Engineering and Material Science Faculty

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Design and Implementation of a Smart Beverages Dispensing Machine

Bachelor Thesis

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Declaration

I, Maya Ayman, declare that this thesis, submitted in partial fulfillment of the requirements for the award of the bachelor degree, from the German University in Cairo, is wholly my own work otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Author Name

19 May, 2024

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Abstract

This thesis presents the design and implementation of a Smart Beverages Dispensing Machine, enhancing the traditional vending machine experience with advanced mechatronics concepts. The device integrates mechanical design, electrical components, and user interface innovations to offer customizable hot beverage options with a focus on user convenience and efficiency. Key components include a user-friendly touchscreen, a robust mechanical structure for dispensing various ingredients, and an Arduino Mega-based control system ensuring precise operations. The smart machine supports diverse beverage creations, from coffees to hot chocolates, with the capability of integrating snack options, significantly improving user interaction compared to conventional vending machines. This project not only pushes the boundaries of automated beverage services but also provides insights into improving consumer interactions with automated systems.

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List of Abbreviations

BLDC	Brushless Direct Current
CPS	Capacitive Proximity Sensor
DC	Direct Current
EPDM	Ethylene Propylene Diene Monomer
FKM	Fluoroelastomer
HMI	Human Machine Interface
IR	Infrared
LCD	Liquid Crystal Display
NBR	Nitrile Butadiene Rubber
NPN	Negative-Positive-Negative (type of bipolar junction transistor)
PCB	Printed Circuit Board
PID	Proportional-Integral-Derivative
PLC	Programmable Logic Controller
PTFE	Polytetrafluoroethylene
PWM	Pulse Width Modulation
QFN	Quad Flat No-leads
RTP	Resistive Touch Panel
SLC	Single Level Cell
SRD	Signal Relay Device
UI	User Interface

Chapter 1

Introduction

The Smart Beverages Dispensing Machine project aims to revolutionize the traditional vending machine experience by introducing advanced technology and innovative features. This project seeks to address the limitations of conventional vending machines by implementing a smart system capable of dispensing a wide variety of hot beverages, including coffee, tea, and hot chocolate, with customizable options for users. Through the integration of a user-friendly touchscreen interface, precise control mechanisms, and intelligent sensors, this project endeavors to enhance user convenience, satisfaction, and overall vending machine efficiency. By leveraging cutting-edge engineering and design principles, the Smart Beverages Dispensing Machine project strives to redefine the landscape of automated beverage services, catering to modern consumer preferences and lifestyle demands.

1.1 Motivation

Hot beverage consumption, including coffee, tea, and hot chocolate, has increased significantly in recent years, due to shifting consumer preferences and lifestyle changes. According to a Grand View Research analysis, the worldwide hot drinks market was valued at USD 234.4 billion in 2020 and is expected to reach USD 290.7 billion by 2027, with a compound yearly growth rate (CAGR) of 3.1 % from 2021 to 2027[1]. This development is ascribed to a variety of factors, including a growing urban population, rising disposable incomes, and a global culture of coffee and tea consumption. Despite the broad popularity of hot beverages, typical vending machines sometimes fail to match consumer expectations for variety, customization, and convenience. The limited selection of beverages and lack of customization options offered by conventional vending machines have left consumers seeking alternative solutions that better cater to their preferences and lifestyle. In addition to beverages, the integration of complementary products such as biscuits has become increasingly important in enhancing the vending machine experience. According to a survey conducted by Statista, 78% of consumers indicated that they would be more likely to use vending machines that offer a range of snack options alongside beverages [2]. This underscores the importance of diversifying vending machine offerings to meet the evolving needs and preferences of consumers.

1.2 Thesis Objective

The key objective of this thesis is to overcome the problems of standard vending machines by creating and implementing an improved instant beverage vending machine capable of dispensing a wide range of hot drinks, including coffee, tea, hot chocolate, and customizable mixes of these. The vending machine will have a user-friendly touchscreen interface for intuitive interaction and will be controlled by an Arduino Mega microcontroller installed on a PCB to ensure efficient electrical control. Specifically, the project aims to achieve the following objectives:

1. Expanded Beverage Selection: Develop a vending machine that offers a diverse selection of hot beverages, including coffee, tea, hot chocolate, and customizable combinations thereof. The machine will incorporate five stackable containers (stacks) for storing ingredients such as coffee, milk, sugar, tea leaves, and cocoa powder, enabling users to select their preferred beverage with ease.

2. Intuitive Touchscreen Interface: Design an intuitive touchscreen interface that facilitates seamless navigation of beverage options, customization of drink preferences, and completion of transactions. The interface will feature visually appealing graphics and interactive elements to enhance user engagement and satisfaction.

3. Integration of Biscuit Dispensing: Integrate a biscuit dispensing mechanism into the vending machine to offer complementary snacks alongside beverages. Users will have the option to add biscuits to their order, providing added convenience and enjoyment.

