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ICreamatic

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Dedication

First and foremost, we are grateful to God for his boundless mercy and guidance, which made our journey easier.

The teachings of our beloved prophet Muhammad, peace and blessings be upon him, have been a source of knowledge and illumination in our lives.

To the innocent souls of our martyrs, whose courage inspired hope in our hearts and whose hardships and sacrifices keep us going.

We sincerely thank our families, devoted friends, and outstanding teachers—those who secretly prayed for us, who unwaveringly believed in us, and who loved us without conditions.

This modest endeavor is an expression of the love, support, and fortitude you have shown us during this journey.

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We can demonstrate that this result is a direct result of their guidance and assistance. For this, we truly appreciate all of the information, support, and motivation they have given us.

Disclaimer Statement

At An-Najah National University's Faculty of Engineering, Computer Engineering Department, **Aisha Abu Jeib** and **Basmalah Samaneh** prepared this report. Other than a few minor editorial corrections made during the assessment process, it has not been changed or edited in any way, so it might still have content and/or arena errors.

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Nomenclature / List of Symbols:

Roman Letters

V – Voltage (Volts, V)
I – Current (Amperes, A)
P – Power (Watts, W)
T – Temperature (°C)

Greek Letters

θ – Step angle of stepper motor (degrees)
Ω – Ohm, unit of resistance

Subscripts

DC – Direct Current
AC – Alternating Current

Superscripts

° – Degree symbol, angular measurement

List of Abbreviations

LCD – Liquid Crystal Display
LED – Light Emitting Diode
PWM – Pulse Width Modulation
DC – Direct Current
AC – Alternating Current
ICSP – In-Circuit Serial Programming
I2C – Inter-Integrated Circuit
IDE – Integrated Development Environment
CAGR – Compound Annual Growth Rate

Abstract

The project involves creating and designing an automatic ice cream production line. The system is a miniaturized form of an industrial machine that automates the whole ice cream making process, right from selecting a flavor to decorating it. The user chooses a flavor on the first touchscreen interface of the system. The machine automatically releases the base ingredients and the selected flavoring into a mixing chamber when selected.

The mixture is cooled by initiating an inbuilt cooling system through gas pipes and a compressor. While cooling the mixture, a motorized mixing device shakes the mixture to ensure even freezing and the right consistency for the ice cream. The machine is set to dispense the prepared ice cream into a cup as soon as it detects a cup under the dispensing cup.

The last process includes a decoration module that allows the user to activate the release of a topping above the cup. All this process is done automatically for each cycle.

This project is significant since it applies embedded systems, sensor integration, mechanical control, and realtime automation in a food-grade environment. It is pedagogically valuable because it demonstrates an actual industrial application through low-cost components and scalable design.

The key issues covered include subsystem integration (mixing, cooling, dispensing, decoration), user interface as a touchscreen, feedback control systems, and process synchronization. The overall objectives of the project are to develop an end-to-end functional prototype for complete automation of the entire ice cream production process and providing the students with hands-on experience in developing a real-time electromechanical system.

While commercial ice-cream machines are available, it is rare that systems offer total automation of flavor selection, manufacturing, cup control, and decoration in a matter of minutes in a miniature educational version. Therefore, the current project is a new and practical application suitable for learning as well as development.

Chapter 1

Introduction

The global ice cream market is expected to grow at a compound annual growth rate (CAGR) of 3.9% from its estimated USD 113.40 billion in 2023 to USD 147.74 billion by 2030 [1] . By 2030, the ice cream market in the United States alone is projected to generate about USD 26.23 billion, with a projected compound annual growth rate (CAGR) of 3.7% from 2024 to 2030 [2] . This not only demonstrates how well-liked ice cream is all over the world, but it also supports the expansion of the frozen dessert sector as ice cream keeps growing.

The statistics on per capita consumption support this popularity. The US consumes roughly 23 liters per person annually, while New Zealand consumes nearly 28 liters per person annually. This illustrates regional variation even though the global average consumption is much lower—roughly 2.4 liters per person in 2018 [3] Goff, H. D., & Hartel, R. W. 2013). Ice Cream, 7th ed. Business & Science Media, Springer.

Automation technologies have been introduced into food preparation and service as the food industry expands and changes. Customers now demand customization from automated coffee makers and vending machines in addition to speed and consistency. Even with the notable advancements, there are still few fully automated ice cream production systems (from flavor selection to dispensing and decoration), particularly in smaller-scale and educational settings.

The goal of this project is to design and construct an automated ice cream manufacturing line that can complete tasks without the need for human intervention. The entire system functions, enabling the user to select from a variety of flavors through a touch screen. After that, it can mix and dispense the ingredients automatically, cool the mixture with a compressor-based cooling system, dispense the ice cream when the cup is detected, and garnish it with the user's preferred toppings.

This project is significant because it demonstrates how sensors, embedded systems, electromechanical designs, and real-time automation can all be integrated in a food-grade setting. It provides an illustration of how industry scales can be duplicated at smaller scales using scalable components and low cost. From an educational standpoint, it helps students bridge the gap between theory and practice in practical industrial applications by providing them with practical experience integrating systems, synchronizing processes, and designing controls.

The format of this report is as follows: Chapter 2 examines relevant and earlier research. System design, software and hardware development, and process integration are all covered in Chapter 3's description of the methodology. Results and analysis are presented in Chapter 4. The new findings are thoroughly discussed in Chapter 5. Chapter 6 concludes with conclusions, suggestions, and potential improvements.

Chapter 2

Literature Review

2.1 Similar Machines (Systems)

2.1.1 Soft-Serve Ice Cream Vending Machines (Huaxin)

Soft-serve vending machines are increasingly being used in public areas because they offer the same level of control over temperature, texture, and air incorporation (30–40%) to guarantee that each cone contains high-quality product. According to tests carried out in more than 30 locations across 8 countries, machines with technical optimization achieved a "perfect consistency ratio" of 72%, while basic machines only achieved 45% [1] .

2.1.2 Industrial Continuous Freezers

Since continuous freezers can produce ice cream continuously, they are widely used in industrial ice cream production. Continuous freezers work by scraping frozen material from the inside of a refrigerated cylinder and then adding compressed air to the mixture to form a consistent structure. This process not only ensures continuous production but also maintains consistency. Additionally, manufacturers can fully control the structure of their product by adding fruits or other ingredients just before freezing thanks to continuous freezers [2] .

