ECE 445

SENIOR DESIGN LABORATORY

Design Document

Smart Climate-Controlled Rice Dispenser

Team #22

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Content

1. Introduction

1.1 Problem Statement

Rice is one of the most commonly stored staple foods in many households, but maintaining its quality during storage is not always easy. When rice is exposed to warm and humid conditions for extended periods, it becomes more vulnerable to mold growth, moisture absorption, and pest infestation [1]. These problems can reduce food quality, create health concerns, and increase waste. In addition, many common home rice containers are passive storage solutions. They can hold rice, but they do not monitor environmental conditions or actively respond when the internal storage environment becomes unfavorable. As a result, users often do not notice problems until spoilage has already begun. Another inconvenience is that dispensing rice is usually done manually, which is often imprecise, messy, and inconsistent when users want a specific amount for cooking [2].

These issues create a clear need for a household device that can both improve rice storage conditions and simplify portion dispensing. A more effective system should not only store rice, but also monitor the storage environment, reduce the risk of moisture-related spoilage, and provide accurate on-demand dispensing. Such a device would improve convenience for users while also supporting better food safety and reducing waste.

1.2 Solution

Our solution is a smart climate-controlled rice dispenser that combines environmental monitoring, active climate regulation, and precision dispensing in a single household device. The system uses a temperature and humidity sensor to continuously monitor the internal storage conditions of the rice container. When the temperature or humidity rises above preset thresholds, the microcontroller activates a Peltier-based cooling unit and a circulation fan to lower the temperature and remove excess moisture from the enclosed space [3]. In addition, the device includes a screw-based dispensing mechanism driven by a stepper motor, allowing rice to be dispensed automatically according to a user-selected target mass. A load cell provides real-time weight feedback so that the system can adjust dispensing speed and stop accurately near the target amount [4]. A rotary encoder and OLED display give the user a simple way to set the desired amount and view operating status.

The novelty of this project is that it integrates two functions that are usually separate in ordinary kitchen products: food-preserving climate control and precise automatic grain dispensing. Traditional rice containers mainly focus on storage, while kitchen dispensers usually focus only on portion control and do not address humidity or temperature inside the container. Our design improves on these existing approaches by combining protection and convenience in one system. By doing so, it aims to reduce spoilage risk, improve dispensing accuracy, and create a smarter and more useful storage solution for everyday household use.

1.3 Visual Aid

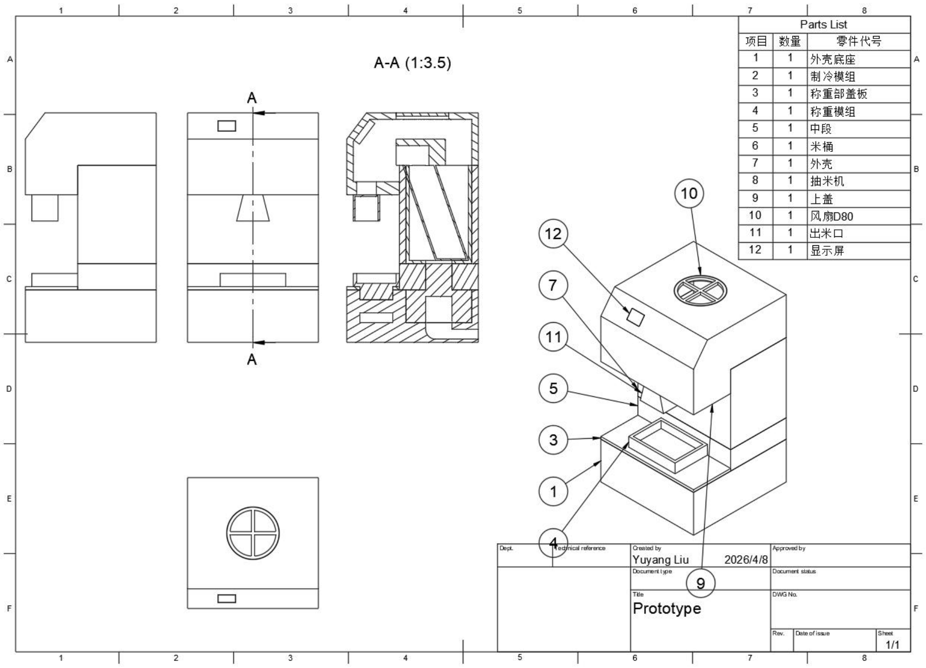
Figure 1: Device overview

1.4 High-level Requirements List

- The device must dispense a user-selected amount of rice between 100 g and 500 g with a final mass error no greater than ±5% [5].
- The device must monitor the storage environment and automatically activate its climate-control hardware whenever the internal temperature exceeds 25°C or the relative humidity exceeds 60% RH [6].
- The device must provide a user interface that allows the user to set the target dispensing amount, start the dispensing process, and view real-time system status, including dispensing progress and environmental data.
- The device must safely store and dispense rice using food-safe mechanical structures that prevent direct user contact with moving parts and isolate moisture generated by the climate-control subsystem from the electrical components.

