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Technical Report

Coffee On Demand

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Abstract

Coffee On Demand is an automated vending machine designed to enhance the coffee purchasing experience through advanced technology. Motivated by the increasing prices of coffee in Brazil, this project aims to provide consumers with a flexible and intelligent way to purchase gourmet coffee beans. The machine offers four different types of coffee and utilizes facial and voice recognition to personalize the user experience. Guests can make one-time purchases, while registered users benefit from customized coffee recommendations based on past purchases or real-time inquiries.

The machine operates through a Raspberry Pi 4, which controls four stepper motors responsible for dispensing the selected coffee beans according to the weight specified by the user via voice command. The system includes a camera for facial recognition, a microphone and speaker for interactive communication, a scale for precise measurement, and an LCD screen for displaying QR codes for payment processing, using PIX. Additionally, an online interface is available for machine owners, allowing them to monitor purchases, manage inventory, and update product details. The integration of AI-driven conversation and real-time customization provides an innovative and user-friendly coffee purchasing experience, making high-quality coffee more accessible and tailored to individual preferences.

1 Introduction

For Brazilians, coffee is becoming increasingly expensive by the day. The latest coffee crop in Brazil has seen a decrease in quality and volume of production, leading to an increase in prices on the shelves of supermarkets in the country [1]. In addition, every year, many coffee brands are removed from the markets because they are not suitable for consumption. For instance, in 2024, there were at least 19 brands of coffee that had their sales interrupted by the Ministry of

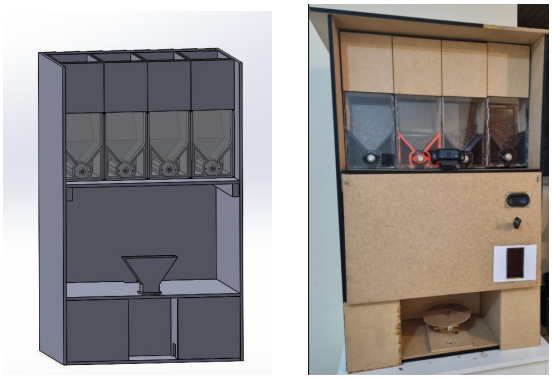
Agriculture [2]. As a result, the search for special coffee has relevantly increased [3], with 4.9 million sacks of 60 kg being consumed in 2024.

The shift in the consumer profile encouraged a new way of selling coffee grains. Coffee On Demand is an automated vending machine that supports the selling of four different types of coffee grains. In addition, it is equipped with facial recognition and voice command technology. The system's uniqueness lies in its ability to deliver a personalized experience, analyzing the user's purchase history and product characteristics to suggest beans that best match their preferences. Furthermore, Coffee On Demand allows customers to acquire customized quantities between 20 and 300 grams. Finally, the machine is also compatible with PIX payment.

Coffee on Demand is powered by a Raspberry Pi 4 micro-controller, the central processing unit of the system, and integrates multiple hardware components to deliver an automated coffee dispensing solution. The system's core hardware architecture consists of four precision stepper motors with their respective drivers, coupled with an Archimedes Screw each for bean dispensing, a load cell for weight measurement, and a user interface comprised of essential peripherals.

The user interaction system incorporates a camera for facial recognition, enabling the software to differentiate between registered customers and guest users, thus personalizing the service experience. Audio interaction is facilitated through an integrated speaker and microphone system, which interfaces with a natural language artificial intelligence model. The system's display output is handled by an LCD screen, primarily used to present payment QR codes for PIX transactions and display relevant system information.

The system's structural design is illustrated in Figure 1, which provides a comprehensive 3D view of the assembly. The third level of the machine houses the four dedicated containers for storing coffee beans.



(a) Overall 3D view of the machine.

(b) Image of the vending machine.

Figure 1: Overview of the vending machine. Source: Authors (2025)

2 Project Specification

This section outlines the essential requirements identified for the system, encompassing both functional and non-functional specifications. These requirements were established based on market research, technical constraints, and user experience considerations. The specifications are categorized to address various aspects of the system, including mechanical functionality, user interaction, payment processing, and safety measures. Tables 1, 2 and 3 presents the list of these requirements, which guided the system's development and served as benchmarks for evaluating the final implementation. These requirements are categorized into different types, including Functional Requirements (FR), which define the specific functionalities the system must perform, and Non-Functional Requirements (NFR). The tables only show the obligatory requirements of the system; a full list of the requirements is in our blog [4].

Table 1: Mandatory Mechanical Requirements

ID	Description of Requirement	Achieved
FR01	Ensure different types of coffee beans remain separated until dispensing.	Yes
FR02	Include a weighing mechanism to ensure accurate quantity.	Yes
FR03	Provide a cup for customers to collect purchased beans.	Yes
FR04	Dispense coffee beans in a container.	Yes
FR05	Move coffee beans to the funnel and dispense.	Yes
FR07	Dispense at least the ordered weight with max +10% error.	Yes
FR08	Allow the owner to replenish coffee bean stocks.	Yes
NFR01	Use MDF and acrylic for the container.	Yes
NFR02	Motor-to-screw coupling mechanism required.	Yes
NFR03	Motor mount located outside coffee bean container.	Yes
NFR04	Four PVC pipes to guide coffee beans to the funnel.	Yes
NFR05	One bearing per Archimedes screw.	Yes

Source: Authors (2025).

Table 2: Mandatory Hardware Requirements

ID	Description of Requirement	Achieved
FR38	LCD screen must show PIX QR code.	Yes
FR39	LCD screen must display machine state (e.g. loading).	Yes
FR40	Microcontroller must detect when weight reaches required value.	Yes
NFR19	3.5-inch LCD screen required for display.	Yes
NFR20	1080p USB camera required for facial recognition.	Yes
NFR25	Arduino must control LCD screen.	Yes
NFR26	1 kg load cell required for weighing coffee beans.	Yes

ID	Description of Requirement	Achieved
NFR27	12V 15A power supply required.	Yes
NFR28	Each motor control circuit must have an A4988 driver.	Yes

Source: Authors (2025).