2.1.3 Fully Automated Soft-Serve Prototype (Academic Project)

As part of a university thesis, a fully automated soft-serve ice cream maker was constructed (2005). A microcontroller-powered pneumatic actuator system dispensed the soft-serve ice cream, accepted coins, and dispensed cups. The study's findings demonstrated that the dispensing was reliable, accurate, and had the potential to become commercially viable.

2.2 Technology and Process Techniques

2.2.1 Automation, Quality Control, and Predictive Maintenance

Nowadays, thermal cameras and monitoring algorithms on automated production lines enhance the quality of the final product. By identifying non-conforming products and anticipating maintenance needs before a breakdown occurs, these systems can increase the industrial ice cream production process's efficiency and dependability [3] Goff, H. D., & Hartel, R. W. (2013). Ice cream (7th ed.). Springer Science & Business Media.

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2.2.2 Smart Vending Machine Features

Current research highlights technological trends in vending machines, such as smart manufacturing principles, biometric authentication (fingerprint scanning), and contactless vending services. These developments in technology are altering consumer behavior and increasing automated retail's adaptability [4] Academic Project. (2005). Automated soft-serve ice cream prototype. University Thesis, University of California.

[5] .

2.2.3 The Science of Soft-Serve Machines

The best possible interactions between ingredients, incorporated air (overrun), and freezing are essential to soft-serve systems. Maintaining a 50–60% overrun is crucial to producing ice cream with the light, creamy texture that consumers desire. Soft-serve is intended to be consumed right away and offers more feasible freezing and action than ice cream, even though the latter is frozen at lower temperatures [6] .

2.3 Summary and Comparison

Aspect	Existing Systems Provide

Smart Soft-Serve Machines	Automated production with high control of air content (30–40%) and temperature consistency [1]
Industrial Continuous Freezers	Non-stop production, precise texture control, option to add inclusions [2]
Academic Automated Prototype	Cup dispensing + automated pouring using pneumatics and microcontroller
Industrial Quality Control	Thermal cameras + predictive maintenance algorithms [3] Goff, H. D., & Hartel, R. W. (2013). Ice cream (7th ed.). Springer Science & Business Media.
Modern Vending Trends	Contactless, biometric features, integration with smart retail [4] Academic Project. (2005). Automated soft-serve ice cream prototype. University Thesis, University of California. [5]
Soft-Serve Science	Overrun (50–60%) + higher freezing temp ensures creamy texture [6]

There are numerous systems available today that automate the production of food or ice cream, but they are primarily designed for large-scale industrial use or commercial vending. In a low-cost educational prototype that is sufficiently small to allow for complete automation of the processes—from flavor selection to mixing, cooling, dispensing, and decorating—very few systems can take this into account.

The project intends to close this gap by developing a fully automated ice cream production line that combines sensors, embedded systems, and electromechanical design to provide both automation and educational advantages.

The system design, hardware and software components, materials and tools, as well as the standards and limitations adhered to in this project, are presented in the following chapter, Chapter 3 (Methodology).

Chapter 3

Methodology

3.1 Design

3.1.1 User Interface & Interaction

The user can interact with the machine through:

- **Keypad**: used to navigate menus and make selections (e.g., number keys to choose an option, * to confirm, # to cancel/back).
- **LCD Screen**: displays all steps of the interaction. The sequence is:
  1. **Welcome Screen**: shows a greeting and the **project name (ICreamatic)** on startup.
  2. **Flavor Selection Page**: lists available flavors with numeric codes for keypad input (e.g., 1-Apple, 2- Cherry, 3-Lemon).
     User action: press the number on the keypad, then (*).
  3. **Topping Selection Page**: lists available toppings with numeric codes (e.g., 1-Sprinkles, 2- Coconut).
     User action: press the number on the keypad, then *.

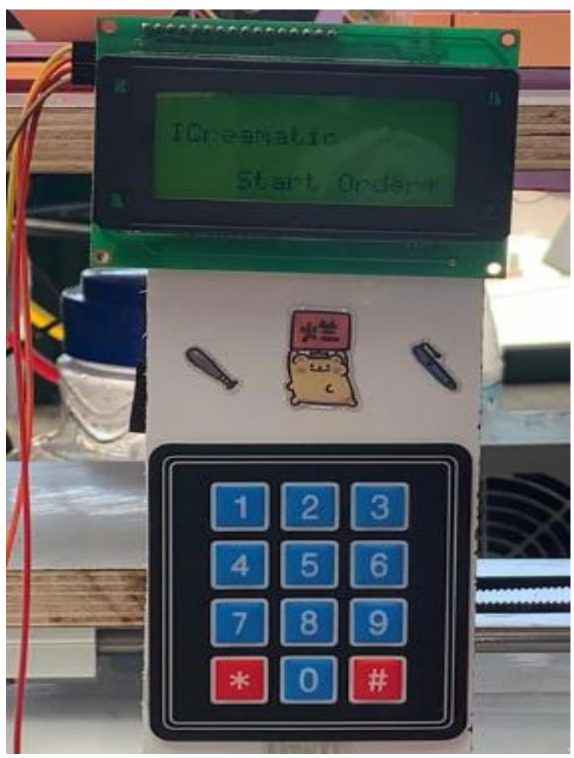

Figure 3.1:Welcome Screen

3.1.2 Flavour Dispensing Unit

Three syringes, each with a distinct flavor, are part of the system. The device dispenses the selected flavor into the mixing chamber and moves the selected syringe in accordance with the user's selection on the LCD screen.

