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Choco Matic

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Disclaimer

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Abstract

The rising demand for high-quality, customized chocolate bars has driven the need for small-scale, automated production solutions. This project presents the design and implementation of a chocolate bar production line that incorporates a fully automated chocolate tempering machine and a topping system for nuts and raisins.

The system integrates three microcontrollers: an Arduino Mega 2560 for production line control, an ESP32 for managing the tempering machine and wireless app connectivity, and an Arduino Uno for monitoring filling levels and driving additional LCD displays. Key features include a PT100 temperature sensor for precise heating, a 1950W heating element controlled via SSR, ultrasonic sensors for topping level monitoring, and mode-selection keypads for both chocolate type and topping. Chocolate dispensing and topping systems are actuated using NEMA23 stepper motors, while a windshield-wiper motor drives the conveyor belt.

Additionally, real-time feedback is provided through LCD displays, and the entire system can be operated manually or remotely via a mobile application. Thermal behavior and energy usage were modeled using fundamental heat transfer formulas, ensuring reliable tempering with realistic time estimates. The project aims to deliver a scalable, energy-efficient, and user-friendly solution suitable for artisan or semi-industrial chocolate production environments.

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Chapter one

Introductory

Chapter one: Introductory

1.1 Problem Statement

In small-scale chocolate manufacturing, one of the most significant challenges lies in maintaining consistent product quality while minimizing manual labor and production time. Traditional chocolate tempering processes are labor-intensive and require precise temperature control to avoid bloom, grainy texture, or poor molding. Likewise, topping customization (such as adding nuts or raisins) often relies on manual intervention, limiting production speed and scalability.

Furthermore, there is a lack of affordable, compact, and modular systems that can manage both chocolate tempering and bar assembly including molding, filling, topping, and vibration for customized chocolate products. Existing solutions are either too costly for small producers or too simplified to ensure precision and consistency.

In many student or prototype-level projects, the integration of hardware components such as high-power heating elements, industrial sensors, and motor drivers is rarely explored in a production context with real chocolate behavior. Thus, there exists a gap between theoretical automation solutions and real-world food-safe systems.

This project aims to address these challenges by designing and implementing a fully automated chocolate bar production line with a real-time monitored tempering system, topping dispensers, and wireless control via a mobile application offering a scalable and modular solution for educational, or semi-industrial environments.

1.2 Objectives

The primary goal of this project is to design and implement an automated chocolate bar production line with integrated tempering and topping systems. The system is built to ensure precise temperature control, consistent bar quality, and efficient topping customization. The detailed objectives are:

- **Automate the chocolate tempering process** using real-time temperature monitoring (via PT100 sensor and MAX31865 module) and a 1950W heating element controlled through an SSR and ESP32.
- **Provide support for three chocolate types** milk, dark, and white each with its unique tempering profile.
- **Enable topping customization** by allowing users to select between raisins or/and nuts or no topping via a dedicated keypad.
- **Control the mold-filling process** using a stepper-controlled stainless-steel pipe and IR sensors to detect mold positioning.
- **Ensure proper mixing and setting** by integrating a vibration motor for uniform chocolate distribution in the mold.
- **Drive the production line** using a windshield-wiper motor controlled by a BTS7960 motor driver for cost-effective and reliable belt movement.
- **Monitor the filling levels** of toppings and chocolate containers using ultrasonic sensors and display them in real time on dedicated LCDs.
- **Integrate user interaction** through keypads, a 20x4 LCD for system status, and remote operation through a mobile app via Wi-Fi (ESP32).
- **Use modular microcontroller architecture**, employing Arduino Mega for the main line, Arduino Uno for filler monitoring, and ESP32 for the tempering control and network interface.
- **Implement heat transfer calculations** to estimate heating time and ensure energy efficiency.

These objectives aim to deliver a scalable, user-friendly, and technically sound solution for small-batch chocolate manufacturing, with the potential for future upgrades and industrial applications.

1.3 Importance of work

This project plays a significant role in demonstrating how embedded systems and industrial automation can be applied to real-world food production challenges specifically in the context of small-scale, customized chocolate manufacturing. The importance of this work lies in several key areas:

1. Automation of Craft Chocolate Processes

Tempering chocolate is a temperature-sensitive process that directly impacts the texture, appearance, and shelf life of the final product. Automating this with precise temperature control improves product consistency and quality while reducing the dependency on skilled manual labor.

2. Integration of Real Hardware Systems

This project bridges the gap between academic microcontroller-based automation and real hardware deployment. It involves integrating high-power heating components (1950W heating element), industrial motor drivers (YS-DIV268N-5A and BTS7960), and real-time sensors into a functional production line.