Table 3: Mandatory Software Requirements

ID	Description of Requirement	Achieved
FR09	Allow customers to choose coffee bean type.	Yes
FR10	Allow customers to select quantity.	Yes
FR13	Dispense coffee only after successful payment.	Yes
FR16	Allow owner to update coffee bean data via web app.	Yes
FR16.2	Enable updating coffee bean names via web app.	Yes
FR16.3	Enable updating coffee bean descriptions via web app.	Yes
FR17	Owner can register when coffee beans are replenished.	Yes
FR19	Stop dispensing if the user removes the container.	Yes
FR20	Update stock in web interface after a purchase.	Yes
FR22	Alert customers if selected quantity exceeds stock.	Yes
FR23	Confirm details before executing payment.	Yes
FR24	Cancel purchase if no response within 1 minute.	Yes
FR25	Store customer data such as name, pictures, etc.	Yes
FR26	Store stock levels for each type of coffee bean.	Yes
FR27	Deny coffee orders above 300g or below 20g.	Yes
FR28	Detect voice commands.	Yes
FR28.1	Detect when customer starts talking.	Yes
FR28.2	Detect when customer stops talking.	Yes
FR29	Generate voice messages for customer interaction.	Yes
FR29.1	Guide users through the selection process via voice.	Yes
FR30	Recognize registered customers using facial recognition.	Yes
FR32	Support PIX as a payment method.	Yes
FR34	Serve only one client at a time.	Yes
FR35	Provide a web interface.	Yes
FR36	Allow owner to input stock details, description, last replenishment.	Yes
FR37	Customers can buy only one type of coffee bean per purchase.	Yes

Source: Authors (2025).

3 System Architecture

The system architecture is organized into three interdependent layers: the mechanical structure, the hardware, and the software. The mechanical structure provides the physical foundation of the coffee vending machine. The hardware layer integrates electronic sensors and actuators. Finally, the software layer

orchestrates the overall functionality by processing inputs, executing control algorithms, and facilitating user interactions through intuitive interfaces.

3.1 Mechanical Structure

The Coffee On Demand machine is constructed primarily from MDF, chosen for its durability and cost-effectiveness. The four coffee containers are made from MDF (Figure **??**) and acrylic, allowing users to see the coffee beans inside. The dispensing mechanism is based on an Archimedes screw system, which is 3D-printed along with the funnel used to direct the beans into the dispensing chute.

3.1.1 Coffee containers

The coffee containers are also constructed of MDF. Additionally, the front part of the container is built of an acrylic shape, that allows users to visualize the mechanism and the coffees. Figures 2 and **??** describe the dimensions (in millimeters) and views of both parts.

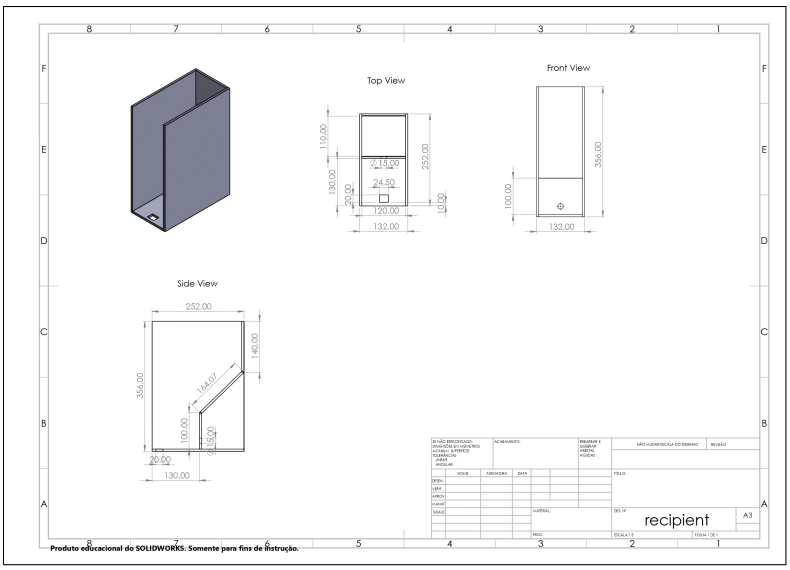


Figure 2: Container structure.

3.1.2 Dispensing structure

The dispensing structure consists of an Archimedes screw to guide the grains until the dispense. In addition, the screw is located in the middle of a channel. All these parts were 3D printed using PLA.

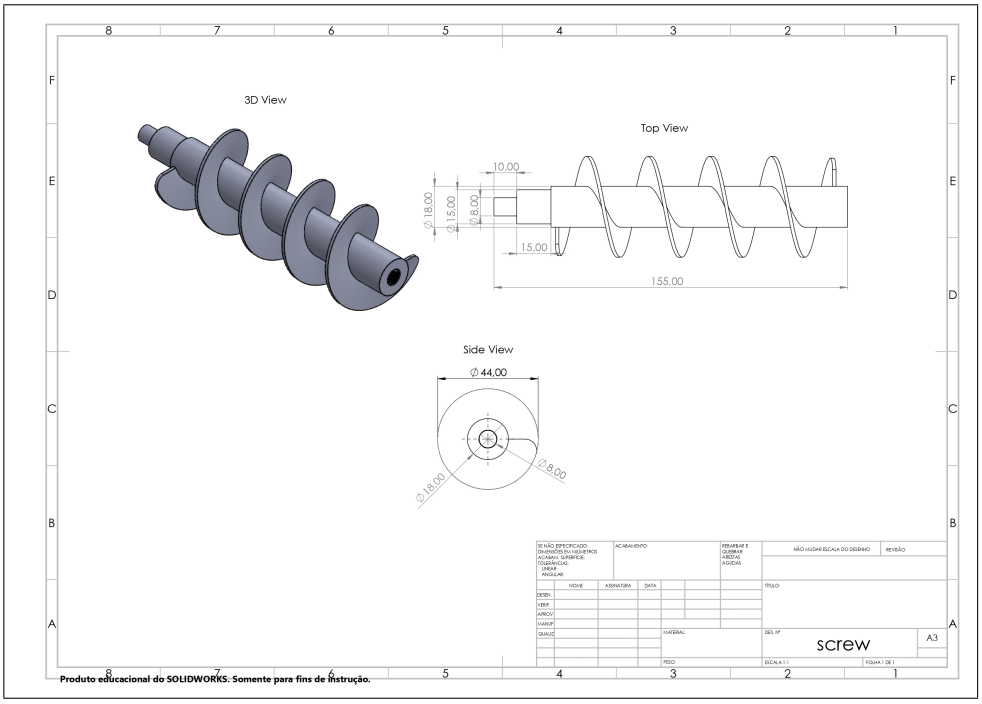


Figure 3: Archimedes screw.