2. Design

2.1 Physical Design & Housing



Parts List

项目	数量	零件代号
1	1	外壳底座
2	1	制冷模组
3	1	称重部盖板
4	1	称重模组
5	1	中段
6	1	米桶
7	1	外壳
8	1	抽米机
9	1	上盖
10	1	风扇D80
11	1	出米口
12	1	显示屏

Dept.
Technical reference
Created by
Yuyang Liu 2026/4/8
Approved by
Document type
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Prototype
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Figure 2: Engineering Drawing of Prototype

2.2 Block Diagram

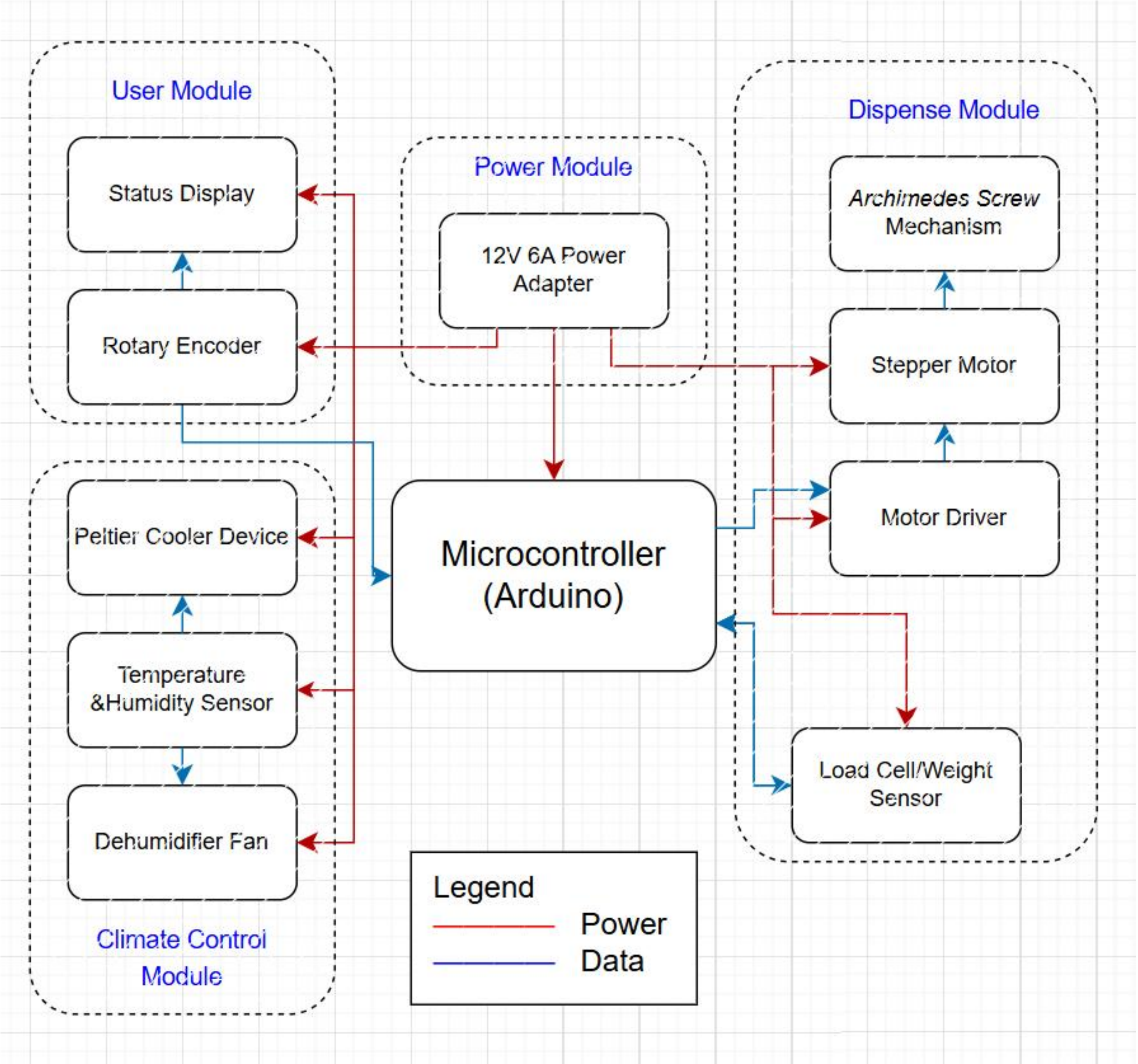

Figure 3: Block Diagram

2.3 Climate Control Subsystem

The Climate Control Module is essential for maintaining an optimal storage environment inside the smart rice dispenser. Rice is highly susceptible to mold growth and grain weevils when exposed to warm and damp conditions. This module proactively monitors and adjusts the internal microclimate to prevent spoilage and ensure food safety.