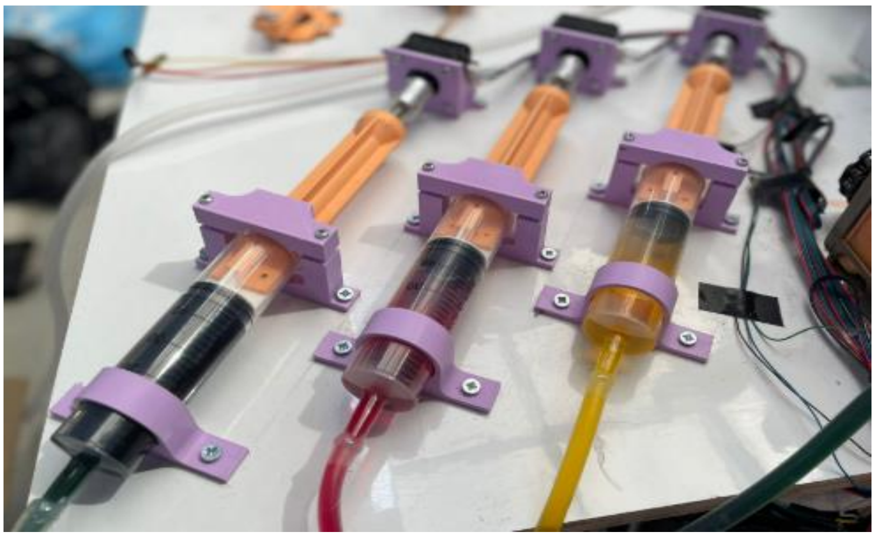

Figure 3.2:Flavour Syringes

3.1.3 Cup Dispenser with Hall Effect Sensor

The user can get cups from the machine's automatic cup dispenser. A Hall Effect sensor built into the dispenser detects when each rotation of the entire mechanism is complete. In order to notify the controller that precisely one cyclical rotation has been completed and that one cup will be released, the Hall Effect sensor will detect the magnetic field from a magnet fixed onto the rotating portion's mechanism. This ensures that the cups are dispensed correctly, stops several cups from being released simultaneously, and permits the cup to be placed at the same time as the following procedures.

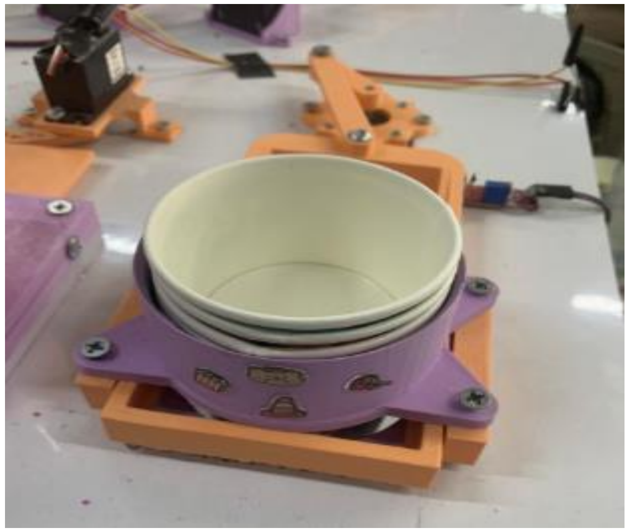

Figure 3.3:Cup Dispenser

3.1.4 Milk and Powder Dispensers

Milk container with pump: a milk container that is connected to a pump so that milk can enter the mixing chamber. During the process, the microcontroller can safely turn the pump on and off thanks to its connection to a relay module.

Powder cream dispenser: a device that automatically dispenses powdered cream into the mixing chamber.

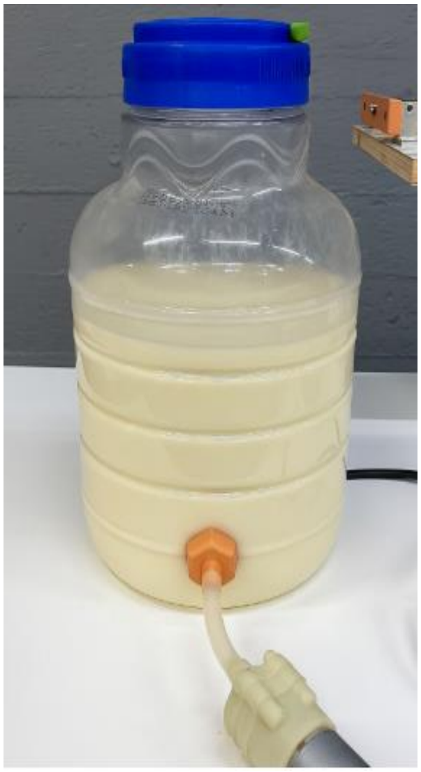

Figure3.4: Milk container with pump

Figure3.5: Powder cream dispenser

3.1.5 Mixing Unit

The ingredients (milk, flavor, and powdered cream) are mixed together in a motorized mixing chamber until the mixture is homogenous, and then it is cooled.

Figure3.6: Mixer

3.1.6 Cooling System

The cooling system serves as the central component of the ice cream preparation process, guaranteeing that the mixture quickly reaches the desired frozen consistency. The process starts as soon as the milk, powdered cream, and chosen flavor are put into the cooling cylinder. A dedicated motor powers an internal auger screw that rotates continuously inside the cylinder. This screw serves two purposes: it keeps the mixture moving continuously to avoid solid ice blocks forming and it presses the mixture up against the cooled cylinder walls to achieve uniform freezing.

The compressor and the associated refrigerant cycle maintain the refrigeration process. The refrigerant gas passes through copper pipes that are wrapped around the cooling cylinder after being compressed by the compressor. The temperature of the ice cream mixture is lowered as the refrigerant absorbs heat from it as it expands in the evaporator section. The radiator (condenser) subsequently releases the heat that has been absorbed into the surrounding air. By dissipating the heat extracted from the mixture, the radiator serves as a heat exchanger, preventing overheating and allowing the refrigerant to continuously cycle between gaseous and liquid states.

Throughout this process, two motors work in parallel: the compressor motor, which drives the refrigerant cycle, and the auger screw motor, which blends and advances the ice cream mixture. When combined, they guarantee the effective completion of the freezing process's mechanical and thermal components. Both motors are connected via relay modules, which serve as

electronic switches under the microcontroller's control, in order to safely operate them. Because the controller can now handle high-power components without direct electrical risk, dependable operation is ensured.
The system's integrated mixing, cooling, radiator-assisted heat dissipation, and controlled refrigeration ensures that the ice cream has a smooth, creamy texture and is prepared for dispensing once the desired consistency is attained.