3.2 Eletronic

The eletronic architecture of the system is built around a collection of specialized components that work together to control the dispensing mechanism and external data acquisition for the coffee vending process. It includes both components and peripherals.

3.2.1 Dispensing Mechanism Hardware

The hardware controlling the dispensing mechanism is engineered for precision and reliability in coffee preparation.

- **Raspberry PI 4**: Serves as the central processing unit of the system, coordinating all hardware-software interactions through its GPIO interface.
- **NEMA 17 Stepper Motor and A4988 Driver [4x]**: Each coffee container has one NEMA 17 attached to the Archimedes screw. They are utilized to drive the dispensing system, ensuring accurate movement and dosage control for each coffee container.
- **Load Cell 1kg and HX711 Module**: This two components are responsible to send to the microcontroller the weight in the dispense stage.

- **Obstacle Sensor**: The obstacle sensor is positioned in the back wall of the dispense area. The goal is to detect if the cup is in the correct position for dispensing.

3.2.2 User interface hardware

The user interface hardware is mainly comprised of peripherals. All of them are connected to the microcontroller. The main function of the peripherals is to promote a better user interface.

- **USB Camera C920**: A USB Camera is employed for facial recognition of registered customers, allowing the system to provide personalized suggestions based on historical data.
- **USB Microphone**: Detects when customer is talking and captures his voice.
- **Speaker 3W**: Emit system's voice response.
- **LCD Screen**: The 3.5' LCD screen is controlled by an Arduino Uno. The main function is to provide a state machine feedback to the client (talking, listening, processing, dispensing), and also display the current weight during dispensing stage.

Figure 4 presents the full schematic diagram of the system's electronic architecture, detailing the interconnections between power management, sensor, drivers, motors and the core microcontroller. The power management is done by two power supplies of 12V each.

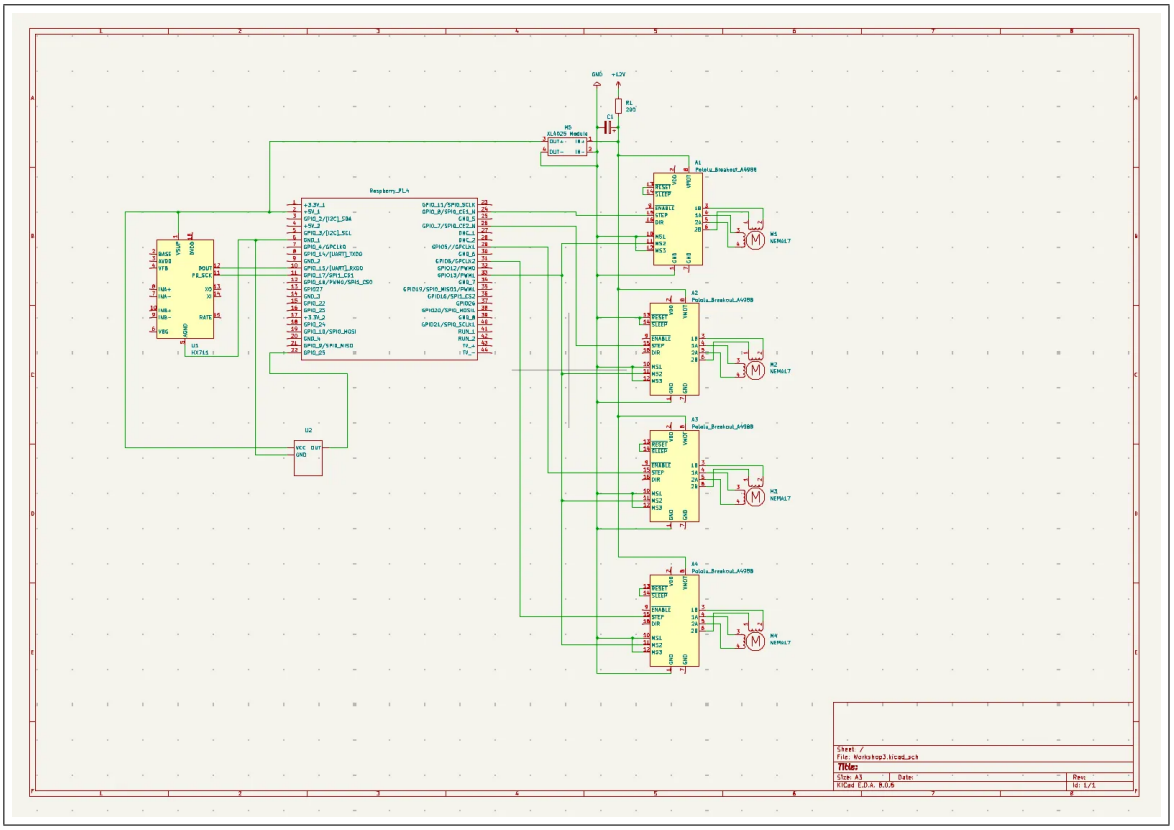


Figure 4: Full hardware schematic of the project. Source: Authors (2025)

3.3 Software

The software architecture is divided into two primary segments: an embedded component for direct hardware control and a web interface for machine owner management. The embedded software is further subdivided into modules dedicated to user interaction and to the control of the dispensing mechanism.