This module consists of three primary components: a Temperature & Humidity Sensor, a Peltier Cooler Device, and a Dehumidifier Fan. The Temperature & Humidity Sensor continuously measures the environmental conditions inside the rice storage bin and transmits this data to the Microcontroller. Based on these readings, if the internal temperature or humidity exceeds the safe thresholds programmed into the system, the Microcontroller will send a control signal to activate either the Peltier Cooler Device or the Dehumidifier Fan.

The Peltier Cooler utilizes the thermoelectric effect to generate a cold surface (heatsink) inside the container. Simultaneously, the Dehumidifier Fan circulates the trapped air across this cold surface. This dual action not only lowers the internal ambient temperature but also causes excess airborne moisture to condense on the cold heatsink, effectively pulling humidity out of the air [7]. Because the Peltier device and fan operate on the high-power 12V line from the Power Module, the Microcontroller interfaces with them using logic-level signals driving a relay module.

Table 1: Climate Control Subsystem Requirements and Verification

Requirements	Verifications
Sensor Accuracy & Update Rate: The Temperature & Humidity Sensor must measure the internal temperature with an accuracy of ±2°C and relative humidity within ±5% RH, updating the Microcontroller at least once every 5 seconds.	Place the sensor inside the dispenser alongside a calibrated thermohygrometer. Output the sensor data via the Microcontroller's serial monitor. Record the values and verify they fall within the ±2°C and ±5% RH error margins compared to the thermohygrometer. Verify via the serial timestamp that readings arrive at least every 5 seconds.
Cooling Capability: The Peltier Cooler Device and Dehumidifier Fan must be capable of reducing the internal temperature of the sealed dispenser by at least 5°C below the ambient room temperature within 30 minutes of continuous operation.	Place the sealed dispenser in a room with a stable ambient temperature (e.g., 25°C). Manually override the system to activate the Peltier and Fan. After 30 minutes, read the internal temperature via the sensor and verify it has dropped by at least 5°C (e.g., to 20°C or lower).
Automated Trigger Logic: The Microcontroller must successfully send an activation signal (HIGH) to the cooling hardware whenever the sensor reads a temperature exceeding 25°C or a relative humidity exceeding 60% RH.	Power on the device. Use a damp, warm cloth near the sensor to artificially raise the local humidity above 60% RH and temperature above 25°C. Use a digital multimeter to probe the Microcontroller's control output pins for the Peltier and Fan. Verify that the voltage shifts from LOW to HIGH when the thresholds are crossed.