3. Real-Time Monitoring and Control

The system provides clear feedback through LCD displays and offers remote control capabilities via Wi-Fi and mobile apps. This enhances usability and safety allowing operators to track temperatures, filling levels, and operational states without needing constant manual supervision.

4. Modular Design for Expansion

Using three microcontrollers (Arduino Mega, Uno, and ESP32) allows independent handling of tasks like motion control, temperature regulation, and level monitoring. This modularity ensures the system is scalable and easy to upgrade or adapt for other confectionery automation use cases.

5. Scientific Engineering Approach

This project does not rely on trial-and-error. It incorporates thermal energy calculations to estimate the heating time of water and chocolate, factoring in real losses. This ensures that energy efficiency and time estimation are based on physical models, enhancing engineering credibility.

6. Educational and Industrial Relevance

The system serves as both an academic demonstration of interdisciplinary engineering (combining electronics, control, thermal physics, and mechanical design) and a practical foundation for small-scale industrial chocolate production.

7. Real-World Impact and Innovation

The prototype showcases how students can develop meaningful, cost-effective hardware that addresses real business and manufacturing needs especially in regions or startups that can't afford industrial-grade chocolate production lines.

1.4 Organization of the Report

This report is organized into several chapters that outline the complete lifecycle of the chocolate bar production line project from concept to implementation. Each chapter serves a distinct purpose and builds upon the previous to provide a comprehensive view of the work carried out.

Chapter One: Introduction

Introduces the project background, identifies the problem being addressed, outlines the project's objectives, and highlights its significance in both academic and real-world contexts.

Chapter Two: Constraints, Standards, and Component Selection

Presents the constraints faced during development, the industry standards and safety considerations followed, and the rationale for selecting specific components such as microcontrollers, motor drivers, sensors, and heating elements.

Chapter Three: Literature Review

Explores previous work in the field of chocolate automation, embedded control systems for food processing, and comparable tempering or topping systems. It positions the project in context with current technologies.

Chapter Four: System Methodology and Design

Details the design of the system, including hardware architecture, microcontroller roles, sensor integration, temperature control, and user interface development. It also includes system-level block diagrams and heat transfer calculations.

Chapter Five: Implementation and Testing

Covers the hardware assembly, software development, and individual component testing. It discusses the results of integration testing and the performance of the full system under real use-case scenarios.

Chapter Six: Conclusion and Future Work

Summarizes the project's outcomes and discusses possible improvements such as full app integration, more advanced topping mechanisms, safety features, or extending the system to support multiple mold trays.

References and Appendices

Includes a list of all academic and technical sources referenced, along with appendices containing full schematics, system code, and any additional data that supports the project.

Chapter Two

Constraints, Standards/ Codes and Earlier course work

2.1 Constraints

Throughout the design and implementation of our automated chocolate bar production line, we encountered several constraints that shaped the design and technical decisions made. Despite these challenges, the system was successfully implemented using real-world food-safe hardware and a functioning conveyor-based prototype.

1. Budget Constraints

Working with a limited student budget, we carefully selected cost-effective yet reliable components. The use of repurposed items such as a 1950W heating element from a washing machine and open-source hardware like Arduino microcontrollers allowed us to balance functionality with affordability.

2. Integration of High-Power and Food-Grade Components

The system integrates a **real, fully functioning stainless-steel chocolate tempering machine**, complete with a food-safe chocolate tank and water bath layer. This presented challenges in terms of safety, thermal control, and interfacing with low-voltage logic, but it greatly improved realism and credibility compared to a simulated setup.

3. Prototype Space Constraints

The working prototype for the production line -including the mold tray, conveyor belt, and topping dispensers was designed to fit within limited lab space. This required a compact yet modular layout, particularly for wiring and mechanical component placement.

4. High-Voltage Handling

The tempering machine's 1950W, 230V heating element demanded strict adherence to safety precautions. The solid-state relay (SSR) was safely isolated from the microcontroller logic, and all wiring was protected to prevent accidental contact or overheating.

5. Multi-Controller Synchronization

The system uses three separate controllers: an **ESP32 for Wi-Fi and heating control**, an **Arduino Mega 2560 for the production line**, and an **Arduino Uno for managing ultrasonic level sensors and display units**. Coordinating tasks between them required careful management of data sharing, timing, and logical state handling.

6. Thermal Calibration

Accurate temperature control was essential to achieve proper chocolate crystallization. Factors such as heating lag, thermal conductivity of water and chocolate, and real-world losses required calibration beyond theoretical calculations. Temperature readings from the PT100 sensor were processed using the MAX31865 module and tuned for precision.