3.3.1 User interface

The core of the user interface are the Large Language Models (LLMs). These are a class of artificial intelligence (AI) models designed to process and generate natural language. They are trained on extensive datasets comprising books, articles, and other text sources, enabling them to understand context, grammar, and even nuances in human communication. In Coffee On Demand, the LLM is specifically instructed, via prompt, to interpret voice commands related to coffee selection, ensuring accurate and context-aware responses. The section below describes all AI models used in the system.

- **Whisper**: Serves as the primary speech recognition engine, converting

user audio into text representations. The model leverages acoustic and linguistic modeling to ensure transcription across diverse accents, noise conditions, and speaking styles. It integrates contextual biasing to improve recognition accuracy for domain-specific vocabulary [5].

- **GPT-4o-mini**: Acts as a interpretative layer for transcribed audio from Whisper and applies structured prompt-based analysis. It employs semantic filtering to detect out-of-context sentences and generates appropriate response in audio. Additionally, this model receives customer purchase history and coffee information to provide a better experience during the conversation flow. In addition, it analyzes the current stage of conversation to generate appropriate response to the customer [6]. It also extracts critical transactional entities (coffee type, price and container number of the chosen coffee, first name and last name) to complete purchase or register customer.

- **dlib_face_recognition_resnet_model_v1**: This model is responsible for recognizing registered clients, comparing their facial embeddings with stored profiles. Facial recognition is used solely for personalization and does not serve as an authentication or payment method. Users can interact with the machine without requiring an account or login credentials.

The Figure 5 describes the AI model chain used in the conversation flow.

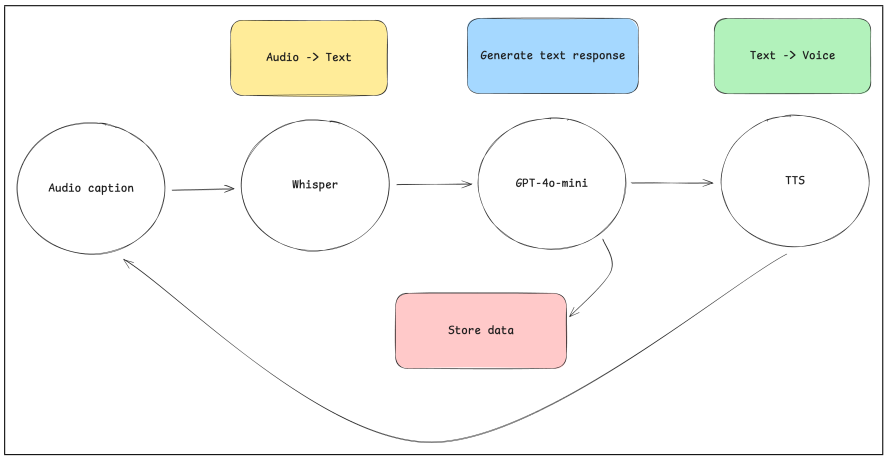


Figure 5: AI model flow.

Additionally, Figure 6 shows how the prompt was build, and how it controls the conversation so the user can be assisted in their coffee needs or registration. Once GPT-4o-mini gets all necessary information to complete the purchase or registration, the conversation is headed to the confirmation phase.

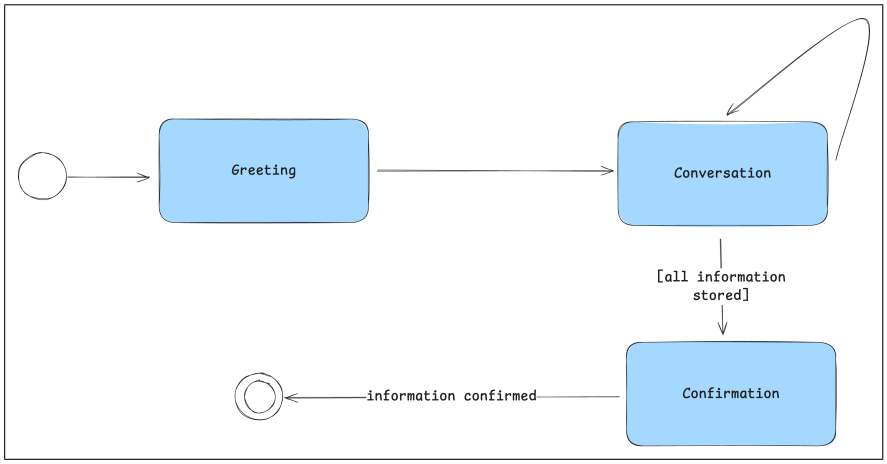


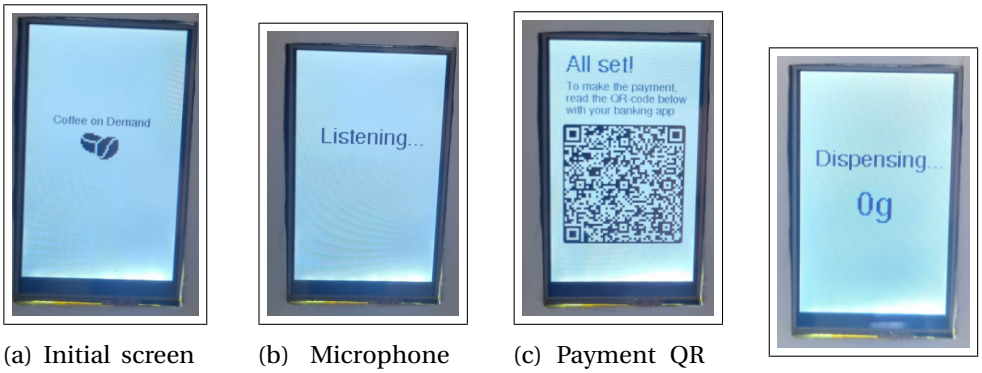
Figure 6: Conversation flow.

The prompt is based in a phase structure. Each phase has a guideline and a goal, and GPT-4o-mini uses goals to identify in which phase the conversation is. When determined, it uses the guideline of said phase to decide what to say to keep the conversation.