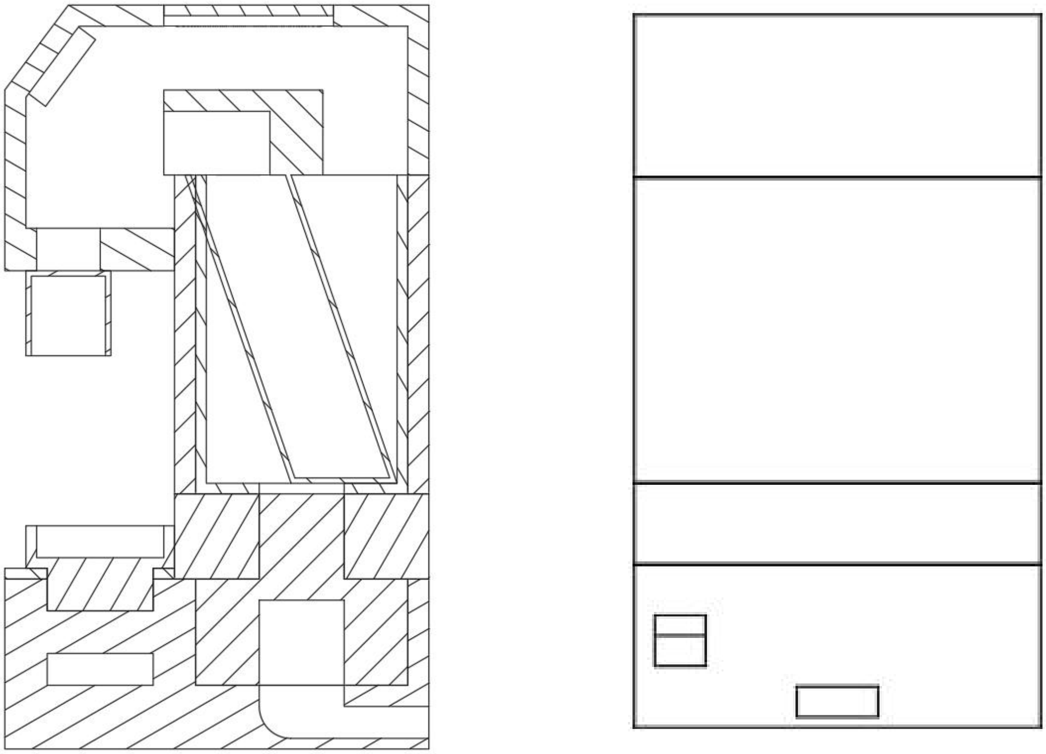

Figure 4. Intake duct and exhaust duct

2.4 Precision Dispensing Mechanism

The Precision Dispensing Subsystem is the functional core of the smart rice dispenser, responsible for translating digital user inputs into accurate physical mass. To meet the high-level requirement of a ±5% weight tolerance, the system utilizes a dual-stage closed-loop control algorithm synchronized with real-time weight feedback.

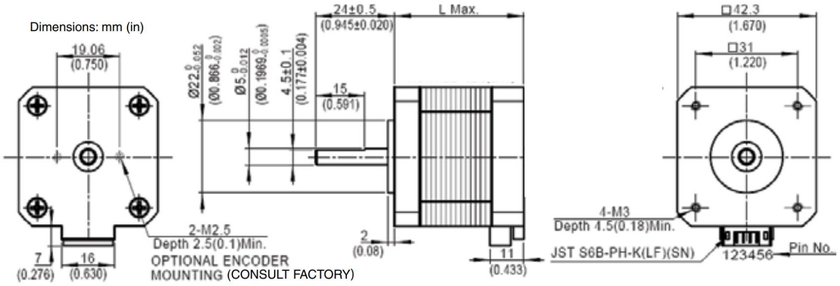

Figure 5: Mechanical design of the Archimedes screw feeder [8].

The mechanical assembly comprises an Archimedes screw driven by a Nema 17 stepper motor. The choice of a stepper motor over a standard DC motor allows the MCU to maintain discrete control over the rotation via precise pulse sequences, leveraging the motor's 1.8° step angle for granular adjustments [8]. The operation is guided by the following mathematical model:

$$W_{total}=(\rho_{textrice}\cdot V_{textpitch})\cdot N$$

This formula enables the firmware to calculate the required steps relative to the calibrated volume of each screw pitch.

To optimize the balance between speed and precision, the dispensing logic is executed in two distinct phases. During the High-Speed Coarse Phase, the motor operates at peak RPM to deliver the bulk of the material. Once the HX711 load cell reports that the weight has reached 90% of the target, the system transitions to the Fine-Tuning Phase. In this stage, the MCU modulates the pulse frequency to the A4988 driver, significantly decelerating the screw to prevent overshooting [9].

Finally, the controller implements a Predictive Stop Offset to account for the "in-flight" mass—grains that have already cleared the screw but have yet to land in the container. By factoring in this latency through empirical calibration, the algorithm ensures that the motor terminates rotation at the optimal millisecond to hit the target weight accurately

Table 2: Sensor Subsystem Requirements and Verification

Requirements	Verifications
Closed-Loop Dispensing Accuracy: The system must dispense rice with a final mass tolerance of ±5% for user-defined targets (100g–500g) using a dual-stage velocity and predictive offset algorithm.	- Place a container on the load cell and set a target of 200g. Initiate the routine: the motor must switch from high-speed to micro-stepping at180g (90% threshold). Once the settled weight is reached, compare the internal HX711 reading against an external high-precision laboratory scale [10]. Repeat for 10 trials to calibrate the delta w constant, ensuring the average error remains centered within the ±5% margin to account for "in-flight" grains and mechanical inertia.
UI Responsiveness and Feedback: The OLED display must update the target weight within 100ms of an encoder pulse, and the system must trigger the	- -Use an internal software timer to measure the latency between the EC11 rotary encoder's quadrature pulse detection and the completion of the I2C OLED refresh cycle [11]. Rapidly rotate the encoder to verify no pulses are dropped during high-speed adjustment. Additionally, confirm that pressing the encoder button

dispensing sequence immediately upon button interrupt.	triggers a hardware interrupt that preempts background environmental monitoring tasks (DHT22 polling) to initiate the motor driver without perceived lag.
System Robustness (Anti-Jamming and Filtering): The system must maintain stable weight readings during motor vibration and detect mechanical stalls within 2 seconds to initiate a recovery sequence.	- Activate the Nema 17 motor at maximum RPM and monitor the Serial Plotter to verify that the software-based moving average filter keeps weight fluctuations under ±1.0g. - To test fault recovery, manually obstruct the Archimedes screw; the MCU must detect a "zero weight change" state while the motor is pulsed, trigger a 3-turn reverse rotation sequence within 2 seconds to clear the jam, and display a persistent "Clog Alert" on the UI until the error is resolved.

