awareness.

3.5 Tolerance Analysis

- **Water Leakage:** There are multiple factors contributing to water leakage.

  1) The materials we use, which are not of industrial grade, can lead to water seeping through gaps or cracks between components.

  2) The presence of impurities in the water can lead to accumulation and blockages in the pipes. This can result in increased pressure, causing the components to crack or in more severe cases, even burst.

  3) Improper connections between components can cause the pump to redirect water outside the intended system inadvertently.

- **High Temperature:** To brew a delightful cup of coffee, water heated to about 90 to 100 degrees Celsius is typically required. However, certain materials used in the brewing process may not withstand this high temperature. As a result, they might partially dissolve, potentially releasing harmful substances into the water that could be toxic and even carcinogenic.

- **Electronic Circuit Tolerance:**

- 1) For the sensor/control system and user interface, if the circuit quality or the connecting method is poor, the circuit will only work sometimes. Some of the materials will change their shape if they encounter a high-temperature environment, which will badly affect the connectivity.

- 2) If there are any water leaks in those systems, the circuit will be destroyed.

- **Delay of the Sensor:** As the electronic signals travel along the wires, they encounter a series of cascade delays. This results in the machine reacting more slowly than anticipated, leading to discrepancies in the water quantity, pH value, and temperature.

- **Machine Longevity:** Since this project is not intended for industrial use, the materials we've employed are of a lower quality compared to those available commercially. Consequently, if the machine is subjected to excessive use, it's likely to incur damage or potentially even break down completely.

- **Hygiene Issues:** The coffee bean grounds remain in the filter bowl after use. It's important to clean this promptly; otherwise, bacteria can proliferate, potentially damaging both the machine and the quality of the coffee.

4 Cost and Schedule

4.1 Cost Analysis

4.1.1 Introduction

The cost analysis provides a detailed breakdown of the estimated expenses required to prototype our intelligent coffee machine. This analysis takes into consideration material costs, component procurement, and potential economies of scale. Our team use Notion, a co-working software, to record all costs in detail for every team member to refer to, as shown in Figure 15. It offers transparency in the financial planning of the project and ensures we allocate our resources wisely.

Aa Name	Buyer	price
电子称	hjy	
DPS sensor	wj	
Max的自动手冲咖啡机	wj	0
PTC heating sheet	krc	10
Dc waterproof heating rod drive module	krc	50
Dc 12V pump	krc	60
Water Tank	krc	20
DC Motor	krc	30
Silicone hose flexible water pipe	krc	15
旋转喷头	krc	24
10米软管	krc	15
加热驱动单元	krc	100
直流12V抽水泵	krc	85
食品级塑料盒	krc	20
单片机扇叶	krc	30
铝合金元件加工费（学校内不能加工我们所需的食品级金属件）	qxb	750

Figure 15: We used Notion to Manage the Cost

Table 12 recorded the estimated material costs of our design. We've sourced various components essential to emulate professional barista techniques. These include heating elements for temperature control, DC motors for mechanical movements, and silicone hoses for fluid transfers, among others. The cost estimates are based on current market prices and are denominated in RMB, adhering to our budget provided by ZJUI's Innovation Lab.

4.1.2 Labor and Development Costs

Table 10 summarized the labor and manufacturing cost to date included in our design. Our labor costs are computed based on the cumulative hours spent by team members in designing, programming, and assembling the coffee machine. This cost is factored in to provide a realistic estimate of the project's non-material expenses.

Table 10: Human Labor Cost Table

Description	**Hours**	**Rate (RMB/hr)**	**Total (RMB)**
Design and Programming	25	20	500
Assembly and Testing	25	20	500
Documentation and Reporting	15	20	300
Alluminum Alloy Component manufacturing	10	75	750
Total Labor Cost	**75h**	**-**	**2050**

4.1.3 Overall Project Cost

Table 11 shows the overall project cost, including both material cost and labor cost.