4. Efficient Electrical Control: Implement an Arduino Mega microcontroller to ensure efficient electrical control of the vending machine's components, including the dispensing mechanism, boiler, and touchscreen interface. The microcontroller will enable precise control and coordination of machine operations, enhancing overall performance and reliability.

1.3 Thesis Organization

This thesis is structured into five chapters, each contributing to the understanding and realization of the project objectives:

Chapter 2: Literature Review: Provides a comprehensive review of existing literature and research in the field of vending machines, beverage dispensers, touchscreen interfaces, and commonly used control systems.

Chapter 3: Mechanical Design: This chapter focuses on the mechanical components of designing a beverage dispensing machine. It lays out the design considerations, processes, and technical principles that go into designing the machine's physical structure and components, such as material selection, component placement, and practical concerns.

Chapter 4: Electrical and Control Design: This chapter focuses on the beverage dispensing machine's electrical and control systems. It addresses the selection and integration of electrical components such as sensors, actuators, microcontrollers, and control algorithms. It also explains the programming and software development aspects that are required for the machine to perform efficiently.

Chapter 5: Testing and Commissioning: This chapter presents and analyzes the development and testing results for the beverage dispensing machine. It incorporates data, observations, and insights gathered during prototype testing, performance evaluations, and user feedback. The chapter also addresses any issues that arose during testing and how they were resolved.

Chapter 6: Summary and Future Recommendations: The last chapter concludes the thesis by summarizing the important results, contributions, and implications of the research. It also makes recommendations for future research and areas of focus to improve the design, functionality, and usability of beverage dispensing equipment. Additionally, the chapter discusses the study's overall significance and prospective impact on the field.

Chapter 2

Literature Review

This chapter explores the historical evolution and contemporary significance of beverage vending machines. It traces their origins from ancient Egypt to their present-day ubiquity, highlighting their substantial market presence and role in modern convenience culture. By examining historical milestones and contemporary trends, this chapter provides valuable insights into the history, significance, and current state of beverage vending machines.

2.1 The Evolution of Vending Machines

The history of vending machines can be traced back to ancient Egypt. Pneumatica, written by the mathematician and engineer Heron of Alexandria, describes a number of machine inventions applying the properties of air, water and steam. Included among these is an illustrated description of a device that dispensed water (holy water) when a coin was inserted. This is held to be the origin of the vending machine [3].

Although the original text has been lost, a Latin manuscript dating to 1587 has survived and is held in the National Central Library in Rome. According to this work, the coin-operated device was used to sell "sacrificial water" at a temple in Egypt around 250 BCE. When a five-drachma coin was placed in the slot on top, the weight of the coin would lower the receptacle underneath, causing a lever to open the lid covering the spout, thus allowing water to pour out until the receptacle returned to its original position.

The beverage vending machine industry has garnered significant attention due to its substantial market presence, with over half of all installed machines totaling approximately 2.60 million units[3]. The earliest extant vending machines are recognized as cigarette dispensers, which were installed in English pubs and hostels as early as 1615.

English inventors further expanded vending machine capabilities to dispense various products, including books and postage stamps [4]. Despite these innovations, commercial practicality remained a challenge until the introduction of gum dispensers in the United States, marking the advent of commercially viable vending machines. Concurrently, in Japan, the post-World War II era saw the emergence of juice vending machines, signaling the country's initial foray into the vending industry during its high-growth period.

Today, vending machines represent a ubiquitous and diverse facet of modern convenience culture. From bustling city centers to quiet suburban streets, these automated vendors offer an array of products ranging from snacks and beverages to electronics and personal care items. With advancements in technology, modern vending machines are equipped with state-of-the-art features such as touch screens, cashless payment options, and real-time inventory tracking. Moreover, the products themselves have evolved to cater to changing consumer preferences, including healthier snack options, artisanal beverages, and even freshly prepared meals. Beyond traditional retail spaces, vending machines are increasingly found in unconventional locations such as airports, gyms, and even college campuses, providing round-the-clock access to essential goods and services. As society continues to embrace automation and convenience, vending machines remain an integral part of everyday life, serving as a testament to the ingenuity of human innovation in meeting the demands of a fast-paced world.

(a) Holy Water Dispenser

(b) Postage Dispenser

(c) Modern Vending Machine

Figure 2.1: Evolution of Vending Machines

2.2 Beverage Dispensing Systems

Beverage vending machines come in various types, each designed to cater to specific preferences and requirements. Traditional cup-type machines, which pour beverages into cups, have a long history of development and improvement. These machines involve the operator in preparing drinks and ensuring safety standards. In contrast, newer prepackaged drink vending machines offer convenience and consistency by delivering beverages in sealed containers. These machines focus on maintaining optimal temperature and storage conditions for the prepackaged drinks. The technologies behind these two approaches differ significantly, impacting the roles of machine operators and beverage manufacturers[5].