2.5 User Interface Subsystem

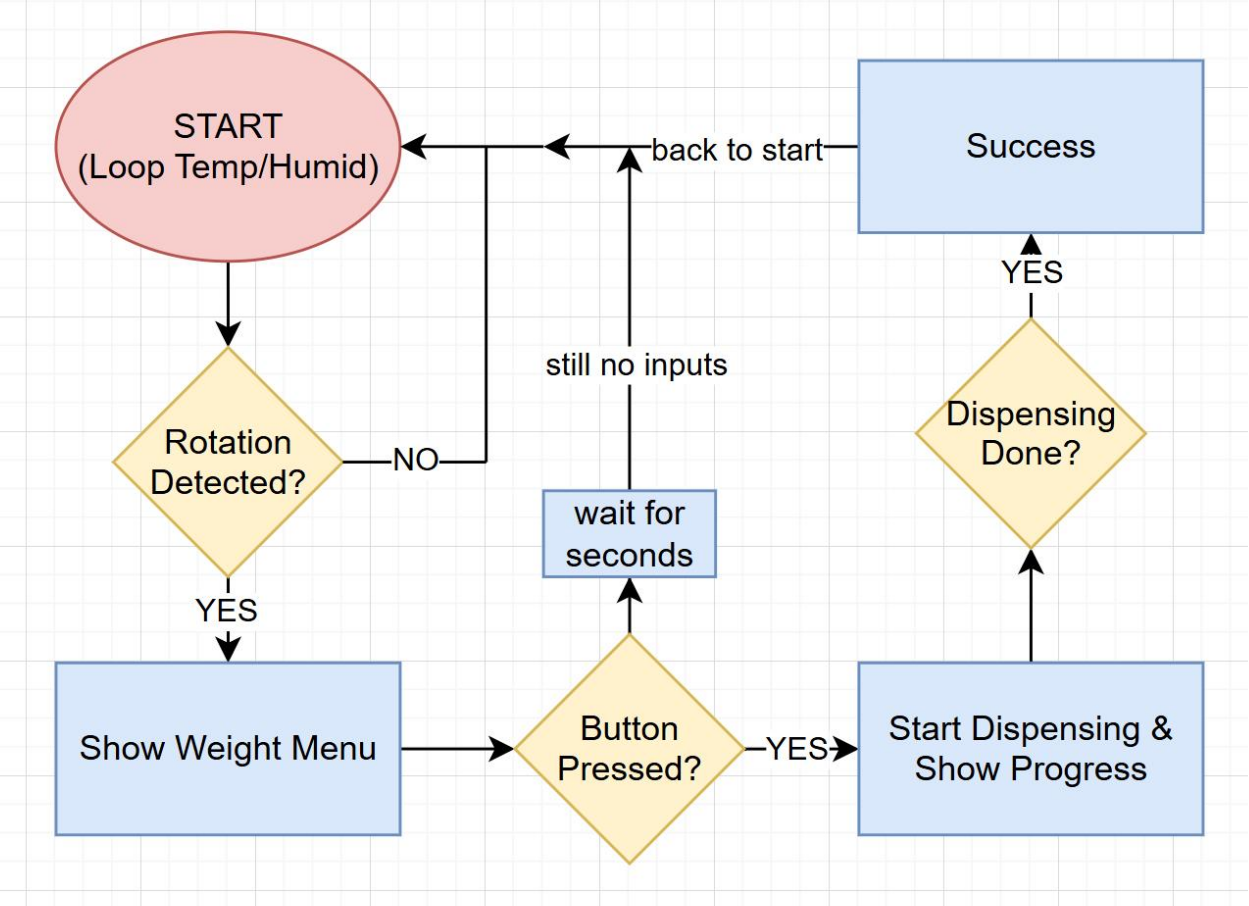

Figure 6: User Interaction Flowchart

The User Interface (UI) Subsystem serves as the critical bridge between user intent and hardware execution. To provide an intuitive and lag-free experience, the system utilizes an EC11 rotary encoder as the primary input paired with a 0.96" OLED display for visual feedback [11].

- Circuit Design and Input Mechanism Unlike traditional potentiometers, the EC11 encoder provides digitized step adjustments via quadrature pulse signals and features an integrated push-button. The circuit design incorporates hardware debouncing and pull-up resistors to ensure the stability of the interrupt signals. When the knob is pressed, the MCU detects a falling edge transition, triggering the dispensing interrupt. This logic is assigned the highest priority in the firmware to ensure instantaneous system response.
- Display Logic and Interaction Flow Communicating via the I2C protocol, the OLED display logic is organized into two distinct functional layers:

1. Standby Mode: The screen cyclically displays real-time internal temperature and humidity data gathered from the DHT22 sensor.
2. Setting Mode: Upon rotating the knob, the screen immediately switches to the weight selection interface. The value increments or decrements linearly in 5g steps (Range: 100g–500g).
3. Execution Mode: Once confirmed, the display shows a dynamic progress bar or real-time weight increments until the process is complete [5].