7. Mechanical Assembly and Precision

All core components of the tempering machine were fabricated using food-grade stainless steel, including the chocolate container, water bath, and pipe valve system. This ensured hygienic standards and real-world reliability. The production line, although a prototype, was designed to accurately demonstrate chocolate dispensing, topping control, and mold handling.

8. Time Constraints

The project was completed within a single academic semester. This imposed strict deadlines across all phases from design and procurement to testing and final integration which required efficient planning and time management.

2.2 Problems and Solutions

During the implementation of our chocolate bar production line and tempering system, we encountered several hardware and software challenges. Below are the key technical problems faced and the corresponding solutions adopted.

1. Safe Control of High-Power Heating Element

Problem: The 1950W 230V heating element required safe switching through a low-voltage microcontroller. Direct connection to Arduino or ESP32 posed a serious electrical hazard.

Solution: We used a **Solid-State Relay (SSR-40DA)** to isolate the high-voltage load. The SSR was triggered by the **ESP32's digital output pin**, with proper heat sinking and current-limiting resistors added for long-term reliability.

2. Inaccurate or Noisy Temperature Readings

Problem: The PT100 RTD sensor initially produced fluctuating readings due to improper grounding and electrical noise from the heating element.

Solution: We used a **MAX31865 module** for accurate digital conversion of the RTD signal. Proper shielding and grounding were implemented, and sensor wires were separated from the high-voltage path to minimize EMI.

3. Microcontroller Workload Distribution

Problem: Handling all sensors, motors, LCDs, and logic on one microcontroller led to slow response times and timing conflicts.

Solution: We distributed the workload:

- **Arduino Mega 2560:** Main production logic (belt, IR sensors, keypad control)
- **Arduino Uno:** Ultrasonic sensors and 3x 16x2 LCDs for chocolate/topping levels
- **ESP32:** Heating logic, temperature, and app communication

- **Another Arduino Uno:** to control the motor through a signal command from the ESP32
- Signal messaging was used to share essential data between controllers mainly ESP32 and Arduino Uno.

4. Topping Dispensing Jams

Problem: Toppings occasionally jammed in the topping dispenser due to their irregular shape.

Solution: We widened the dispenser valve and tested the motor on different speed to get the right results.

5. Electricity Conduction Issues

Problem: Putting the ESP32 and other components on the stainless-steel caused it to malfunction and burn from the electrical transfer.

Solution: We add a thick layer of nonconductive material behind every electrical component to ensure safety and functionality.

6. Noise from Wires

Problem: The noise from all the close wires (especially from the 230V heating element wires & SSR) made reading from the sensors inaccurate and it interfered with code uploading on the ESP32.

Solution: We shielded the wires, put some space between them and hanged them on the stainless-steel machine for easier access and better connection structure.

2.3 Standards and Codes

In the development of this chocolate bar production line and tempering system, adherence to relevant technical standards and safety practices was a critical consideration. While this project is primarily educational, we applied real-world engineering standards where applicable to ensure safe operation and system reliability.

Electrical Safety Standards

- The **230V AC heating element** was isolated from low-voltage control circuits using a properly rated **Solid State Relay (SSR-40DA)**.
- Power wiring was insulated and routed to avoid contact with logic circuits, in line with **IEC 60364** guidelines for safe low-voltage electrical installations.
- A **300W regulated DC power supply** provided separate 5V and 12V rails for different modules, minimizing the risk of voltage instability or overload.

Temperature Control and Sensing

- The temperature sensing system used a **PT100 RTD sensor**, interfaced through a **MAX31865 module**, consistent with **IEC 60751** standards for platinum resistance thermometers.
- Heating was designed to follow safe thermal ramp-up profiles and prevent overheating of chocolate or water, reducing the risk of caramelization or phase damage.

Food Safety Considerations

- All chocolate-contact components, including the container, dispensing pipe, and water bath shell, were fabricated from **food-safe stainless steel**, compliant with **FDA and EU food-grade materials standards**.
- stepper mechanisms used for chocolate and topping handling were mounted externally and mechanically decoupled from food surfaces to avoid contamination.

Microcontroller Communication and Software Practices

- Communication between the ESP32, Arduino Mega, and Arduino Uno followed **serial protocol standards** using voltage-matched logic levels and common GND reference.
- Code development followed basic **embedded systems programming best practices**, including interrupt-safe routines, input validation, and watchdog resets where necessary.

