ZJU-UIUC Institute

ECE 445 / ME470

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL V1

Intelligent Pour-over Coffee Machine based on Pre-trained Imitation Learning

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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 Description

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**. Presented here

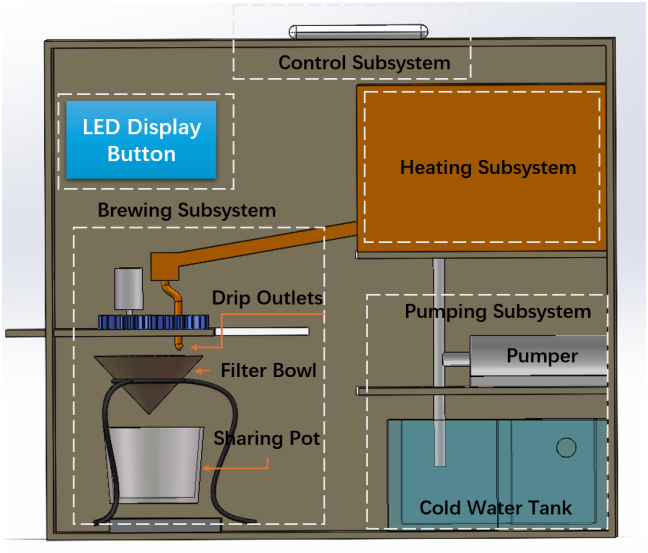

Figure 1: System Component Overview

are the left and right views of current mechanical design:

Machine-based pour over coffee is still a new and exciting trend in the world. Unlike espresso coffee or filter coffee, pour over coffee machine is much rare and harder to build. Because it involves many difficult

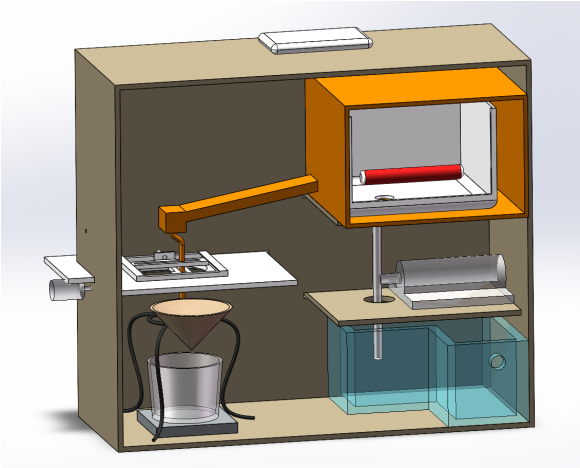

Figure 2: Left View of Mechanical Design

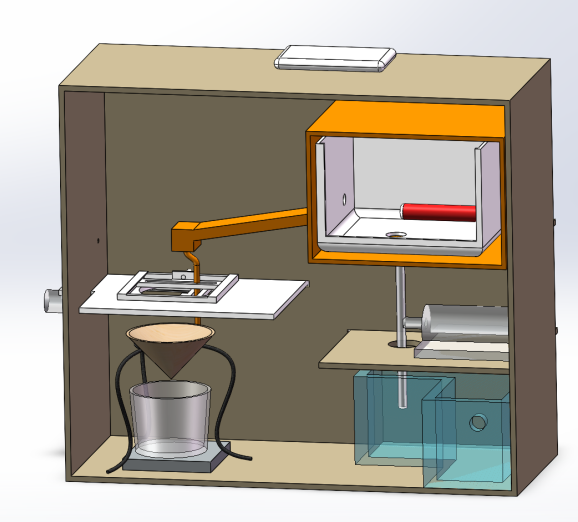

Figure 3: Right View of Mechanical Design

aspects from both mechanical engineering and computer engineering. For instance, today we can easily let Deep Learning model like Alpha Go to beat the best human Go player, while we still cannot build a humanoid robot that moves Go stone easily like a child Go player. And pour-over coffee would be another difficult research project: even the state-of-the-art robot, **Mobile ALOHA**[4], built by Stanford, can only quick simple dishes. Empowering robotic arm is quick hard to manipulate subtle movement of pour over. Therefore, we turned on another ***Philosophy of Design: Learning from the existing product on the market***. Watching product demo video, We investigated products from **Poursteady, Bonavita, Chemex etc.**[5][6][7][8][9]. The drip outlet design by **Poursteady** attracted our attention, we designed a similar water drip outlet as below:

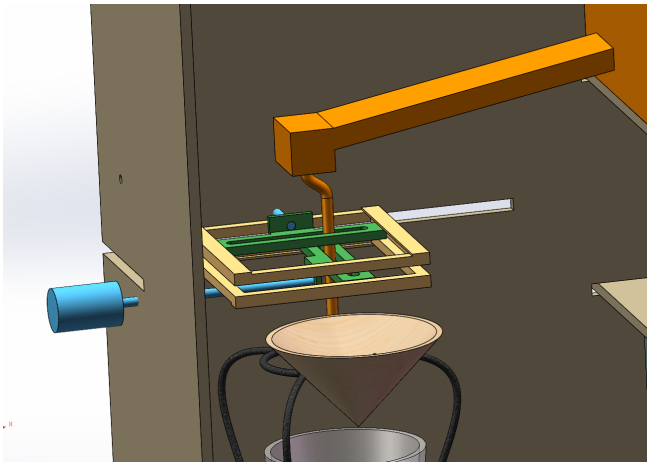

Figure 4: detail of drip outlet

Finally, we expect our machine can produce stable and delicious pour-over coffee. Thus we have the following expectation:

2.3 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, allowing for easy operation and customization by the user.
- **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 Design

3.1 Block Diagram

Here is the system block diagram of our design.

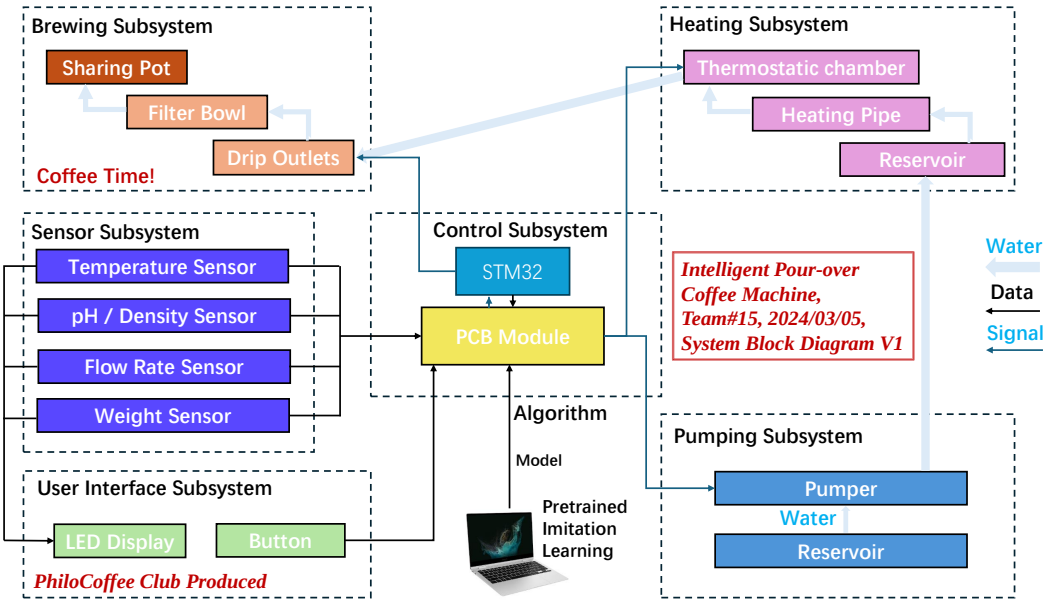

Figure 5: System Architecture of Our Design

3.2 Subsystem Overview

3.2.1 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.

3.2.2 Sensor System

Function: Equipped with various sensors (e.g., temperature, weight, optical), this subsystem monitors the brewing process, ensuring optimal conditions for coffee extraction.

3.2.3 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.

3.2.4 Heating Subsystem

Function: The Heating Subsystem is responsible for heating water to the optimal temperature range for brewing coffee, which is typically between 85°C and 95°C. This temperature control is crucial for extracting the full flavor from the coffee grounds. The subsystem uses a heating element, such as a thermocoil or a boiler, to heat the water. The subsystem also includes sensors to monitor water temperature and ensure precision.