Before:

Figure3.7: Cooling System before

After:

Figure3.8: Cooling System after

3.1.7 Decoration (Topping) Unit

Several containers for toppings are installed. The chosen topping (selected via the LCD) is automatically released over the cup once the ice cream has been dispensed into it.

Figure3.9: Topping

3.1.8 Linear Movement System with Limit Switch

The cup is moved between the various stages of the system—cup dispensing, mixing, cooling, dispensing, and decorating—using a linear movement mechanism. The linear carriage is driven by a motor, which guarantees coordinated and seamless movement between the modules. A limit switch is positioned at the end of the rail to ensure precise positioning and avoid over-travel. To ensure safe operation and dependable stage transitions, a signal is sent to the controller to stop the motor when the carriage reaches the switch.

Figure3.10: Linear Movement

3.2 Materials and Tools

3.2.1 Microcontrollers

- **Arduino Mega 2560** [6] : A well-known microcontroller based on the ATmega2560, with the following features:

  - ❖ 54 digital input/output pins (of which 15 can be used as PWM outputs).
  - ❖ 16 analog inputs.
  - ❖ 4 UARTs (hardware serial ports).
  - ❖ 16 MHz crystal oscillator.
  - ❖ USB connection.
  - ❖ Power jack.
  - ❖ ICSP header.
  - ❖ Reset button

In this project, two Arduino Mega 2560 boards were used.

First Arduino Mega 2560: dedicated to handling the user interface and control logic, including the LCD, keypad, flavor syringes selection mechanism, topping dispensers, cup dispenser with Hall Effect sensor, and the linear movement system with limit switch.

Second Arduino Mega 2560: dedicated to controlling the high-power actuators through relay modules. These include the milk pump, mixer, and the cooling system (compressor and screw motor). In addition, a servo motor is connected between the mixing unit and the cooling system to release the prepared mixture into the cooling chamber.

This distribution of tasks ensured efficient processing, reduced wiring complexity, and provided safe control of high-current devices by isolating them through relay modules.

Figure3.11: Arduino Mega 2560

3.2.2 Motors

Secop SC18G Compressor Motor : Refrigerant (R134a) is compressed and circulated through the cooling cycle by this hermetically sealed refrigeration compressor. It has a displacement of about 18.7 cm^3 and runs at a voltage of 220–240 V, 50 Hz. Automatic ice cream makers, freezers, and coolers are examples of medium-capacity refrigeration systems that use compressors.

Vapor-compression refrigeration is the primary working principle:

- **Compression:** This process increases the temperature and pressure of the refrigerant gas (R134a).
- **Condensation:** The hot, high-pressure refrigerant is moved to the radiator, or condenser, where it releases heat and turns into a liquid.
- **Expansion:** The refrigerant cools even more as it travels through an expansion device, where pressure drops.
- **Evaporation:** The temperature of the ice cream mixture drops and freezing is started when the cold refrigerant absorbs heat from the cylinder holding it.

The cooling chamber is kept at low, steady temperatures for the ideal ice cream texture thanks to this ongoing cycle. A relay module manages the compressor motor's high current and voltage needs in a safe manner.

Figure3.12: Secop SC18G Compressor Motor

<u>Iwaki Motor (KB-2X):</u> An AC motor unit originally designed as part of a bellows pump system, here repurposed to drive the cooling screw (auger) in the custom refrigeration unit. The motor converts electrical energy into rotational mechanical power to continuously rotate the screw, ensuring proper mixing and transfer of the ice cream mixture through the cooling chamber:

The main specifications are:

- **Rated Voltage:** 220/240 V AC.
- **Power Consumption:** 3.2 W.
- **Operating Frequency:** 50/60 Hz.
- **Maximum Flow/Pressure (Pump rating):** 710/850 ml/min at 50/60 Hz, 0.05 MPa.

In this project, the motor is specifically employed to rotate the **internal auger screw** inside the cooling cylinder. This rotation guarantees both **continuous movement of the mixture** and **efficient heat exchange** with the refrigerant coils, which is essential for achieving the desired ice cream consistency.

Figure3.13: Iwaki Motor

<u>NEMA 17 / 103H548 Stepper Motor </u>[11] Toshiba. (n.d.). *TB6600 stepper motor driver datasheet*. Retrieved from https://toshiba.semicon-storage.com/

<u>:</u> A DC motor moves in discrete steps and coverts the electrical power into rotation. It has 1.8°degree/step and it can be controlled in terms of degree of rotation, direction and speed. It consists of:

- Stator: the stationary (fixed) part.
- Rotator: the moving part.

It has two modes:

- Full-Step Mode: the motor is operated with only one phase energized at a time. The advantage of this mode is using least amount of the power from the driver.

  Number of steps for one cycle = θ 1.8 ∘ = 360∘ 1.8 ∘ = 200 steps

- Half-Step Mode: it is a combination of one phase and two adjacent phases at a time. The advantage of this mode is having smoother operation and better resolution.

  Number of steps for one cycle = θ 1.8 ∘ 2 = 360∘ 1.8 ∘ 2 = 400 steps

It is connected to a 3-stage gear-box that moves the arm that holds the vacuums, the desired steps are **1100 steps (5.5 full-cycles).**

Figure 3.14: Stepper Motor

Servo Motor [7]: The S3003 is an analog hobby servo that converts electrical PWM signals into precise rotational displacement. It features:

Key specifications include:

- **Speed**:
  - 4.8 V: 0.23 sec per 60°
  - 6.0 V: 0.19 sec per 60°
- **Torque (Stall)**:
  - 44 oz·in (≈ 3.2 kg·cm) at 4.8 V
  - 57 oz·in (≈ 4.1 kg·cm) at 6.0 V
- **Dimensions:**
  approximately 1.6 in × 0.8 in × 1.4 in (≈ 40 × 20 × 36 mm)
- **Weight:**
  ~1.3 oz (≈ 37 g)
- **Operating Voltage:**
  4.8 – 6.0 V DC

- **Motor & Drive:**
  Brushed motor, plastic gears, bushing bearings, control via standard PWM (pulse width 500–3000 µs, ~50 Hz cycle)
- **Additional Details:**
  - Deadband: ~0.1 ms
  - Operating temperature range: –20 °C to +60 °C

Figure 3.15: Servo Motor

3.2.3 Sensors

Hall Effect Sensor [8] Allegro Microsystems. (n.d.). Hall-effect sensor fundamentals. Retrieved from https://www.allegromicro.com/

It is a magnetic field sensor that detects changes in the presence of a magnetic field and converts it into an electrical signal. It consists of:

- **Hall Element:** a thin semiconductor layer that generates a small voltage (Hall voltage) when exposed to a magnetic field.
- **Amplifier Circuit:** used to strengthen the small Hall voltage.
- **Output Stage:** provides a digital signal when a magnet is detected.