Table 3: User Interface Subsystem Requirements and Verification

Requirements	Verifications
Display ambient temperature and humidity on the OLED screen during standby mode, updating periodically [7].	- Power on the device and wait for the initialization sequence to finish. - Verify the OLED displays the current temperature and humidity readings as the default standby screen. - Use a serial console to verify the I2C data sent to the display updates the environmental values at least once every 5 seconds. - Apply a warm/damp cloth near the DHT22 sensor and verify the displayed temperature and humidity values update to reflect the change within the next refresh cycle.
Enter the weight setting mode and adjust the target dispensing weight	- From standby mode, rotate the encoder clockwise by one physical detent (click). - Verify the display immediately switches from environmental data to the "Set Weight" prompt.

(100g - 500g) in 5g increments by rotating the EC11 encoder [11].	- Verify the initial weight displayed is the minimum starting value of 100g. - Rotate the encoder clockwise continuously and verify the displayed value increases by exactly 5g per detent. - Continue rotating clockwise past 500g and verify the value does not exceed the 500g maximum cap. - Rotate the encoder counter-clockwise and verify the value decreases by 5g per detent, stopping exactly at the 100g minimum floor.
Initiate the dispensing process by pressing the encoder button after setting the target weight.	- Observe the OLED screen immediately after initiating a 200g dispense cycle. - Verify the screen dynamically updates the current dispensed weight (or a visual progress bar) at least twice per second as the load cell data changes. - Once the final target weight is reached and the motor halts, verify the screen displays a "Dispense Complete" or "Success" message. - Wait for 3 to 5 seconds and verify the display automatically clears the success message and reverts to the default standby screen (displaying temperature and humidity).
Ignore accidental short button presses (debouncing) to prevent unintended dispensing or rapid double-triggers.	- Navigate to the "Set Weight" screen and set a value of 200g. - Quickly tap or flick the encoder button so the contact time is less than 50ms. - Verify the display does not transition to the dispensing screen and the motor does not engage. - Firmly press the button for >50ms and verify the system accepts the command and initiates the sequence. - Repeatedly spam the button during an active dispensing cycle and verify the system ignores the inputs and does not restart or interrupt the current cycle.
Time out and return to standby if the user abandons the weight setting menu.	- Rotate the encoder to enter the "Set Weight" menu and leave it at 300g without pressing the confirm button. - Start a timer and do not touch the encoder. - Verify that after exactly 10 seconds of inactivity, the display discards the pending 300g command and automatically returns to the standby environmental monitoring screen.

2.6 Power Management Subsystem

The power module is responsible for safely and reliably supplying electrical energy to all other subsystems within the smart rice dispenser. Given the electromechanical and thermoelectric nature of the system, the power architecture must be capable of handling significant current draws without causing voltage drops that could reset logic components or impair sensor accuracy [4].

The primary power source is a wall-connected 12V 6A AC-to-DC Power Adapter, capable of delivering up to 72W of continuous power. This specific rating was selected to accommodate the system's most power-hungry components: the Peltier cooler and the stepper motor.

Power distribution is divided into two main categories based on voltage requirements:

- High-Power 12V Distribution: The 12V output from the adapter is routed directly to the high-current devices. In the Dispense Module, it powers the Motor Driver, which energizes the Stepper Motor responsible for turning the Archimedes Screw [8][9]. In the Climate Control Module, the 12V line directly powers the Peltier Cooler Device and the Dehumidifier Fan.
- Logic-Level 5V/3.3V Distribution: The sensors and logic components cannot operate at 12V. The 12V supply is routed into the Microcontroller (Arduino), which utilizes its onboard linear voltage regulators to step the voltage down to a stable 5V and 3.3V. This regulated low voltage is then distributed to the User Module (Status Display, Rotary Encoder), the Weight Sensor, and the Temperature & Humidity Sensor.

Table 4: Power Subsystem Requirements and Verification

Requirements	Verifications
The power adapter must supply a continuous 12V ± 0.6V even when the system is operating at maximum capacity	- Connect a digital multimeter (DMM) or oscilloscope in parallel with the 12V output. Manually trigger both the Dispense Module and the Climate Control Module at the same time. Verify that the measured voltage remains between 11.4V and 12.6V throughout the test.
The system must step down the 12V supply to provide a stable 5V ± 0.25V	- Probe the 5V output pin of the Microcontroller with an oscilloscope. Operate the stepper motor at its maximum dispensing speed. Verify that the average DC voltage remains between 4.75V and 5.25V, and that transient voltage spikes/drops do not exceed 200mV peak- $W_{total}=(\rho_{rice}\cdot V_{pitch})\cdot N$ to-peak.