Mechanical Components and Motor Drivers

- Motors and drivers were selected based on torque, current, and voltage specifications consistent with manufacturer datasheets. The **YS-DIV268N-5A** stepper driver supports current tuning for compatibility with **NEMA23 stepper motors**.
- The **BTS7960 motor driver** for the windshield wiper motor included overcurrent and overtemperature protections in accordance with the module's spec sheet.

User Interface and Mobile App

- The mobile application and ESP32 interface were developed following standard **HTTP-based communication protocols**, ensuring future expandability and secure operation.
- UI feedback on LCD screens (16x2 and 20x4 I2C) followed established usability principles clear status labels, numeric feedback (like °C, %, slot), and limited refresh to avoid flickering.

This combination of safety, compatibility, and hygiene considerations ensures that the prototype aligns with real-world design expectations, even in a university research setting.

2.4 Hardware Components

This section outlines the major hardware components used in the chocolate bar production line and tempering machine, including their functions, justification for selection, and how they contribute to the overall system.

1. 1950W Washing Machine Heating Element (230V)



Figure 1: 1950W Washing Machine Heating Element (230V)

Used to heat the water bath under the chocolate container. Its high-power rating enables fast heating of both the water and indirectly the chocolate. Controlled via an SSR and powered by AC mains.

2. PT100 RTD Sensor + MAX31865 Module



Figure 2: PT100 RTD Sensor + MAX31865 Module

A high-precision platinum resistance temperature sensor used to monitor the chocolate temperature. The MAX31865 module converts the signal to digital and interfaces with the ESP32 for accurate control and feedback.

3. ESP32 Microcontroller

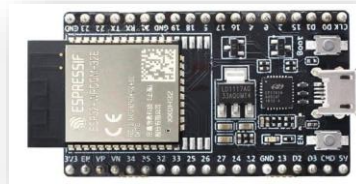


Figure 3:ESP32 Microcontroller:

Responsible for controlling the tempering machine, including heating logic, temperature monitoring, and Wi-Fi connectivity for mobile app control. Chosen for its dual-core performance and built-in wireless features.

4. Arduino Mega 2560



Figure 4:Arduino Mega 2560

Handles all logic and control for the production line prototype. Its large number of digital and analog I/O pins makes it ideal for managing the conveyor motor, IR sensor, keypads, and the chocolate/topping dispensers.

5. Arduino Uno



Figure 5:Arduino Uno

Dedicated to controlling the three ultrasonic sensors and corresponding 16x2 I2C LCDs that display topping and chocolate level percentages. Helps offload the Mega and simplifies modular control.

6. IR Sensor

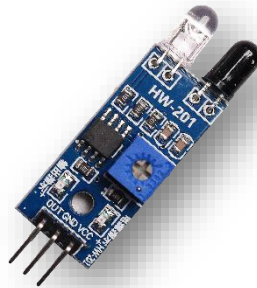


Figure 6:IR Sensor

Used to detect the presence of a mold container at a specific point on the conveyor belt. Triggers the dispensing of chocolate when aligned.

7. 1x4 Keypads (x2)



Figure 7: 1x4 Keypads (x2)

- One is used to select the chocolate type (milk, dark, white, or app mode).
- The other selects the topping option (raisins or nuts).

Simple, tactile input devices that make the system user-friendly.

8. I2C LCD Displays



Figure 8: I2C LCD Displays

- **20x4 LCD:** Displays system status such as temperature, current mode, and operation step.
- **Three 16x2 LCDs:** Each is linked to a container (chocolate, nuts, raisins) and shows filling percentage using data from ultrasonic sensors.

9. Ultrasonic Sensors (x3)



Figure 9: Ultrasonic Sensors

Mounted above chocolate and topping containers to monitor the amount of material remaining. Data is converted to % and displayed on corresponding LCDs.

10. NEMA23 Stepper Motors (x3)



Figure 10: NEMA23 Stepper Motors

Used to open/close topping and chocolate containers. Chosen for their high torque and precision ideal for slow, controlled dispensing.

11. YS-DIV268N-5A Stepper Drivers



Figure 11: YS-DIV268N-5A Stepper Drivers

Compatible with NEMA23 motors, these drivers allow for fine current adjustment and micro stepping. Controlled via digital signals from the Arduino.

12. Windshield Wiper Motor



Figure 12: YS-DIV268N-5A Stepper Drivers

Drives the conveyor belt. Chosen for its durability, low RPM, and cost-effectiveness. Operated via an H-bridge motor driver.