The Hall Effect Sensor has the following connection pins:

- **VCC:** Power supply.
- **GND:** Ground.
- **OUT:** Digital output signal.

In this project, it is used in the **Cup Dispenser**. When the rotating mechanism completes one full cycle, the magnet attached to it passes by the sensor, generating a pulse. This notifies the controller that exactly one cup has been released.

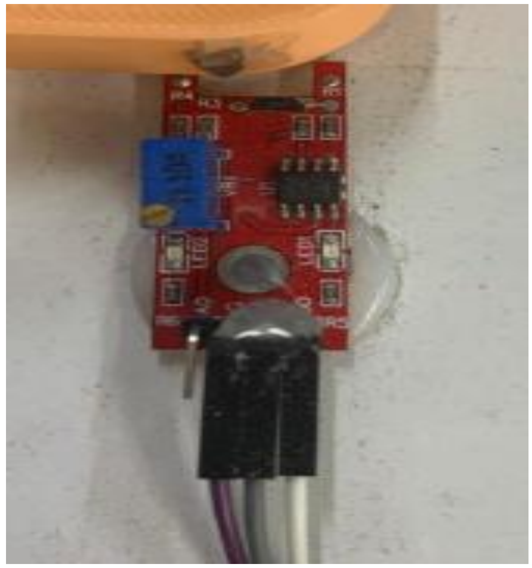

Figure 3.16: Hall Effect Sensor

<u>IR Obstacle Avoidance Sensor:</u> Using reflected infrared light, an infrared proximity sensor finds objects in the vicinity and transforms the information into a digital output for a microcontroller. Typical modules combine:

- **IR Emitter (IR LED):** sends out infrared light in the direction of the target.
- **IR Receiver (photodiode/phototransistor):** detects the reflected (returned) infrared energy.
- **Comparator stage (often LM393) with a trimmer potentiometer:** generates a clean digital HIGH/LOW output after comparing the analog receiver signal to a user-specified threshold; the detection distance is programmable. Typically, indicator LEDs display the power and detection status.
- **Typical range & supply**: designed to run from a 3.3–5 V supply at a surface-dependent distance of about 2–30 cm. When an obstacle is detected, many boards switch to active-low output by default.

Connection pins:

- **VCC** – Power (3.3–5 V)
- **GND** – Ground
- **OUT** – Digital output (often LOW when an object is detected).

How it works: When an object is within the designated range, enough infrared light from the emitter is reflected back to the receiver to cross the comparator's threshold and toggle the digital output, usually to LOW. You can adjust the trigger distance for your application using the onboard potentiometer.

Use in this project (Cup Dispenser alignment): The sensor is placed close to the outlets of the decorating/topping containers and adjusted (using a potentiometer) so that the OUT pin switches (usually to LOW) when a cup is positioned precisely underneath. Before distributing toppings, the controller reads this transition to make sure one cup is positioned correctly each cycle. (Application logic according to our system; sensor behavior according to the sources mentioned above.)

Figure 3.17: IR Obstacle Avoidance Sensor

3.2.4 I/O Devices

4 × 3 Matrix Keypad : A matrix of 12 keys (Numbers between 0 – 9 and the special characters * and #) organized in rows and columns. To be interfaced with a microcontroller, it has 7 digital pins (4 for rows and 3 for columns). It is used in this machine to allow the user to navigate menus, select flavors and toppings, and confirm or cancel inputs.

Figure 3.18: 4 * 3 Matrix Keypad

<u>16 * 4 LCD :</u> An informative output that can be used to display characters and sometimes graphics, it supports two types of information: data or control commands (clear the screen, set the cursor, etc.) and it can be used in both byte-mode (8-bits) or nibble mode (4-bits). It has the following connection pins:

- **Vcc**
- **Vss or GND**
- **Vo:** for controlling the contrast via a potentiometer
- **D0 - D7:** data pins.
- **R/W (Read / Write):** for selecting reading mode or writing one
- **RS (Register Select):** for setting the information type (data or control command).
- **EN (Enable):** for enabling the LCD.

LCD requires two many pins. So, we used I 2C LCD that uses an adapter PCF8574 that converts the LCD multiple connection pins into only four ones (Vcc, GND, SCL and SDA).

It used in this machine to allow the user to monitor and track the transaction (displaying menus, showing results, etc.).

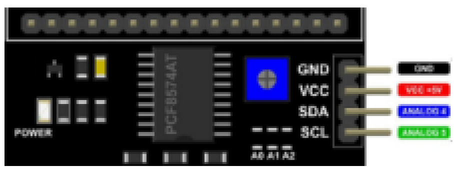

Figure 3.19: PCF8574 Adapter

Figure 3.20: 16 * 4 LCD

3.2.5 Drivers

<u>L298N Motor Driver</u> [10] STMicroelectronics. (n.d.). *L298N dual H-bridge motor driver*. Retrieved from https://www.st.com/

: It is a dual H-bridge motor driver module that allows a microcontroller (such as Arduino Mega 2560) to control the direction and speed of DC motors or stepper motors. It can drive up to two DC motors simultaneously.

It has the following pins:

- **Vcc:** Power supply for the motors (up to 46V).
- **5V:** Logic supply for the internal circuitry.
- **GND:** Ground.
- **IN1, IN2, IN3, IN4:** Control inputs for the motor directions.
- **ENA, ENB:** Enable pins for speed control (typically connected to PWM signals).
- **OUT1, OUT2, OUT3, OUT4:** Outputs connected to the motor terminals.