2.7 Tolerance Analysis

The primary challenge of the Precision Dispensing Subsystem is ensuring that the final mass error remains within ±5% across the operational range of 100g to 500g. For the most demanding case—a minimum 100g target—the system must limit the total absolute error to within ± 5g.

2.7.1 Mathematical Model of Dispensing

The total mass of rice dispensed Wtotal by the Archimedes screw is governed by the rotation of the screw and the physical properties of the grain:

$$W_{total}=(\rho_{rice}\cdot V_{pitch})\cdot N$$

Where:

ρ_{rice} is the bulk density of the rice.

$V_{pitch}$is the calibrated volume of a single screw pitch.

N is the number of discrete rotations (steps) performed by the motor.

2.7.2 Error Source Analysis

The total system error (E_{total}) is the sum of mechanical resolution error (Δm_{res}), sensor sampling noise (Δm_{sensor}), and the variance in "in-flight" mass (Δm_{flight}):

$$E_{total}=\Delta m_{res}+\Delta m_{sensor}+\Delta m_{flight}$$

- **Mechanical Resolution (Δm_{res}):** The Nema 17 stepper motor features a 1.8° step angle, meaning it requires 200 steps for a full 360° revolution. Assuming a single screw pitch dispenses approximately 10g of rice, the resolution per motor pulse is:

$$\Delta m_{res}=\frac{10\text{g}}{200\text{steps}}=0.05\text{g/step}$$

This mechanical precision is significantly higher than the required 5g tolerance.

- **Sensor Sampling Noise** (Δm_{sensor}):

The HX711 24-bit ADC provides high-resolution feedback from the load cell. While motor vibrations during operation can introduce noise, the firmware utilizes a software-based moving average filter to maintain stable weight fluctuations within $\pm 1.0 g$.In-Flight Mass Variance (Δm_{flight}):

The largest potential error comes from "in-flight" mass—grains that have cleared the screw but have not yet landed in the container when the motor stops. To mitigate this, the system employs a two-phase strategy:Fine-Tuning Phase: At 90% of the target weight (e.g., 90g), the MCU reduces the pulse frequency to the A4988 driver, drastically decelerating the screw to minimize inertia.Predictive Stop Offset: The system triggers the motor to stop at a calculated threshold $W_{stop} = W_{target} - C$, where C is the empirically calibrated mass of grains in transit. In the decelerated fine-tuning state, the variance of this in-flight mass (Δm_{flight}) is reduced to approximately $\pm 0.5 g$.

2.7.3 Total Error Simulation

For a 100g target, the cumulative worst-case error is estimated as:

$$|E_{total}| \approx 0.05 g + 1.0 g + 0.5 g = 1.55 g$$

Since $1.55 g < 5 g$ (the 5% limit for a 100g dispense), the design is mathematically sufficient to meet the high-level requirements.

By integrating a dual-stage closed-loop control algorithm with predictive stop offsets, the system successfully compensates for mechanical latency and sensor noise. This approach ensures that even at minimum dispensing volumes, the accuracy remains well within the $\pm 5\%$ tolerance zone.

3. Cost and Schedule

3.1 Bill of Materials

Table 5: Itemized list of components and costs

Description	Manufacturer	Part Number	Quantity	Total Cost
Bi-color LED	Generic	3 mm diffused, red-blue, 3-pin	1	0.99 RMB
LED Lamp Beads (Green)	Generic	3 mm, white body, green light, long lead, 10 pcs pack	1	0.55 RMB
LED Lamp Beads (Yellow)	Generic	3 mm, white body, yellow light, long lead, 10 pcs pack	1	0.49 RMB
Rotary Encoder	Generic	EC11 with push button, 20 mm shaft	1	2.09 RMB
Driver IC	UMW	ULN2003A	2	0.72 RMB
Stepper Motor	Generic	28BYJ-48, DC 5V	1	4.80 RMB
Buck Converter Module	Generic	LM2596S adjustable DC-DC step-down module	1	3.96 RMB
Temperature and Humidity Sensor	Generic	DHT22 / AM2302 module	1	5.28 RMB
Relay Module (1-channel)	Generic	5V relay module	3	10.38 RMB
Relay Module (2-channel)	Generic	5V relay module	3	18.39 RMB
Desiccant Pack	coolclean	Silica gel moisture absorber, 10-pack	1	6.80 RMB
Cooling Fan	Generic	4010 cooling fan	1	5.00 RMB
DC Power Jack	Generic	DC005, 5.5 × 2.1 mm	2	0.30 RMB
OLED Display Module	Generic	0.96 inch SSD1306, I2C / SPI	1	8.00 RMB
Microcontroller Board	Arduino-compatible	Nano V3.0, ATmega328P	1	17.80 RMB
Thermoelectric Cooling Kit	seebeck	12V Peltier cooling module kit with heatsink and power adapter	1	65.00 RMB

The total cost of this project includes labor cost and purchased electrical components. Since this prototype mainly focuses on proof-of-concept validation, the cost of 3D-printed structural parts is not included in the estimate. Therefore, the main hardware cost comes from the electrical components used for sensing, control, display, actuation, and climate control.