Beverage vending machines typically feature sleek, user-friendly designs with intuitive interfaces for selecting and customizing drink options. They often incorporate touchscreen displays that guide users through the beverage selection process and allow for personalized preferences such as sugar levels, milk quantities, and flavorings. The physical appearance of these machines varies widely, with some models designed for countertop placement, while others are freestanding units with built-in refrigeration systems for dispensing cold beverages.

In terms of control mechanisms, beverage vending machines leverage sophisticated technologies to automate the dispensing process and ensure optimal drink quality. Common control systems include Proportional-Integral-Derivative (PID) controllers, microcontrollers, and Programmable Logic Controller (PLC)s. These systems regulate parameters such as temperature, pressure, and ingredient proportions to deliver consistent and high-quality beverages with each dispense[6]. Additionally, sensors play a crucial role in monitoring machine operation and ingredient levels, while wireless connectivity enables remote monitoring and management for operators.

Another popular microcontroller in this application is, the Arduino Mega 2560, it is a robust microcontroller board built around the ATmega2560 datasheet [7]. It boasts an impressive array of features, including 54 digital input/output pins, with 14 pins configurable as Pulse Width Modulation (PWM) outputs, 16 analog inputs, and 4 UARTs (hardware serial ports). Additionally, it features a power jack, a 16 MHz crystal oscillator, an ICSP header, a USB connection, and a reset button, making it a versatile and comprehensive solution for various projects [8].

Overall, beverage dispensing machines represent a convergence of advanced engineering, user-centric design, and cutting-edge control technology, offering convenient and efficient solutions for quenching thirst and satisfying cravings in various environments [4].

2.3 User Interfaces and Interaction Design

Modern beverage vending machines often feature touchscreen displays that provide users with a visually appealing and intuitive interface for selecting their desired beverages. These displays may incorporate high-resolution graphics, vibrant colors, and intuitive navigation menus to guide users through the drink selection process. Additionally, touchscreen interfaces enable interactive features such as swipe gestures, pinch-to-zoom, and drag-and-drop functionality, enhancing the overall user experience [1].

Interaction design principles play a vital role in shaping the user experience by focusing on usability, accessibility, and user engagement. Designers must consider factors such as button placement, menu layout, font size, and color contrast to ensure that the interface is easy to navigate and accessible to users of all abilities. Moreover, the design should facilitate efficient decision-making by presenting relevant information clearly and concisely, thereby minimizing user frustration and reducing the likelihood of errors [9].

Incorporating feedback mechanisms into the User Interface (UI) design can further enhance user satisfaction and confidence in the vending machine. Real-time feedback, such as visual and auditory cues, provides users with confirmation that their selections have been registered and processed successfully. Moreover, error messages and prompts should be presented in a clear and non-intimidating manner, guiding users on how to rectify any issues that may arise during the interaction.

One of the famous HMIs is Nextion which is mainly applied to IoT or consumer electronics field. It is the best solution to replace the traditional Liquid Crystal Display (LCD) and LED Nixie tube. With the Nextion Editor software, users are able to create and design their own interfaces for Nextion display. The screen operates with 5V dc and has two wires other than the voltage and ground wires, one for receiving data and the other for transferring data.

Overall, user interfaces and interaction design play a critical role in shaping the user experience of beverage vending machines. By employing intuitive interfaces, interactive features, and feedback mechanisms, designers can create vending machines that are user-friendly, engaging, and capable of meeting the diverse needs and preferences of consumers.

2.4 Integration of Complementary Products

The integration of complementary products, such as biscuits, alongside beverages, is a key consideration in enhancing the value proposition of vending machines. Consumer preferences for snack options and strategies for effectively incorporating snack dispensing mechanisms into vending machines are explored in this section. By understanding the demand for complementary products and the challenges associated with integration, insights are gained to guide the implementation of biscuit vending capabilities in the instant coffee vending machine.

One common approach to integrating complementary products is through strategic product placement within the vending machine. For example, snacks and confectionery items may be positioned adjacent to beverage options, encouraging consumers to make additional purchases while selecting their drinks. Similarly, condiments such as sugar packets, creamers, and stirrers may be conveniently located near the beverage dispensing area, making it easier for consumers to customize their drinks to their liking [2].

In addition to physical product placement, vending machines can also leverage digital interfaces to promote complementary products. For instance, touchscreen displays can feature dynamic menus that showcase recommended pairings or special offers, encouraging consumers to explore additional items beyond their initial beverage selection [5]. Moreover, interactive features such as ”add-on” options or personalized recommendations based on consumer preferences can further motivate impulse purchases of complementary products.

The integration of complementary products within beverage vending machines presents opportunities for operators to enhance revenue generation and profitability. By strategically aligning product offerings with consumer preferences and consumption patterns, vending machine operators can capitalize on cross-selling opportunities and drive incremental. Moreover, the availability of complementary products can contribute to a more satisfying and convenient vending experience for consumers, fostering brand loyalty and repeat business [1].