13. BTS7960 Motor Driver

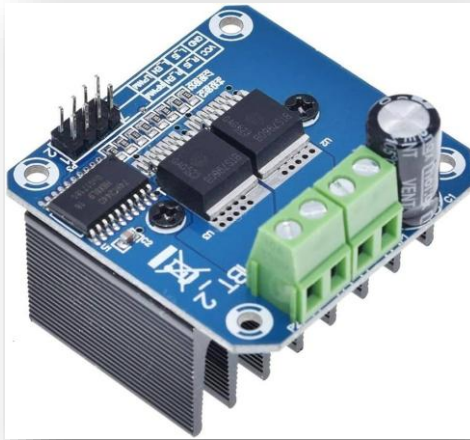


Figure 13: BTS7960 Motor Driver

Used to control the wiper motor. Supports high current (up to 43A) and includes built-in protections. Controlled through PWM and direction signals from the Mega.

14. 2430 Vibration Motor



Figure 14: 2430 Vibration Motor

Attached to the mold platform. Activated briefly after chocolate dispensing to ensure even spreading and remove air bubbles from the mold.

15. 300W Power Supply (5V and 12V)



Figure 15: 300W Power Supply (5V and 12V)

Provides regulated power for all low-voltage components including motors, sensors, and logic boards. Prevents brownout when multiple devices run simultaneously.

16. Jumper Wires (Male-Male / Male-Female)



Figure 16: Jumper Wires (Male-Male / Male-Female)

Used for modular connections between all sensors, drivers, and controllers. Enables prototyping and easy maintenance.

17. Electric Heating Wire 5 Ohm/M



Figure 17: Electric Heating Wire 5 Ohm/M

Used to convert electrical energy into heat. Ideal for heating elements in projects like incubators, de-icing, or temperature control systems.

2.5 Earlier Coursework and Related Skills

This graduation project builds upon multiple courses and skills acquired during our Computer Engineering program. The design, implementation, and testing of both the chocolate tempering machine and the production line prototype reflect a practical application of our academic background.

1. Microcontrollers and Embedded Systems

Courses involving Arduino, ESP32, and real-time control systems laid the foundation for implementing logic-driven automation. Interrupt handling, serial communication, and PWM control were directly applied in tasks like motor control, temperature regulation, and sensor interfacing.

2. Digital and Analog Electronics

Understanding voltage levels, current control, and interfacing circuits was crucial for safely combining low-voltage microcontrollers with high-power components like the 230V heating element, SSRs, and motor drivers.

3. Programming and Software Design

Experience in C/C++ programming for microcontrollers enabled the development of reliable firmware. State machines, modular functions, and efficient use of memory (especially on the Uno) were implemented to ensure responsiveness and clarity.

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Experience in C/C++ programming for microcontrollers enabled the development of reliable firmware. State machines, modular functions, and efficient use of memory (especially on the Uno & ESP32) were implemented to ensure responsiveness and clarity.

5. Networks and Wireless Communication

The use of the ESP32's Wi-Fi capabilities builds upon coursework in IoT protocols and wireless networking. This knowledge was applied to enable remote monitoring and control through a mobile app, allowing flexible and user-friendly operation.

6. Circuits and Electrical Safety

Understanding of power ratings, circuit protection, and safety design was essential when working with the heating element, power supply unit, and high-current motor drivers.

7. Critical Thinking, Technical Writing and Project Management

Skills in documentation, presentation, and collaborative project planning were essential in organizing tasks, maintaining timelines, and preparing this final report.

Chapter Three

Literature Review

Chapter Three: Literature Review

This chapter explores prior work and relevant technologies that informed the design of our automated chocolate production system. It covers existing tempering systems, topping automation, sensor integration, and multi-controller embedded design establishing the academic and industrial context of our work.

3.1 Chocolate Tempering Automation

Chocolate tempering is a well-studied process that requires precise temperature control to achieve proper crystal structure (form V) for glossy, snap-quality chocolate. Industrial machines typically use PID controllers with thermocouples or RTD sensors to maintain temperatures between 40–45°C for melting and 28–32°C for tempering, depending on the chocolate type.

In academic and DIY projects, tempering is often simplified or replaced with simulation. However, a real stainless steel-based system with accurate temperature sensing, thermal modeling, and active heating control like the one implemented in this project is uncommon. Our work builds upon thermal physics and embedded systems literature to bridge the gap between lab models and functional chocolate equipment.

3.2 Topping and Filling Automation

Automated topping systems are common in bakery and confectionery industries. These use conveyors, gravity-fed dispensers, or vibratory feeders. Raisins and nuts present unique challenges due to irregular shapes and flow issues.