4.1.4 Cost Optimization

While our current cost estimates are based on prototype quantities, we are actively seeking bulk pricing options for future scalability. Additionally, we are exploring partnerships with NGOs and corporations for possible sponsorships or bulk discounts.

Table 11: Overall Cost Table

Cost Type	**Estimated Cost (RMB)**	**Notes**
Material Costs	215	As detailed in Cost Analysis
Labor Costs	2050	Estimated labor
Miscellaneous Expenses	300	Contingency funds
Grand Total	**2565**	**-**

4.1.5 Conclusion

The cost analysis lays the groundwork for financial accountability and helps us in maintaining cost efficiency throughout the development of our coffee machine. We will continue to monitor and update this section as we progress, ensuring we adhere to our financial plan.

4.2 Acknowledgement

Thanks @Maxspresso for supporting us with a coffee machine. The inverse engineering on it really helps our design process a lot!

Table 12: Material Cost Table

Item	Quantity	Description	Estimated Cost (RMB)	Justification of cost
Acrylic plate	10	Crafting Material for Whole Structure	0	Provided by Innovation lab ZJUI, free of charge
PTC heating sheet	2	5V, 180℃, 4-9W; 24V, 230℃, 8-20W (2*5=10)	10	-
Dc waterproof heating rod drive module	1	4A, 5V, 8W	50	-
Dc 12V pump	1	High temperature resistant	60	-
Water Tank	2	Food grade, storage for pure water, 2.52L per tank	20	(10*2=20)
DC Motor	4	9mm*2mm, 1-6V, 0.35-0.4A, 16000-20000RPM	30	-
STM32 Board	1	Basic IO, Linux System, Support Camera and Audio	128	-
Silicone hose flexible water pipe	1	10m long, inner Diameter 3mm, Outer Diameter 5 mm, Food grade, odorless, transparent, high temperature resistant	15	-
12V, 20N Push-pull Electromagnet	1	12V, 20N	30	-
Coffee Bean	N/A	Additional, Not Counted in Cost of Coffee Machine Manufacturing	0	Additional, Not Counted in Cost of Coffee Machine Manufacturing
			Total Estimated Cost	**215**

4.3 Schedule

Table 13 shows our team's estimated schedule. We plan to divide the tasks into 2 stage:

1. First Prototype using cold water and acrylic housing.
2. Second Prototype using hot water and 304 stainless metal housing.

Thus, we can not waste the time and get progress on the real design.

Table 13: Team Estimated Schedule

Date	Jie	Jingyuan	Xubin	Rucheng
Week 6 (3.18)	Brewing System Electronic Design	FSM Conceptual Design	Brewing System Mechanical Design	Get Designed Parts 3D Printed and Assemble the Prototype
Week 7 (3.25)	System Parameter Design & DD writing	Python Coding for FSM & DD writing	& Assemble the Printed Parts and Do Improvements &DD writing	Redesign the Pump Tube Configuration & Improve Brewing System Design & DD writing
Week 8 (4.1)	STM32 board basic IO deployment	PCB Design and Code Loading (Brewing System, Heating System)	Assemble the Plastic prototype with Rucheng & Improve the Design to Next Generation	Dictate Aluminum Alloy Manufacture & Assemble the Prototype with Xubin & Seek Potential Improvement of Prototype
Week 9 (4.8)	First Prototype Assembly	PCB Design and Code Loading (Control System, Pumping System)	Design PCB Circuit with Jie	Optimize the Control System and Design better codes with Jingyuan
Week 10 (4.15)	Overall Electronic Design Enhancement	Start implementation & Debug	Prototype and Final Product Manufacturing with Rucheng	Prototype and Final Product Manufacturing with Xubin
Week 11 (4.22)	Second Edition Assembly	Continue implementation & Debug	Back up Flexible Time	Back up Flexible Time
Week 12 (4.29)	Back up Flexible Time	Design optimization	Back up Flexible Time	Back up Flexible Time
Week 13 (5.6)	Back up Flexible Time	Design optimization	Back up Flexible Time	Back up Flexible Time
Week 14 (5.13)	Begin final report.	Begin final report.	Begin final report.	Begin final report.
Week 15 (5.20)	Continue on final report.	Continue on final report.	Continue on final report.	Continue on final report.