2.5 Summary

This chapter delves into the evolution of beverage vending machines, tracing their origins from ancient Egypt to their present-day ubiquity. It explores the substantial market presence of vending machines, with over 2.60 million units installed worldwide, and examines their historical milestones, including the introduction of gum dispensers in the United States and juice vending machines in post-World War II Japan. The chapter also discusses the diverse array of products offered by modern vending machines, their advanced features such as touch screens and cashless payment options, and their presence in unconventional locations like airports and gyms. Additionally, it explores the integration of complementary products and the role of user interfaces and interaction design in shaping the vending machine user experience. Overall, this chapter provides a comprehensive overview of the evolution, significance, and contemporary trends of beverage vending machines.

Chapter 3

Mechanical Design and Implementation

This chapter explains the working mechanism of the beverage dispensing machine and the materials utilized for its mechanical components. It discusses the assembly process for achieving optimal machine efficiency, beginning with an overview of its operation and an investigation of materials such as metals and polymers. It then describes how these components are integrated for smooth machine operations and gives insights into the assembly process to guarantee proper construction and operational integrity. (Table 3.3) lists the manufacturing processes of the manufactured parts and (Table 3.3) shows the material and quantity of each part.

3.1 Design Overview

The beverage dispensing machine, enhanced with the capability to dispense biscuits, operates seamlessly to fulfill customized orders initiated by users through the HMI. Upon receiving the user's order, the machine orchestrates a series of precise actions to deliver the desired beverage. Firstly, the machine activates the dispensing of hot water, synchronized with the collection of powders required for the ordered drink. These powders, including milk powder, tea, instant coffee, cocoa and sugar are stored in individual stacks, each equipped with a spiral rod connected to a stepper motor. As the stepper motor completes one revolution, the respective powder drops from the opening at the front of the stack.

Additionally, the machine features a water reservoir, ensuring a steady supply of water for the pump to provide to the heater, maintaining optimal temperature for beverage preparation. Subsequently, the collected ingredients converge through a cone mechanism, meticulously calibrated to blend them uniformly, before dispensing the prepared beverage into the awaiting cup. This streamlined process ensures the accurate and efficient delivery of customized drinks, catering to the diverse preferences of users with precision and reliability.Fig.3.1 shows the mechanical components and (Table 3.1) names those components