The LCD screen is used along with a shield to connect to an Arduino. The communication between the Arduino and the Raspberry is done by serial USB, as the Raspberry sends the information required by the Arduino to be displayed in the screen. In the section below, the states of the screen are listed.

- **Idle State**: Waiting for customer to arrive.
- **Listening State**: Waiting for the customer to answer or ask something.
- **Processing State**: The machine is processing customer answer or question.
- **Talking State**: Machine is emitting sound.
- **Dispensing State**: Machine is dispensing coffee.

The final versions of the screens presented to the user are shown Figure 7.



(a) Initial screen in idle. (b) Microphone on. (c) Payment QR code (d) Live weighting

Figure 7: User interface screens. Source: Authors (2025)

3.3.2 Embedded software

This software layer manages the real-time operation of the coffee dispensing mechanism, including the precise control of stepper motors, monitoring of the load cell for accurate measurements, and ensuring proper cup positioning via the obstacle sensor. Additionally, it controls the peripherals. Figure 8 shows the full cycle of the machine.

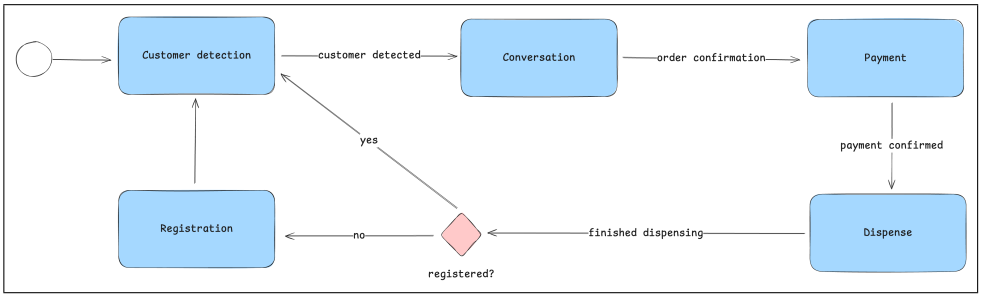


Figure 8: States of the embedded software. Source: Authors (2025)

First, for the customer recognition, in the initial stage, the system captures camera frames every second. If a face is recognized, the system enters in registered customer mode. Figure 9 illustrates a state machine of customer detection.

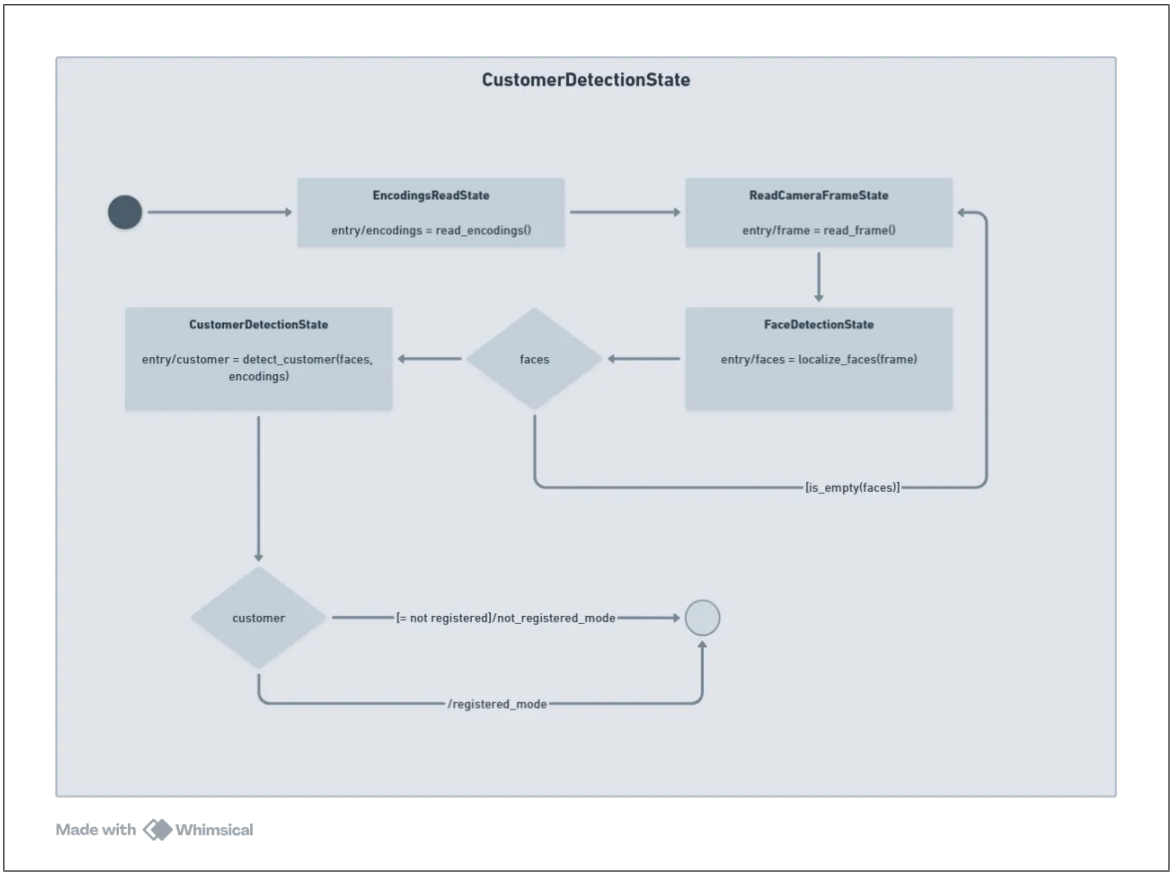


Figure 9: State machine for facial recognition. Source: Authors (2025)

For the voice processing, the system starts capturing ambient audio. In case of high levels of sound, the sample is characterized as speech, until new samples be marked with low level. Figure 10 illustrates a state machine of voice detection and capture mechanism.