Some DIY solutions use time-based stepper dispensing, while others include vibratory motors for improved material flow. Our use of NEMA23 stepper motors and a vibration motor combined with keypad-based mode selection draws from both industrial practices and open-source automation designs.

3.3 Embedded Multi-Controller Architecture

Most embedded control systems for food processing are centralized. However, decentralized designs (using multiple microcontrollers) are growing in popularity for modularity and scalability. This technique reduces software complexity on a single controller and allows parallel development.

Our approach using an **ESP32 for temperature and app interface**, an **Arduino Mega for production line logic**, and an **Arduino Uno for ultrasonic sensing and display control** demonstrates this principle in a real production environment.

3.4 Sensor Integration and Real-Time Monitoring

Using **PT100 RTD sensors** with the **MAX31865 interface** is a proven solution for high-precision temperature measurement in industrial and food-safe systems. Similarly, **ultrasonic sensors** have been widely adopted for level detection in container-based systems (liquids, grains, toppings).

Our integration of these sensors with live LCD feedback mirrors practices found in small-scale manufacturing setups, such as automated feeders and small packaging machines.

3.5 Mobile Control and IoT Applications

Many recent student and commercial projects have leveraged **ESP32** for IoT-based control of appliances, brewing equipment, and environmental systems. These often use basic HTTP servers or Bluetooth-based controls.

Our project builds on this trend by creating a Wi-Fi-enabled chocolate tempering system that can be monitored and controlled through a phone application. This enhances flexibility, user interaction, and remote access, which is increasingly important in modern smart manufacturing systems.

3.6 Gaps in Existing Projects

From our survey, we found that while many automation projects exist for bakery and confectionery tasks, few:

- Integrate **real heating hardware with food-safe materials**
- Include **working topping systems with adjustable modes**
- Use **multi-controller synchronization with mobile integration**
- Include **scientific modeling (thermal energy/time calculation)**

We studied several commercial and semi-industrial chocolate machines to understand practical designs and mechanisms. For example:

- [Vantage House chocolate tempering machine overview](#)
- [Bakon USA topping and enrobing machine](#)
- [Vantage House depositors and bar lines](#)

These videos influenced our approach to chocolate flow control, mold vibration, and topping mechanisms. Our project bridges the gap between these industrial systems and affordable, compact educational prototypes.

Chapter Four

Methodology

Chapter Four: Methodology

4.1 The system consists of two major sections:

1. Chocolate Tempering Machine

A real, food-safe, stainless-steel system that melts and tempers chocolate using a water bath heated by a 1950W heating element. It is controlled by an ESP32 that monitors temperature using a PT100 RTD (for chocolate) sensor and an NTC sensor (for water), and enables Wi-Fi app monitoring/controlling.

2. Production Line Prototype

A belt-driven prototype that receives tempered chocolate, fills polycarbonate/silicone molds, dispenses toppings (nuts/raisins), and vibrates the mold tray for leveling. It is managed by an Arduino Mega, with a supporting Arduino Uno for monitoring filling levels.