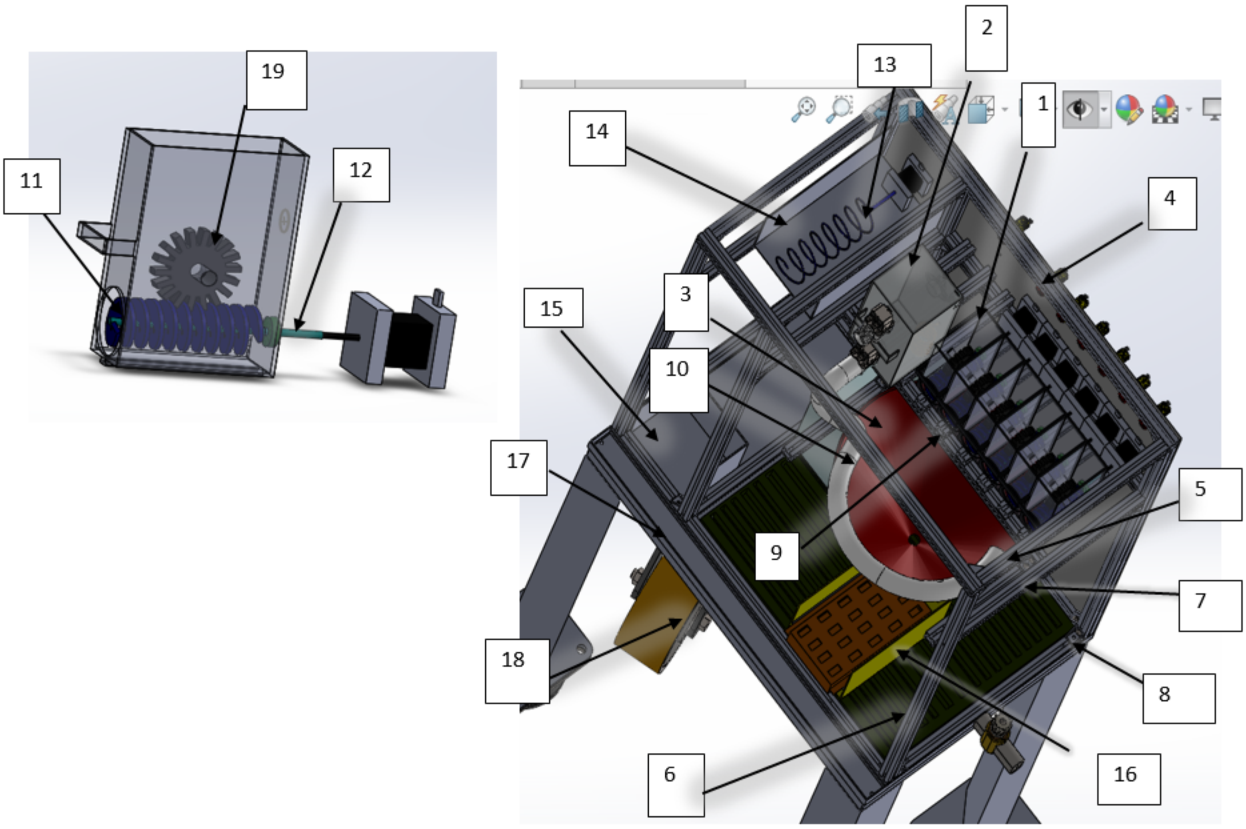


Figure 3.1: Design of Main Components

Number	Component Name
1	Stack
2	Boiler Stack
3	Cone
4	Slotted Rod 1
5	Slotted Rod 2
6	Slotted Rod 3
7	Slotted Rod 4
8	Linkage
9	Slide Rails
10	Hot Water Pipe
11	Spiral Rod
12	Part 1 of Interlocking Mechanism
13	Part 2 of Interlocking Mechanism
14	Water Tank
15	Compression Spring
16	Biscuits Shelf
17	Pick Up Shelf
18	Cup Drain Holder
19	Cup Drain
20	Table
21	Wheels

Table 3.1: Component Names

3.2 Mechanical Components' Designs

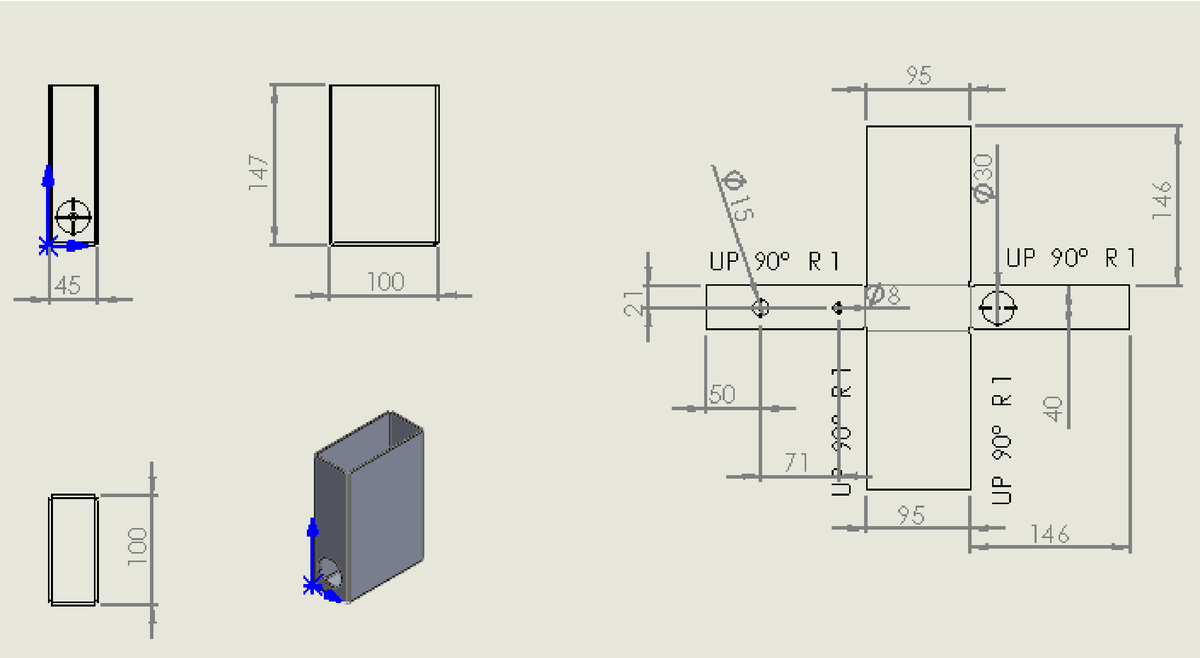
This section discusses every mechanical design's properties, utilization in the machine , dimensions and manufacturing processes.