The L298N allows bidirectional control (forward/reverse) and speed variation using PWM signals, making it suitable for DC motor actuation and simple stepper motor applications.

Figure 3.21: Stepper Motor Driver L298N

3.2.6 Others

<u>Limit Switch</u> [9] Omron. (n.d.). *Limit switch technical guide*. Retrieved from https://www.omron.com/

: An electromagnetic device that respond to a physical force, it is typically used to detect objects or physical actions. It has the following connection pins:

- **NO (Normally Open -Output-)**
- **NC (Normally Closed -Output-)**
- **COM (Common Contact -Output-):** The central connection pin.

In this project, it is used in the Linear Movement System to detect when the carriage reaches the start of the rail. This signal is used to perform the homing process, allowing the system to establish a reference position before operation.

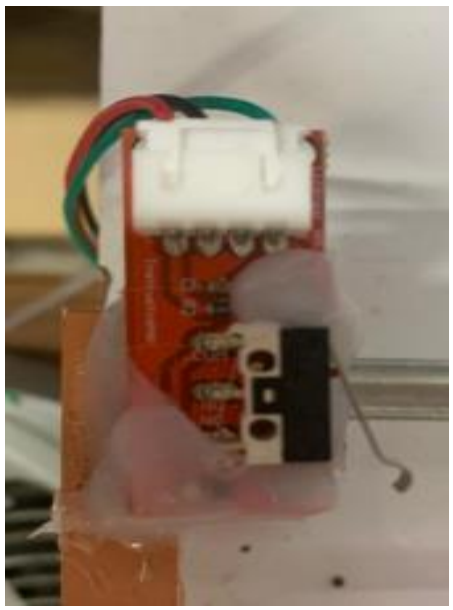

Figure 3.22: Limit Switch

4-Channel Relay Module : An electrically operated switch module that uses low-voltage signals from a microcontroller to control high-voltage or high-current devices. Each relay acts as an isolation layer, allowing safe switching of AC or DC loads.

It has the following connection pins:

- **Vcc:** Power supply (5V).
- **GND:** Ground.
- **IN1, IN2, IN3, IN4:** Control input pins to activate each relay individually.
- **NO (Normally Open):** Output terminal that is open by default, and closes when the relay is activated.
- **NC (Normally Closed):** Output terminal that is closed by default, and opens when the relay is activated.

- ❖ **COM (Common Contact):** Central connection pin for each relay channel.

In this project, the **4-channel relay module** is used for switching high-power components such as the **pump**, **mixer**, **cooling compressor**, and **screw motor**, providing electrical isolation and safe operation controlled by the Arduino Mega 2560.

Figure 3.23: 4-Channel Relay Module

DC Diaphragm Pump [12] : A small electrically driven pump that uses a diaphragm mechanism to transfer liquids. The pump operates by moving a flexible diaphragm back and forth, creating suction on one side and discharge on the other, which enables continuous liquid flow.

The main specifications (typical for this pump type) are:

- ❖ **Operating Voltage:** 6–12 V DC.
- ❖ **Current Consumption:** ~0.5–0.7 A.
- ❖ **Flow Rate:** ~1–3 L/min (depending on voltage and load).
- ❖ **Pressure Capacity:** up to 2–3 bar.
- ❖ **Pump Type:** Diaphragm, self-priming, suitable for low-viscosity liquids.

In this project, the DC diaphragm pump is used to deliver milk from the storage container into the mixing chamber. It is powered via a relay module controlled by the Arduino Mega, ensuring safe switching of the pump during the automated process.

Figure 3.24: DC diaphragm pump

Radiator (Condenser): The heat exchanger that dissipates the heat absorbed from the cooling cylinder into the surrounding environment is the radiator, sometimes referred to as the condenser. It is made up of a system of thin metal fins that connect copper or aluminum tubes, increasing the surface area available for heat transfer.

The following is the operating principle:

- The compressor releases the hot, high-pressure refrigerant gas, which then enters the radiator.
- Heat from the refrigerant is transferred to the surrounding air by the metal fins as it moves through the condenser tubes.
- This heat is removed with the help of a fan or natural airflow, which permits the refrigerant to cool.
- In the process, the refrigerant transforms from a high-pressure gas into a high-pressure liquid, preparing it for the cycle's subsequent expansion and evaporation phase.

This part guarantees that heat is continuously removed from the cycle, which is crucial for preserving the refrigeration system's efficiency. The cooling system would not be able to reach the low temperatures needed to produce ice cream without the radiator because the refrigerant would not be able to condense properly.

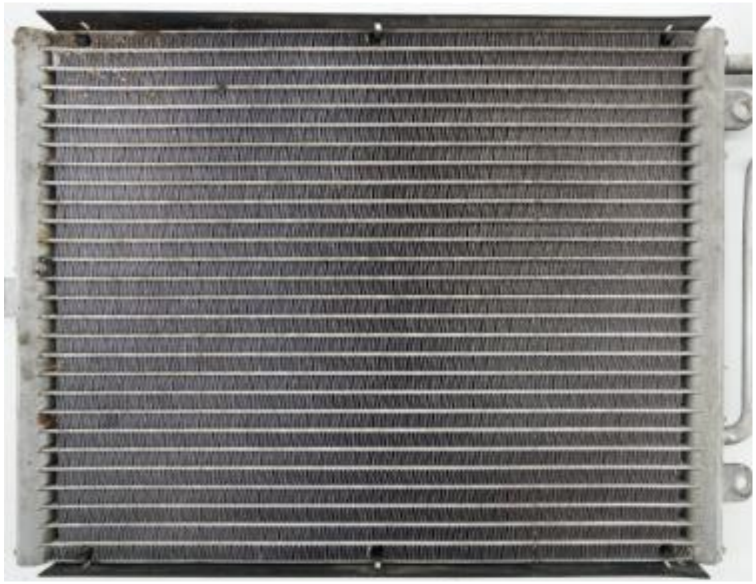

Figure 3.25: Radiator (Condenser)

<u>Power Supply</u>: It is used provide power for the system, the following table shows the voltage required for each device:

Tool	Volt
Screw AC motor Cooling motor	220
NEMA 17 / 103H548 Stepper Motor DC diaphragm pump Drivers L298N	12
Arduino-Mega 2560 16 * 4 LCD Limit Switch Hall effect sensor Servo motor IR Obstacle Avoidance Sensor	5

Table 1Voltage requirements for each device

Figure 3.26: Power Supply

The following table shows the number of each tool used in this machine:

Tool	Number of Items
Arduino-Mega 2560	2
NEMA 17 / 103H548 Stepper Motor	7
Servo Motor	4
4 * 3 Matrix Keypad	1
16 * 4 LCD	1
Stepper Motor Driver L298N	7
Limit Switch	1
4-Channel Relay	1
Hall effect sensor	1
IR Obstacle Avoidance Sensor	2
Iwaki Motor (KB-2X)	1
DC diaphragm pump	1
Power Supply	1

Table 2:Number of each tool used in the machine

3.3 Software Development

3.3.1 Tools

Arduino IDE : An open-source IDE to write Arduino / ESP codes and upload them into the microcontrollers.

3.3.2 Arduino Libraries

Arduino provides multiple libraries to deal with various hardware tools, the following table shows the libraries used in this project:

Tool	Library -If any
Arduino-Mega 2560	Arduino.h
NEMA 17 / 103H548 Stepper Motor	-
Servo Motor	Servo.h
4 * 3 Matrix Keypad	Keypad.h
16 * 4 LCD	LiquidCrystal I2C.h
Stepper Motor Driver L298N	-
Limit Switch	-
Hall effect sensor	-
IR Obstacle Avoidance Sensor	-
4-channel-relay	-
DC diaphragm pump	-
Iwaki Motor	-

Table 3:Arduino libraries used in the project

3.5 Standards and Constraints

3.5.1 Standards

Electrical Safety Standards: All electrical connections and high-powered devices (such as the pump, compressor motor, auger motor, etc.) are made using relay modules, which isolate the high-voltage circuits from the microcontroller's low-voltage circuits.

Food-Grade Safety Standards: The syringes, powder dispenser, milk container, toppings unit, and other components that come into direct contact with the ice cream mixture are all constructed of food-safe materials and can be used hygienically to satisfy basic food handling regulations.

Embedded System Practices: In control systems and prototyping, Arduino Mega 2560 microcontrollers are used in accordance with commonly accepted embedded systems standards.

3.5.2 Constraints

Cooling System Constraint: The most difficult part of the project was the cooling subsystem. In particular, the design and construction of the cooling screw (auger) required a significant amount of time and work, particularly due to the procurement and assembly of the numerous mechanical components. Because these components are not commonly utilized in small-scale academic projects, finding a compressor, copper piping, and refrigerant gas also required investigation and testing.

Reaching fast freezing in 10 minutes, a crucial prerequisite for making successful ice cream, was another significant challenge. Although the custom cooling unit has been developed, this issue still exists because, regrettably, our project's timeline at the end did not permit this additional development. This time constraint illustrates the technical challenge of cooling design as well as the impact that rigid project durations can have on project work.

Additionally, it became challenging, if not impossible, to dispense the ice cream from the cooling chamber into the cup when the mixture froze too hard. The necessity for more accurate timing between the mixing, cooling, and dispensing phases was further illustrated by this.

Cost Constraint: The project's overall cost exceeded the original projected budgetary limit. Numerous parts, particularly those associated with the cooling system (compressor, copper piping, refrigerant, augur screw fabrication), were not easily accessible locally and were comparatively more costly than other manufacturing components. Not every stackable part could be acquired at the required specifications due to the increased costs. The system's final functional performance output was impacted and was unable to fully realize the intended operations functionality as a result, and it had to be installed at a lower cost.

Time Constraint: Each stage of the design, source, and test phases was severely constrained by the project's need to be completed in a condensed summer academic semester. Certain parts, particularly the cooling subsystem and intricate mechanical components, could not be built or purchased in the short amount of time available. As a result, a lot of problems remained unsolved, like making sure the solidified mixture dispensed smoothly and maximizing the rate at which it freezes. The short timeframe limited the system's ability to be troubleshooted and improved.

Chapter 4

Results

The machine can prepare ice cream in a fully automated cycle, starting with flavor selection and continuing through ingredient dispensing, mixing, cooling, and finishing decoration. Users are able to follow the process step-by-step by controlling the system with a keypad that displays interaction on the LCD screen.

In the following situations, there are some pictures for the LCD:

4.1 General Menus

Figure 4.1: Welcome Screen (ICreamatic Project Name)

Figure 4.2: Flavours Menu

Figure 4.3: After select flavour

Figure 4.4: Toppings Menu

Figure 4.5: After select topping

Figure 4.6: When mixing starting

Figure 4.7: When selected flavour added

Figure 4.8: When selected topping added

Figure 4.9: When Icecream ready

Figure 4.10:The Icecream Cup

Chapter 5

Discussion

5.1 Working Principle

5.1.1 Input Mechanism

Flavor Selection: Using the keypad and LCD screen, the user selects the desired flavor. The LCD first shows a welcome page, then a flavor selection page, and finally a toppings selection page.

Cup Dispensing: The **cup dispenser** releases a cup automatically. A **Hall Effect sensor** detects one complete rotation of the dispenser, ensuring that exactly one cup is released before the process continues.

5.1.2 Mixing and Ingredient Dispensing

Flavor Syringes: Three syringes are available, each containing a different flavor. According to the user's choice, the selected syringe is moved into position and dispenses the flavor into the mixing chamber.

Milk Pump: A DC diaphragm pump transfers milk from the storage container into the mixing chamber.

Powder Dispenser: A dispenser unit automatically releases powdered cream into the mixing chamber.

Mixer: A motorized mixing unit blends the milk, flavor, and powder into a homogeneous mixture.

5.1.3 Cooling Mechanism

The mixed ingredients are transferred to a custom cooling system.

The cooling system consists of:

- A **cylinder with an internal auger screw** that rotates to move and churn the mixture.

- A **compressor motor** connected via copper pipes and refrigerant gas, providing the cooling effect.
- A **radiator** and heat exchange system to maintain low temperatures.

The **auger screw motor** continuously rotates the screw to ensure even cooling and prevent local solidification.