4.2 System Block Diagram

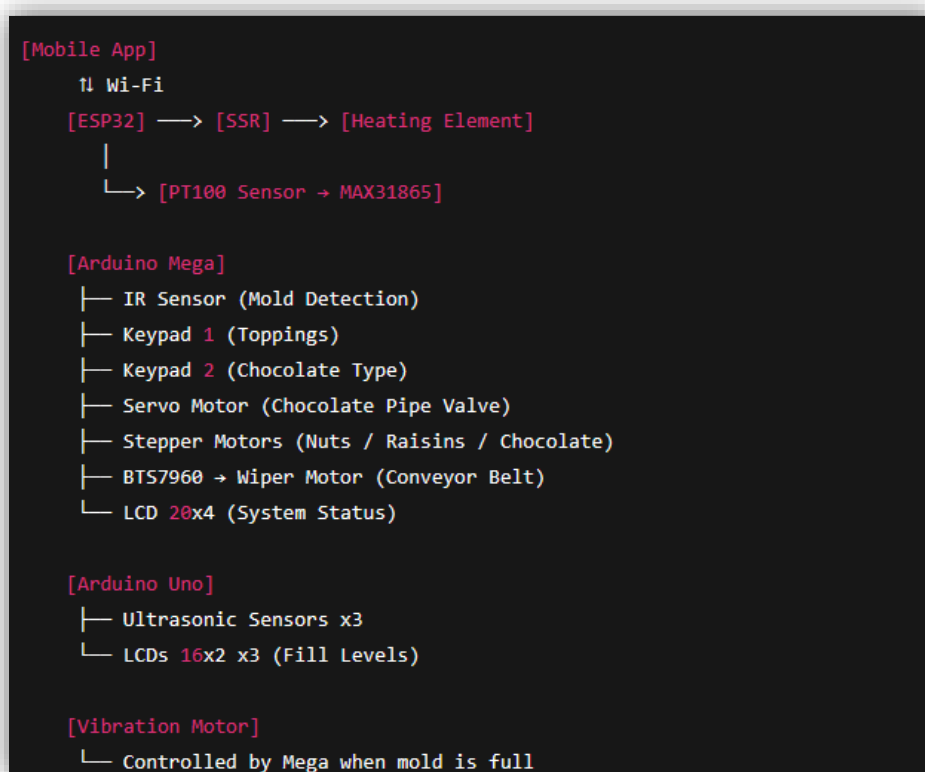


Figure 18: System Block Diagram

4.3 Control Flow Summary

- **Startup:** ESP32 initializes Wi-Fi and heating control. Arduino Mega initializes motor control and keypad states.
- **User Input:** The user selects chocolate type and topping via keypads or app.
- **Tempering:** ESP32 reads temperature via PT100 and controls SSR to maintain target based on chocolate type.
- **Dispensing:** When a mold is detected via IR sensor, a controlled pipe releases chocolate, selected toppings are dispensed using stepper motors, and the mold is briefly vibrated for even distribution.
- **Monitoring:** Arduino Uno continuously updates fill level displays based on ultrasonic data.

4.4 Chocolate Tempering Calculations

We used basic thermodynamic principles to estimate heating time and power needs:

Given:

- *Water:* $8\text{ L} = 8000\text{ g}$
- *Chocolate:* $5\text{ kg} = 5000\text{ g}$
- $\Delta T = 42^{\circ}\text{C} - 25^{\circ}\text{C} = 17^{\circ}\text{C}$
- *Water specific heat capacity* $\approx 4.18\text{ J/g}^{\circ}\text{C}$
- *Chocolate specific heat capacity* $\approx 1.7\text{ J/g}^{\circ}\text{C}$
- *Power (P)* $= 1950\text{ W} = 1950\text{ J/s}$

Energy Required:

- $Q_{\text{water}} = 8000 \times 4.18 \times 17 = \mathbf{568,480\text{ J}}$
- $Q_{\text{choco}} = 5000 \times 1.7 \times 17 = \mathbf{144,500\text{ J}}$
- $Q_{\text{total}} \approx \mathbf{712,980\text{ J}}$

Ideal Heating Time:

$$t = \frac{Q_{total}}{P} = \frac{712,980}{1950} \approx 365 \text{ seconds} \approx 6 \text{ minutes}$$

- Not all heater power goes into chocolate.
- Large solid blocks heat slowly from the outside in.
- Significant heat losses to the environment.
- Lack of stirring slows heat transfer.

Realistic Time:

$\approx 40\text{--}80 \text{ minutes}$

This estimation helped us tune PID parameters and plan delay loops for real-world heating response.

Table 1: ESP32 Mode

Type	Initial Target Temp(°C)	Cooling Temp	Reheating Temp (Working Temp)
Milk Chocolate	42°C	27°C	32°C
Dark Chocolate	45°C	28°C	30°C
White Chocolate	40°C	26°C	29°C

Each mode adjusts the target temperature and app display. Mode 4 enables full mobile app control.

4.6 Safety and Efficiency Design

- **SSR Isolation:** Ensures the ESP32 never directly interacts with 230V AC.
- **Motor Current Limits:** Stepper and DC motor drivers tuned for safe operation.
- **Modular Architecture:** Each controller runs independently, reducing crashes or interference.
- **Display Feedback:** LCDs ensure the user always knows system status and material availability.
- **Vibration Motor:** Only triggered after filling completes to prevent premature flow.

Chapter Five

Implementation and Testing

Chapter Five: Implementation and Testing

This chapter details the process of building the system, connecting hardware components, writing and uploading the control code, and validating performance through systematic testing.

5.1 Hardware Assembly

The implementation phase began with the mechanical construction of the chocolate tempering machine using stainless steel parts, including:

- A **double-layer container**: bottom layer holds 8L water, top curved layer melts and holds up to 10kg of chocolate.
- A **1950W heating element** mounted under the water bath.
- A **stainless-steel pipe** for chocolate dispensing.
- A **vibration motor** mounted under the mold tray.