3.2.1 Stack Design

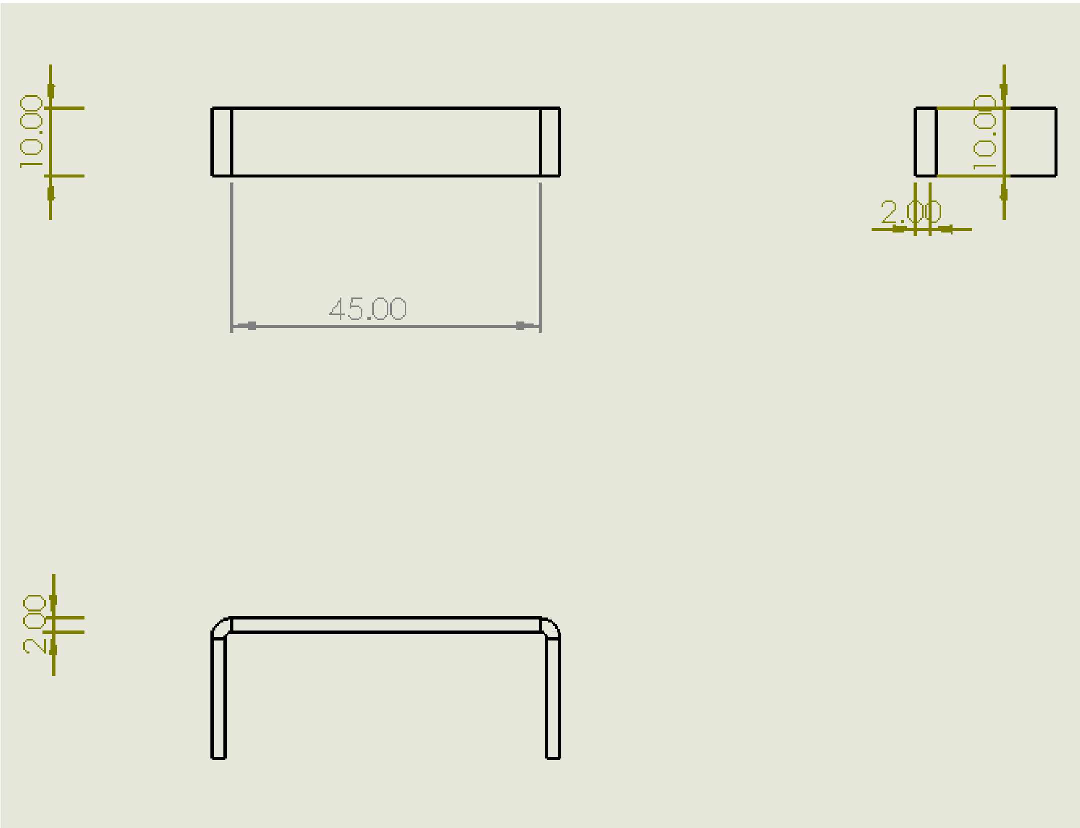
The stack design in Fig.3.2, made of stainless steel to prevent corrosion and maintain beverage quality, measures 5 cm in width, 15 cm in length, and 10 cm in height. Featuring a handle for convenient removal, it can be easily taken out of the machine for refilling or cleaning purposes. The stack is strategically designed with circular openings: one in the front for precise powder dispensing into the mixing chamber, and rear openings for motor connection and sensor installation, ensuring seamless integration into the beverage dispensing system. This component's robust construction and thoughtful design contribute to the overall efficiency and reliability of the beverage dispensing machine.

3.2.2 Boiler Stack Design

Crafted from stainless steel to ensure durability and cleanliness, this stack is equipped with a handle for convenient removal and cleaning. It comprises two circular openings: one serves as the inlet to receive water from the pump in the water reservoir, while the other functions as the outlet, delivering hot water into the cone for beverage preparation. With dimensions of 10 cm in width, 20 cm in length, and 25 cm in height, the boiler stack has can contain up to 4liters of water. This design Fig. 3.3 facilitates efficient water heating and distribution within the beverage dispensing machine, ensuring optimal performance and functionality.