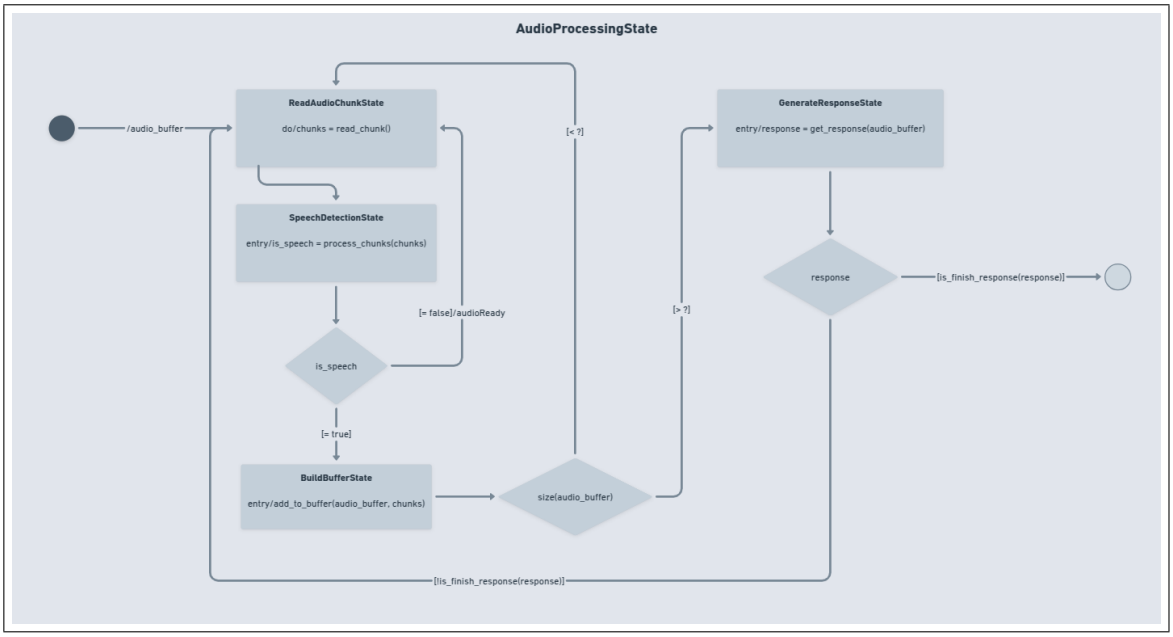


Figure 10: State machine for audio processing.

Coffee On Demand implements a dedicated dispensing logic routine. During the dispensing phase, one thread monitors the cup's position to verify proper positioning, while a second thread controls the stepper motors until the load cell detects that the desired weight has been reached. Figure 11 illustrates a state machine of the dispensing mechanism.

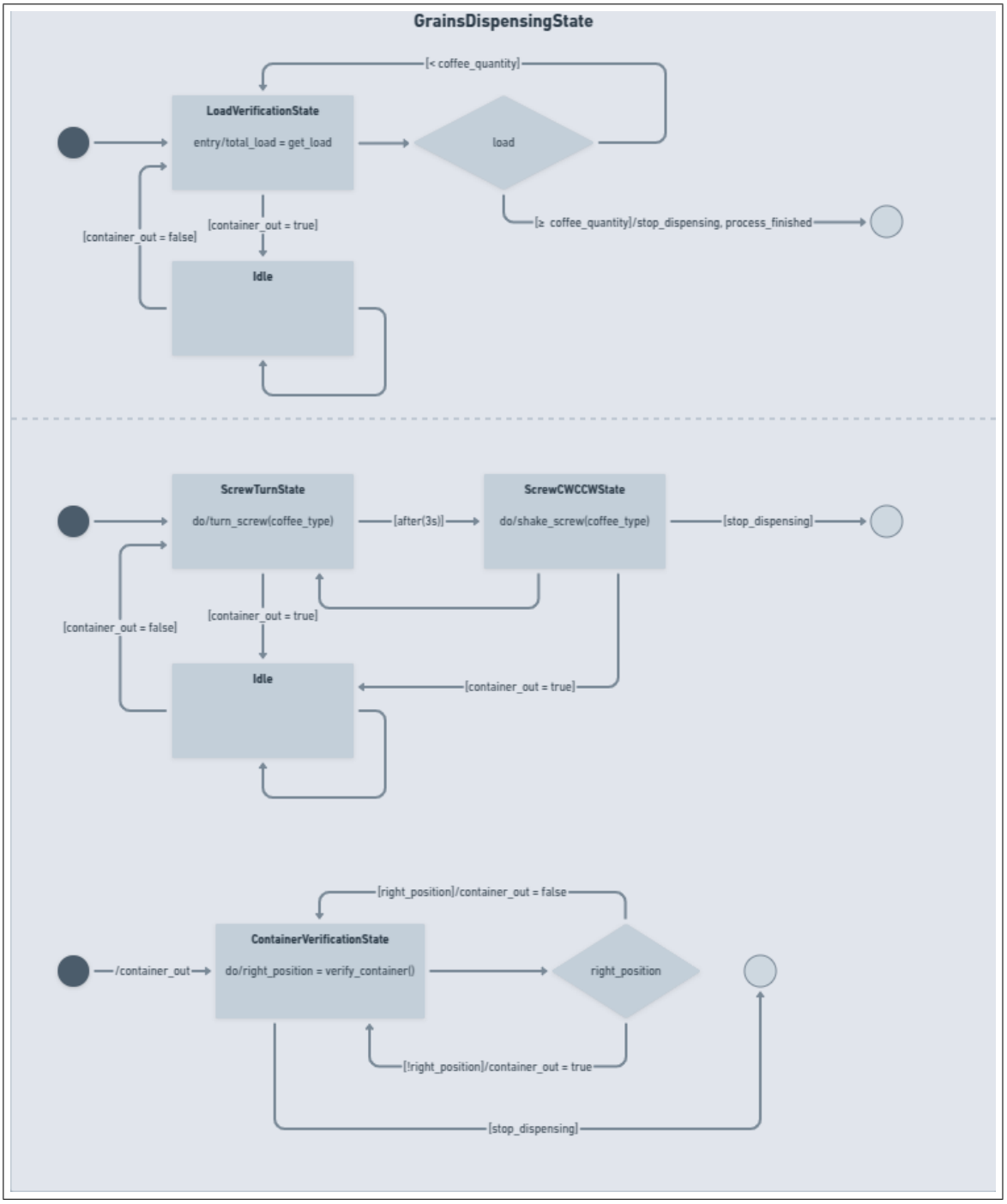


Figure 11: State machine for grains dispensing. Source: Authors (2025)

3.3.3 Web Interface

The web interface provides the machine owner with a convenient way to interact with the backend API, allowing remote monitoring and management of the Coffee On Demand system. Developed using NextJS and deployed on Vercel, the interface communicates exclusively with the backend API rather than directly interacting with the database.