5 Ethics and Safety

Aligning with IEEE and ACM ethical standards[12], we promise to adhere safety regulations during our senior design project.

5.1 Ethics Consideration

1. **Assess Impact on Society:** This project is ethically right to the society, to date cultivating a coffee masters normally requires more than 1000 hrs at least, and also needs consistent training to keep their skills. Our intelligent coffee machine could offer those living in rural or leading a poor life who also want to try well-brewed pour-over coffee a chance to live with high-quality coffee. In all, the coffee machine is designed to enhance the quality of life while minimizing waste and negative impacts.

2. **Fairness and Non-discrimination:** The intelligent pour-over coffee machine will be accessible and usable by a wide range of individuals, ensuring that there are no biases in design or operation based on race, gender, or other personal characteristics.

3. **Honesty and Transparency:** The development process will be conducted with honesty and transparency. Capabilities and limitations of the coffee machine will be communicated clearly, along with safety features, maintenance needs, and any potential risks.

5.2 Safety Factors

1. **Burn Prevention:** To prevent injuries such as severe burns from hot coffee spillage, the machine includes safety features like the emergent button to control the temperature and prevent accidental spillage [13]. Also, we need to take care of the heat. This requires meticulous material to ensure that components can sustain with high temperatures. The hot water pump tube, hot water slider, and hot water reservoir in our design, are effectively insulated. Further, the we need clear warning label and careful user guide to reduce the risk of burns. Moreover, our control system will take temperature regulation mechanisms to prevent overheating incidents, safeguarding users during long time usage.

2. **Pathogen Transmission:** The machine will be designed for easy cleaning to avoid becoming a breeding ground for pathogens, ensuring compliance with hygiene standards in healthcare and food safety regulations [14].The mitigation of pathogen transmission risks constitutes a crucial ethical consideration in the development of the coffee machine. Central to this endeavor is the selection of materials resistant to microbial proliferation and conducive to ease of cleaning. In our design, we choose to apply Aluminum alloy as one of the food-safe materials to components that have potential to be in intimate contact with running water and coffee beam. Furthermore, adherence to stringent hygiene protocols throughout the product's lifecycle is imperative to minimize contamination risks. Attention must also be directed towards ensuring the quality of water used in the machine, adhering to established standards to prevent the transmission of waterborne pathogens. In our design, we try to round all inside edges off, to avoid straight angles which might increase the difficulty for cleaning after operation. By prioritizing these measures, the coffee machine can uphold robust sanitation standards and promote user well-being.

3. **Mechanical and Pressure Safety:** The machine will adhere to the ***Pressure Systems Safety Regulations (PSSR)*** with regular inspections, safety checks, and emergency shutoffs to prevent system failures [15].The part that are related to pressure issues include only the cold and hot water pumps, we solve this concerning by adding two pressure and temperature sensors to them respectively. The assurance of mechanical and pressure safety features within the coffee machine design and manufacturing processes is integral to mitigating risks of accidents and injuries. Rigorous structural analysis and testing are indispensable to ascertain the machine's capacity to withstand operational stresses and pressures. Additionally, After the whole brewing process is accomplished, how to release the remaining pressure inside the water tube is also well-considered and addressed through adding gas-release and liquid release step at the end of programming, since over-pressure scenarios could compromise mechanical integrity. By adhering to these principles, the coffee machine can engender user confidence in its reliability and safety.

During the development of our project, we promise to meet the safety and ethical requirement, protecting ourselves and the potential users in the future.

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