(a) Stack Design



(b) Stack Handle

Figure 3.2: Stack Design Made Using SolidWorks 2022

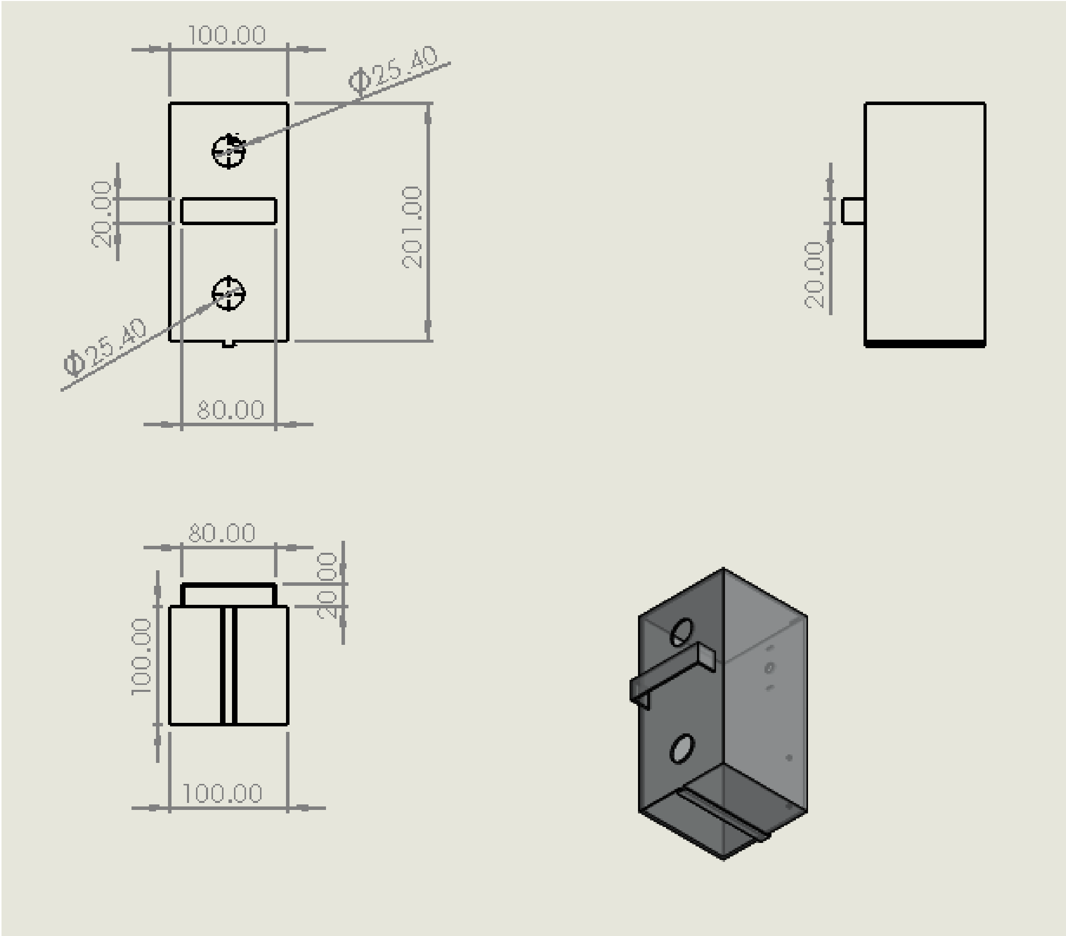


Figure 3.3: Boiler Stack Design Made Using SolidWorks 2022

3.2.3 Cone Design

Constructed from stainless steel to prevent rusting, the cone's design is integral to the machine's functionality. Its conical shape facilitates the smooth movement of powders and hot water, ensuring thorough mixing before dispensing into the cup. Surrounding the cone is a circular edge, designed to fit snugly between two rods equipped with slots for easy removal and cleaning. This thoughtful design feature enhances maintenance accessibility, allowing for efficient cleaning and upkeep of the beverage dispensing machine.