On the production line side, a prototype conveyor system was assembled using:

- A **windshield wiper motor** to drive the belt.
- An **IR sensor** to detect mold arrival.
- **NEMA23 stepper motors** for nut, raisin, and chocolate dispensing containers.
- **Ultrasonic sensors** and **16x2 I2C LCDs** to display fill levels.
- **Keypads, Arduino boards, and a 300W power supply** mounted on a shared control panel.

All components were connected with properly insulated wires, with the high-voltage AC isolated from logic-level circuits.

5.2 Software Development

The control software was written in C++ using the Arduino IDE for all microcontrollers:

- The **ESP32 code** handled:
 - Reading the temperature from the MAX31865 module.
 - Switching the SSR to turn the heater on/off.
 - Communicating with the mobile app via Wi-Fi.
 - Managing chocolate mode profiles and display status.
- The **Arduino Mega code** managed:
 - Reading keypad inputs for chocolate and topping modes.
 - Activating the stepper valve and dispensing motors based on IR input.
 - Controlling the vibration motor after filling.
 - Displaying status messages on the 20x4 LCD.
- The **Arduino Uno code** controlled:
 - Reading ultrasonic sensors.
 - Mapping distances to percentage fill.
 - Displaying readings on three 16x2 LCDs via I2C.

5.3 Integration and Communication

To avoid overload and cross-interference:

- The Uno operated as an independent sensor and display unit.
- The Mega and ESP32 shared operational modes and could be coordinated manually or via app input.
- Common ground and proper logic level matching were maintained.

5.4 Testing Procedures

Each component and subsystem were tested individually:

- **Heating Test:** Verified that the PT100 readings matched real thermometers; system reached 42°C in ~4.5 minutes with ~50% duty cycle.
- **Motor Test:** Stepper motors tested for correct positioning and timing with topping flow. Pipe valve reliably opened/closed without leaking.
- **IR Sensor Test:** Detected mold presence reliably within 2 cm range.
- **Ultrasonic Fill Monitoring:** Calibrated for each container's height and cross-verified with manual measurements.
- **LCD/Keypad Feedback:** All inputs were responsive, and system states were correctly displayed.

5.5 Results

- Chocolate tempering worked reliably with consistent temperatures for each mode.
- Dispensing accuracy was within ± 5 ml per cycle.
- Topping flow improved significantly with the added vibration.
- Ultrasonic-based fill level reporting was accurate within $\pm 10\%$.
- The system was usable both locally (via keypad) and remotely (via app).

Chapter Six

Conclusion and Future Work

Chapter Six: Conclusion and Future Work

6.1 Conclusion

This project successfully demonstrates the design and implementation of an automated chocolate bar production line with an integrated tempering system and topping dispensers. The solution incorporates real hardware, food-safe components, and embedded systems to simulate a compact and semi-industrial chocolate processing workflow.

By dividing system control across three microcontrollers ESP32, Arduino Mega, and Arduino Uno we achieved modularity, improved performance, and flexibility. The use of real-time temperature monitoring, servo-based chocolate dispensing, ultrasonic-level feedback, and vibration-based mold settling contributed to a high degree of realism and functional accuracy.

The mobile app integration via ESP32 adds a modern user interface, enabling remote monitoring and control of the chocolate tempering process.

Thermal behavior and heating times were estimated using scientifically grounded calculations, which helped design a safe and responsive temperature control mechanism. The final system is not only functional but also educational, demonstrating how embedded automation can be applied to real-world food production.

6.2 Future Work

Despite the project's success, several areas offer potential for enhancement and expansion:

1. Advanced PID Control

Replace basic threshold logic with full PID (Proportional-Integral-Derivative) control to fine-tune heating behavior and minimize overshoot.

2. Fully Featured Mobile App

Expand the app to include:

- Real-time status updates
- Topping/mode selection
- Logging of temperature over time
- Alerts for refill and maintenance

3. Improved Mold Handling System

Automate the movement of molds in and out of the filling zone using stepper-based positioning, reducing reliance on static IR detection.

4. Dual or Triple Chocolate Modes

Add separate heating channels or chocolate containers to enable multi-chocolate products (e.g., white/dark layering).

5. Power Optimization

Introduce soft start circuits, energy-saving sleep modes for microcontrollers, and more efficient DC motor control for battery or solar-powered setups.

6. Industrial Food-Safe Certification

Further develop the food-contact surfaces and obtain formal food safety certification, enabling real production use.

7. AI-Based Quality Control

Integrate computer vision (e.g., via ESP32-CAM or Raspberry Pi) to detect fill levels, topping placement, and defects for future AI-assisted refinement.

6.3 References

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