The primary features of the web interface include:

- **Inventory Management**: The owner can update the stock or add new coffees by entering the weight of newly added coffee beans and setting the price per gram for each type of coffee. They can also enter coffee description for AI-driven suggestions. A representation of that feature is shown in Figure 12. In order to edit existent coffee types, the interface is represented in Figure 13.

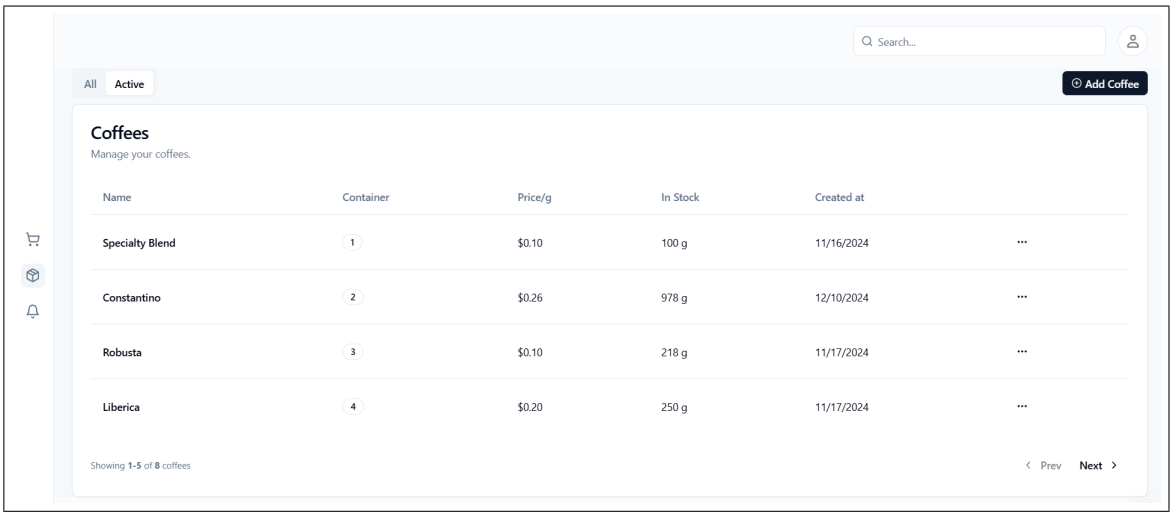


Figure 12: Inventory management screen showing active coffees. Source: Authors (2025)

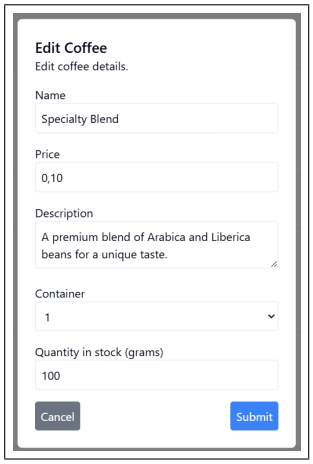


Figure 13: Editing existing coffee data. Source: Authors(2025)

- **Purchase History**: A simple log of all purchases made, distinguishing between registered users and guest transactions. The history is shown in a table, similar to the inventory screen, and can be seen in Figure 14.

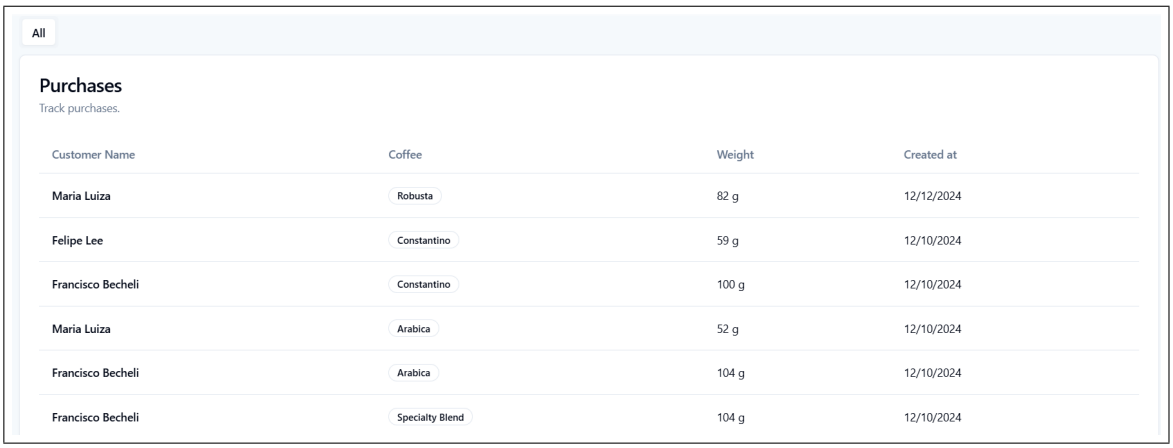


Figure 14: Purchase history screen. Source: Authors (2025)

- **Notifications**: The system generates alerts for low stock levels or potential maintenance needs, ensuring the machine remains operational. The alerts are displayed in a table, presented in Figure 15.