For labor cost, we assume a reasonable starting salary of $50 per hour for an ECE graduate. Following the ECE 445 cost model, the labor cost for each team member is calculated as $50 × 2.5 × 45 = $5,625. For a four-person team, the total labor cost is $22,500.

The parts cost includes the Arduino Nano, OLED display, rotary encoder, DHT22 sensor, relay modules, stepper motor, buck converter, cooling fan, and thermoelectric cooling kit. Based on the current BOM, the estimated total parts cost is **150.55 RMB**. The grand total of the project is the sum of labor cost and parts cost, with labor representing the largest portion of the overall cost.

3.2 Schedule

Table 6: Schedule for Final Project

Week	Task	Person
March 15 - March 31	Review and Update Proposal & Complete Design Document	Everyone
	Component investigation and selection for sensors and MCUs	Shining
	Create block diagram and complete closed-loop flowchart	Shining, Zixin
	Preliminary 3D modeling and structural sketches	Yuyang, Gaoning
April 1 - April 7	Hardware setup and begin PCB schematic drafting	Shining
	Implement code for reading temp/humidity and testing button inputs	Zixin
	Optimize 3D models and add dust-proof/moisture-proof structures	Yuyang
	Design Review & Order all sensors, motors, and components	Gaoning
April 8 - April 12	Design Review & Order all sensors, motors, and components	Everyone
	PCB Review & Finalize initial PCB design for the first order	Shining
	Breadboard testing: integrate stepper motor with basic MCU control algorithms	Zixin
	Finalize 3D CAD models and send out for 3D printing/manufacturing	Yuyang
	Mechanical Assembly: Construct silo, discharge mechanism, and support frame	Gaoning
April 13 - April 22	System Debugging: Fix mechanical jamming and adjust software predictive offsets	Everyone
	Refine system architecture based on integration feedback	Everyone

	System Verification Testing: Run full dispensing cycles and climate control tests	Everyone
April 23 - April 28	Finalize codebase and freeze hardware modifications	Shining, Zixin
	Aesthetic improvements and final mechanical polishing	Yuyang, Gaoning
	Mock demo	Everyone
April 29 - May 7	Mock Presentation and comprehensive system endurance testing	Everyone
	Final Demo Preparation	Everyone
	Work on final paper	Everyone
May 8 - May 15	Complete Final Documentation, Project Report, and Final Presentation slides	Everyone
	Finish writing and submig the final paper	Everyone

4. Ethics and Safety

4.1 Food Safety Requirements

Because our product is categorized as a food storage and dispensing appliance, it must adhere to strict sanitation guidelines to prevent the growth of mold and the proliferation of pests, such as rice weevils. We will design our system with reference to the NSF/ANSI 2 documentation, which establishes food protection and sanitation standards [12].

- Material Safety: All components that come into direct contact with the rice, including the inner storage bin, the Archimedes screw, and the dispensing nozzle, must be manufactured from food-grade, non-toxic materials (e.g., BPA-free plastics or food-grade stainless steel) that will not migrate chemicals into the food.
- Cleanability/Sanitization: The dispensing mechanism and the storage bin must be designed for easy disassembly. Users must be able to regularly clean and sanitize the Archimedes screw and the bin's interior to prevent residue buildup, which can attract pests or cause mold.

- Durability: The product should be durable enough to withstand deep cleaning and continuous use without affecting the food involved

4.2 Electrical & Mechanical Safty

The integration of mechanical, electrical, and thermoelectric systems presents several specific safety hazards that our design must mitigate:

- Mechanical Hazards: The Archimedes screw, driven by a high-torque stepper motor, presents a significant pinch and crush hazard. To mitigate this, the screw mechanism must be entirely enclosed within the dispenser housing. The dispensing outlet must be designed narrowly enough, or equipped with a physical guard, to prevent a user (especially a child) from inserting their fingers into the active rotating mechanism.
- Electrical and Moisture Hazards: The Climate Control Module relies on a Peltier device, which inherently produces condensation (water droplets) as it cools the air. It is absolutely critical that the physical design strictly isolates the water collection/drainage path from all exposed PCBs, the 12V power lines, and the microcontroller. A short circuit caused by condensation could lead to total system failure, electrical shock, or fire. All delicate electronics must be housed in a separate, sealed enclosure away from the cooling sink.
- Power Supply Safety: To protect the user from high-voltage AC mains, we are using an external, commercially certified 12V AC-to-DC power adapter rather than handling 120V/240V AC conversion on our custom PCB.

5. Sources

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