Both motors (screw motor and compressor motor) are controlled via **relay modules**, since they require higher voltage/current than the Arduino pins can supply.

5.1.4 Dispensing Mechanism

Once the ice cream mixture reaches the required consistency, a servo motor positioned between the mixing unit and cooling unit opens a passage for the ice cream to be dispensed into the cup.

The linear movement system (with limit switch) ensures that the cup moves correctly between stages: dispensing, cooling, and finally decoration.

5.1.5 Decoration Mechanism

Multiple topping containers are available.

Based on the user's choice (selected on the LCD and keypad), the corresponding topping dispenser is activated.

The topping is released onto the ice cream automatically after the dispensing stage is complete.

5.1.6 Control and Synchronization

The system is powered by **two Arduino Mega 2560 boards**:

- The first controls the **user interface** (LCD, keypad, topping selection, flavor syringes, cup dispenser).
- The second controls the **actuators and high-power devices** (pump, mixer, screw motor, compressor motor, servo between mixing and cooling).

Synchronization between stages is achieved through sensor feedback:

- **Hall Effect sensor** ensures single cup dispensing.
- **Limit switch** ensures accurate positioning of the linear movement system.

5.1.7 Challenges and Solutions

CHALLENGE 1: Cooling Efficiency
Getting the ice cream mixture to freeze completely in ten minutes was really difficult. Our compressor and auger screw-equipped customized cooling system didn't always achieve the desired consistency in the anticipated amount of time.

SOLUTION: The screw design and cooling cycle were the subject of extensive study and testing. Although a partial freezing was accomplished, time constraints prevented a full optimization. We plan to incorporate improved insulation and possibly a more potent compressor in the future.

CHALLENGE 2: Dispensing Frozen Mixture
It was very difficult, if not impossible, to dispense the mixture smoothly into the cup once it solidified too much inside the cooling cylinder.

SOLUTION: The ability to regulate flow before the entire mixture solidified was established by the addition of a servo-controlled passage between the mixing and cooling chambers. However, to avoid blockages, the cooling and dispensing times need to be better coordinated.

CHALLENGE 3: Cost and Availability of Components
Some parts, like the compressor, auger screw, and refrigerant that make up the cooling system, were extremely costly and hard to find. As a result, the machine's performance was hampered and replacement parts had to be used.

SOLUTION: The prototype was finished using less expensive alternatives. To achieve complete reliability, industrial-grade components are advised for upcoming iterations.

CHALLENGE 4: Time Limitation

Many features could not be optimized due to the academic project's time constraints. Certain features, like the smooth dispensing and cooling efficiency, were still unresolved, and other parts were unavailable for manufacturing or sourcing.

SOLUTION: Although a functioning prototype was delivered in the allotted time, more testing, fabrication, and optimization should be done in the future to fully achieve the desired functionality.

Chapter 6

Conclusion, Recommendations and Future Work

6.1 Conclusion

In this project, an automatic ice cream production line was designed and put into operation as a small-scale industrial machine prototype. Several subsystems were integrated into the system, including the mixing unit, milk and powder dispensers, flavor syringes, cup dispenser with Hall Effect sensor, user interface (LCD and keypad), cooling system with compressor and auger screw, and topping unit. Additionally, a linear movement mechanism with a limit switch was included to guarantee smooth transitions between the process's different stages.

Using sensors, embedded systems, and electromechanical components, the project effectively illustrated the viability of automating every stage of the ice cream preparation cycle, from flavor selection to decoration. Along with sensors, actuators, and high-power devices to ensure the smooth operation of all subsystems, the user interface was controlled by two Arduino Mega 2560 boards.

Even though we saw a lot of progress, we also encountered significant obstacles and limitations, especially with the cooling subsystem. Dispensing a semi-solid mixture and getting the product to freeze completely in 10 minutes were both extremely difficult due to the limited components we could get, the extremely tight budget, and the project's short timeline. These difficulties clearly illustrate how difficult it is to implement food-safe cooling and dispensing systems during the prototype phase.

In conclusion, the system design that we have created has useful educational value since it illustrates how automation is used in the food processing industry in the real world. This project has achieved its goals and given students a rich discussion point to integrate what they have learned about concepts related to system integration, control, and design considering real-world constraints, even though it is not yet at the precision and scale that we would expect from an industrial ice cream machine. In order to create a more durable and dependable solution, future directions should prioritize improving cooling capacities, streamlining the dispensing system, and employing higher grade materials and components.

6.2 Recommendations

Given the experience gained from this project, a number of recommendations for improving the system in its current state can be made. The cooling subsystem should first be reinforced by using a more effective compressor and improved chamber insulation to speed up and improve the reliability of the freezing process. The dispensing flow also needs to be optimized because the mixture often became difficult to release once it solidified. This can be fixed by either applying anti-stick coatings to the screw mechanism or redesigning the internal geometry to reduce obstructions.

Another idea is to replace prototype-level components with industrial-grade, food-safe alternatives. In applications involving food, hygiene and durability are essential, and using certified pumps, syringes, and materials would ensure both. The system's control and safety could also be enhanced by implementing safety precautions to prevent motor overloads and by adding additional sensors, such as temperature and flow monitors. Upgrade the LCD interface to a graphical display and add more customization options, such as different serving sizes or topping combinations, to make the system more user-friendly and appealing to users.

6.3 Future Work

There are several ways that the project can develop in the future. Because it would improve hygiene and reduce the need for manual maintenance in between cycles, the development of an automated cleaning system is an important area. Using smart connectivity features, such as Bluetooth or Wi-Fi, to enable remote updates, data logging for performance analysis, and mobile application control is an alternate strategy. By incorporating intelligent motor control strategies and optimizing the cooling cycle to lower power consumption, future iterations should also consider energy efficiency.

Scalability, which enables the system to be adjusted to support more cups at once or more storage space for ingredients to efficiently serve more users, is another encouraging feature. One of the main future objectives would be to move from the current educational prototype, which is currently scaled down, to a near-commercial version that can operate continuously and meet higher performance, safety, and reliability standards. This advancement would transform the system from a classroom demonstration into a feasible product with real-world application potential.

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Appendix A

Arduino Mega 2560 Source Code

Available upon request.