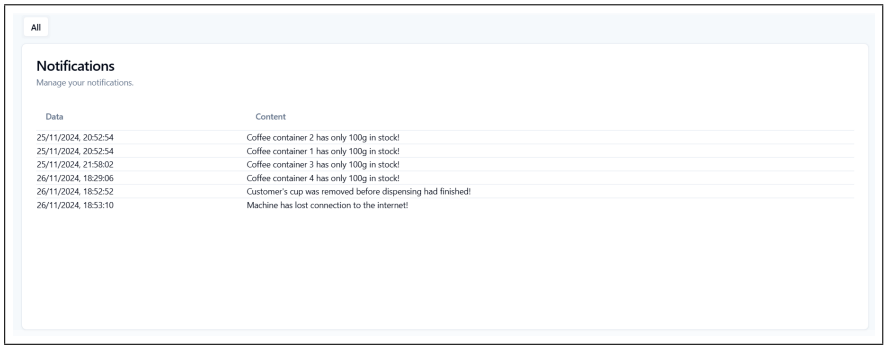


Figure 15: Notifications panel. Source: Authors (2025)

- **Secure Access**: The interface requires login credentials that are pre-registered by the system administrators, ensuring restricted access to sensitive data. The main page for this functionality is shown in Figure 16.

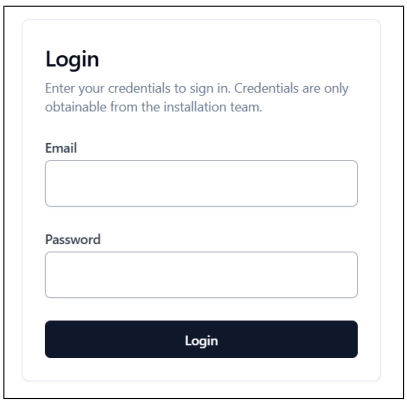


Figure 16: Login page. Source: Authors (2025)

The web interface serves as a bridge between the machine owner and the backend API, providing an intuitive dashboard to maintain smooth operations.

3.3.4 Coffee API

The backend API deals with the requests made by the management website, or the machine itself. The requests by the website include authentication, and creating, editing and deleting customers and coffees. The protocol used in this API is HTTP.

The requests by the machine happen for multiple reasons: when sending notifications to the website (when running out or completely out of a certain type of coffee, for example), when fetching data about available coffees, customers and their purchases, when dealing with the payments and when registering a new customer.

The notification system consists on a route on where the machine posts the error. That creates the alert in the notification center, already shown in section 3.3.3. That allows the system to communicate possible errors to the manager.

Regarding the payment API, the only payment method available is PIX. When the machine concludes a purchase, it requests a PIX QR code based on the price of the bill. Then, it verifies the payment every 3 seconds, by another request, until it is confirmed.

The full documentation of the API is available at our blog [4].

4 Results

The outcome of the work described in the previous sections is presented in the following video: `https://youtu.be/9MHAyQzoQ74`.

The project specifications and requirements were largely met, with all mandatory requirements successfully completed. Only six optional requirements remained unfulfilled, primarily due to time constraints rather than technical limitations.

In Table 4, a detailed cost analysis was conducted, presenting an itemized breakdown of the components along with their respective quantities, unit costs, and total expenses. This evaluation includes all those necessary components for the system's implementation, covering hardware, materials, peripherals, and accessories.

Table 4: Project Components and Costs

Item	**Qty**	**Unit Cost**	**Total Cost**
Raspberry Pi 4	1	240	240
OpenAI API	-	-	60
Arduino UNO	1	40	40
LCD Screen	1	15	15
1kg Load Cell + HX711	1	15	15
Nema 17 Step motor + A4988	4	60	240
Obstacle sensor (infrared)	1	5	5
MDF boards	6	15	90
Acrylic shapes	1	50	50
Power Supply	2	27	54
3D printed parts	12	24	290
Step motor driver	4	10	40
USB Camera	1	40	40
Speaker 3W	1	11	11
Lock	1	10	10
LCD Shield	1	25	25
USB microphone	1	5	5
Pack of plastic cups	1	29	29
Pack of bearings and shafts	1	10	10
Total Cost			1,264

Source: Authors (2025).

The budget was adhered and the selected components performed effectively

while remaining within financial constraints. Additionally, the risk analysis conducted during the planning phase proved valuable, as measures such as purchasing two power supplies helped mitigate potential issues and ensured the project's completion within budget.

The project schedule was also followed, with weekly tasks being completed on time. In cases where delays occurred due to component availability or delivery times, they were promptly addressed at the start of the following week, minimizing disruptions to the overall timeline. Table 5 provides a summary of the team's performance in each deliverable, indicating whether the work progressed as planned or if there were delays.

Table 5: Project Work Progress

Deliverable	Worked Hours	Expected Hours	Delay (h)	Status
Deliverable 1	41	42.25	1.25	Delayed
Deliverable 2	109	63.7	12	Delayed
Deliverable 3	71	73.25	-	On Time
Deliverable 4	87	97	6	Delayed
Deliverable 5	73	52.3	-	On Time
Deliverable 6	48	31	-	On Time

Source: Authors (2025).

While some deliverables were completed as expected, others experienced delays, emphasizing the challenges faced within the given time frame.

5 Conclusion

The Coffee On Demand project presents an innovative approach to automated coffee vending, leveraging AI and automation to enhance user experience.

Since all the mandatory requirements were met, along with several optional ones, it can be concluded that the project was successful. Additionally, the budget was adhered to throughout the process. However, while the current implementation achieved its objectives, there are areas for improvement and further development.

5.1 Future Work

Future improvements could involve expanding payment options beyond PIX, such as integrating credit/debit card payments, NFC-based transactions, or even cryptocurrency support to provide greater flexibility to users. Additionally, refining the machine learning algorithms for personalized recommendations could enhance the user experience by analyzing broader purchasing patterns and incorporating external factors such as seasonal preferences and popular trends.

Enhancing the voice recognition system to support multiple languages and dialects would increase accessibility for a wider audience. Improving the facial

recognition system for better accuracy under different lighting conditions and angles could make user identification more seamless.

Further developments could include remote monitoring capabilities for machine owners, providing real-time analytics on sales and maintenance needs via a mobile or web application.

Finally, exploring the possibility of modular expansions, such as the addition of more coffee bean containers could broaden the machine's capabilities and appeal to a larger market segment.

Acknowledgements

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