3.2.5 Pumping Subsystem

Function: The Pumping Subsystem is designed to deliver water from the water reservoir to the Heating Subsystem and then onto the coffee grounds. The subsystem comprises a water pump, typically a diaphragm or a peristaltic pump, which is suitable for precise control of water flow.

3.2.6 User Interface

Function: This subsystem allows user interaction with the machine, enabling selection of coffee preferences and providing feedback on the brewing process.

3.3 Subsystem Requirements

3.3.1 Mechanical Coffee Brewing System

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

3.3.2 Sensing System

- **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.

3.3.3 Control System

- **Requirements**:
  - Must process sensor data in real-time.
  - 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.

3.3.4 Heating and Pumping Subsystem

- **Requirements**:
  - Must supply at least 500mA continuously at 5V +/- 0.1V.
  - Reliable power source with overload and short circuit protection.
  - Efficient power distribution to all subsystems.
- **Contribution**: Provides the necessary power to each component, essential for the operation of the coffee machine.
- **Interfaces**: Direct power supply to all other subsystems.

3.3.5 User Interface

- **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.

3.4 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 Ethics and Safety

Aligning with IEEE and ACM ethical standards[10], we promise to adhere safety regulations during our senior design project.

4.1 Ethics Consideration

1. **Assess Impact on Society:** This project will take into account the broader implications on society, including social, economic, and environmental aspects. 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.

4.2 Safety Factors

1. **Burn Prevention:** To prevent injuries such as severe burns from hot coffee spillage, the machine will include safety features to control the temperature and prevent accidental spillage [11].

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 [12].

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 [13].

4. **Child Safety:** The design will include features that prevent operation by children and other vulnerable individuals, mitigating the risk of accidents.

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

References

[1] CoffeeGeek. *Pour Over History and Development*. http://www.coffeegeek.com. Accessed: 2024-03-06.

[2] Expert Market Research. *Coffee Machines Market Trends, Share Growth 2024-2032*. http://www.expertmarketresearch.com. Accessed: 2024-03-06.

[3] Nature.com. "Influence of coffee brewing methods on the chromatographic and spectroscopic profiles, antioxidant and sensory properties". In: *Scientific Reports* 11.1 (2021). Accessed: 2024-03-06. DOI: 10.1038/s41598-021-91167-8.

[4] Zipeng Fu, Tony Z. Zhao, and Chelsea Finn. "Mobile ALOHA: Learning Bimanual Mobile Manipulation with Low-Cost Whole-Body Teleoperation". In: *arXiv*. 2024.

[5] *Gevi 4-in-1 Smart Pour-over Coffee Machine*. An automatic coffee machine with customizable barista mode and descaling feature. 2024. URL: https://gevilife.com/.

[6] *Poursteady*. A professional automatic pour-over coffee machine emphasizing precision and quality manufacturing. 2024. URL: https://poursteady.com/.

[7] *Technivorm Moccamaster KBGV Select*. A design-driven automatic pour-over coffee machine with a wide array of colors and fast brewing time. 2024. URL: https://us.moccamaster.com/.

[8] *Bonavita Connoisseur*. A pour-over coffee brewer with stainless steel exterior, one-button control, and powerful boiler. 2024. URL: https://www.amazon.com/.

[9] *Brim 8-Cup Auto Pour Over Coffee Maker*. An automatic pour-over coffee maker with precise temperature control and simple design. 2024. URL: https://www.amazon.com/.

[10] *ACM Code of Ethics and Professional Conduct*. https://www.acm.org/code-of-ethics. Accessed: 2024-03-07.

[11] Lawrence J. Buckfire. *Coffee Burn Injury Lawsuits*. http://www.natlawreview.com/article/coffee-burn-injury-lawsuits. Accessed: 2024-03-06. 2022.

[12] Sarah Victoria Walker et al. "Bug in a mug: are hospital coffee machines transmitting pathogens?" In: *BMJ* 383 (2023). Accessed: 2024-03-06. DOI: 10.1136/bmj.p2564.

[13] Espresso Service. *Coffee Machine Safety*. http://www.espressoservice.co.uk/resources/coffee-machine-safety/. Accessed: 2024-03-06.