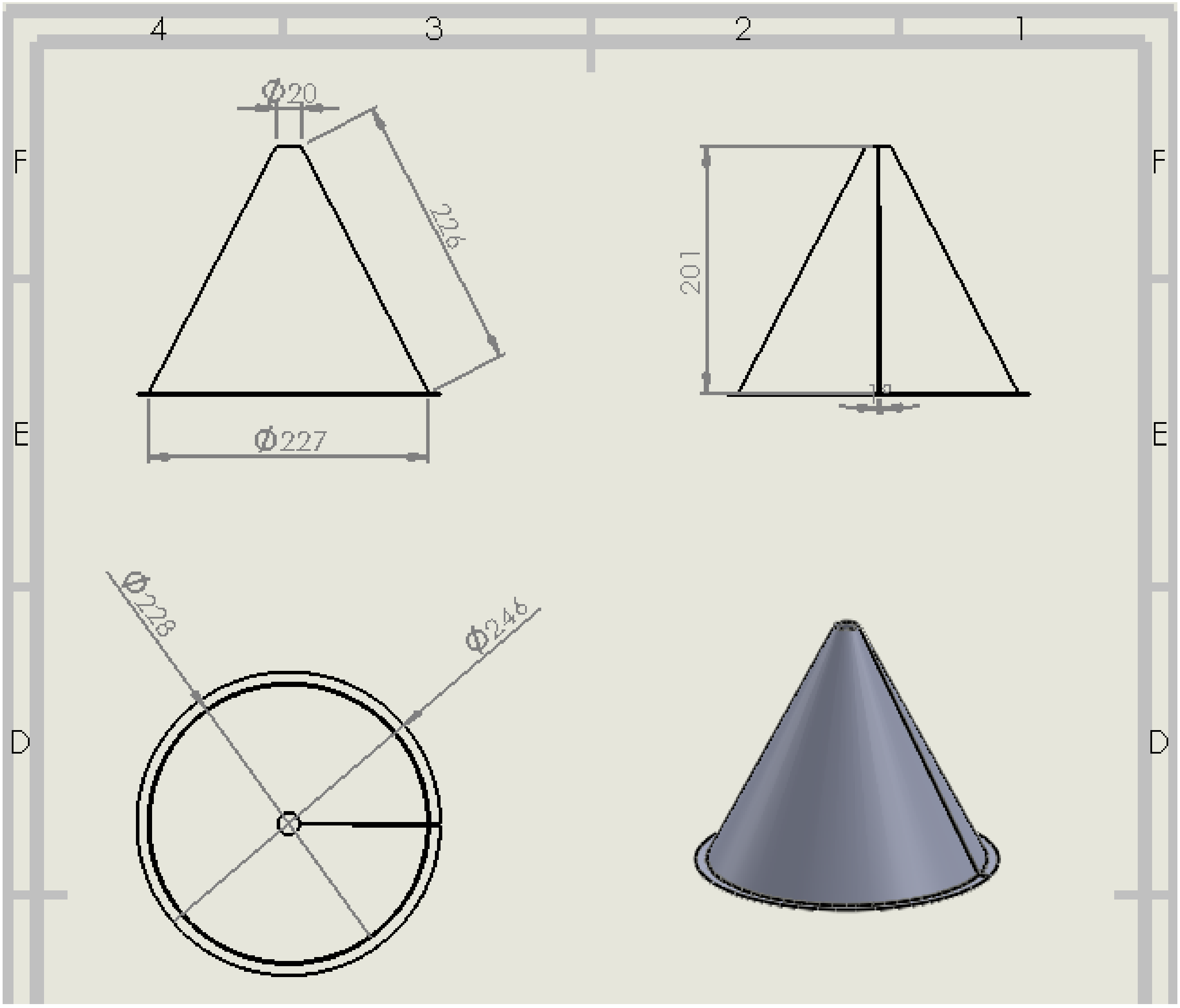


Figure 3.4: Cone Design Made Using SolidWorks 2022

3.2.4 Spiral Rod Design

The spiral rod in Fig.3.5, a crucial component of the beverage dispensing machine, is crafted fromPolytetrafluoroethylene (PTFE) using CNC turning techniques to ensure precision and durability. Positioned within the stack, the spiral rod serves a vital role in the mixing process. Connected to a stepper motor, its rotational motion stirs the powder. At its end, the rod features an opening strategically designed to coincide with the powder drop location within the stack. As the motor completes its revolution, the stirring action effectively dispenses the powder into the cone, facilitating the seamless preparation of customized beverages.

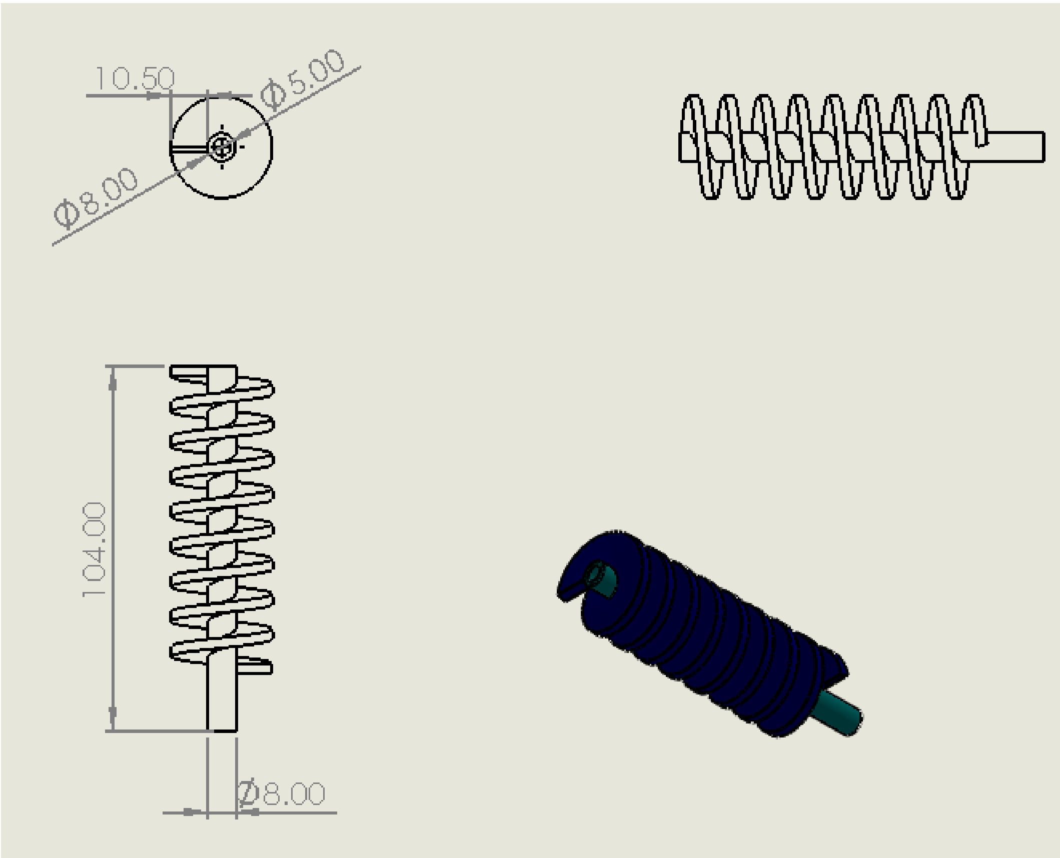


Figure 3.5: Spiral Rod Made Using SolidWorks 2022

3.2.5 Interlocking Mechanism

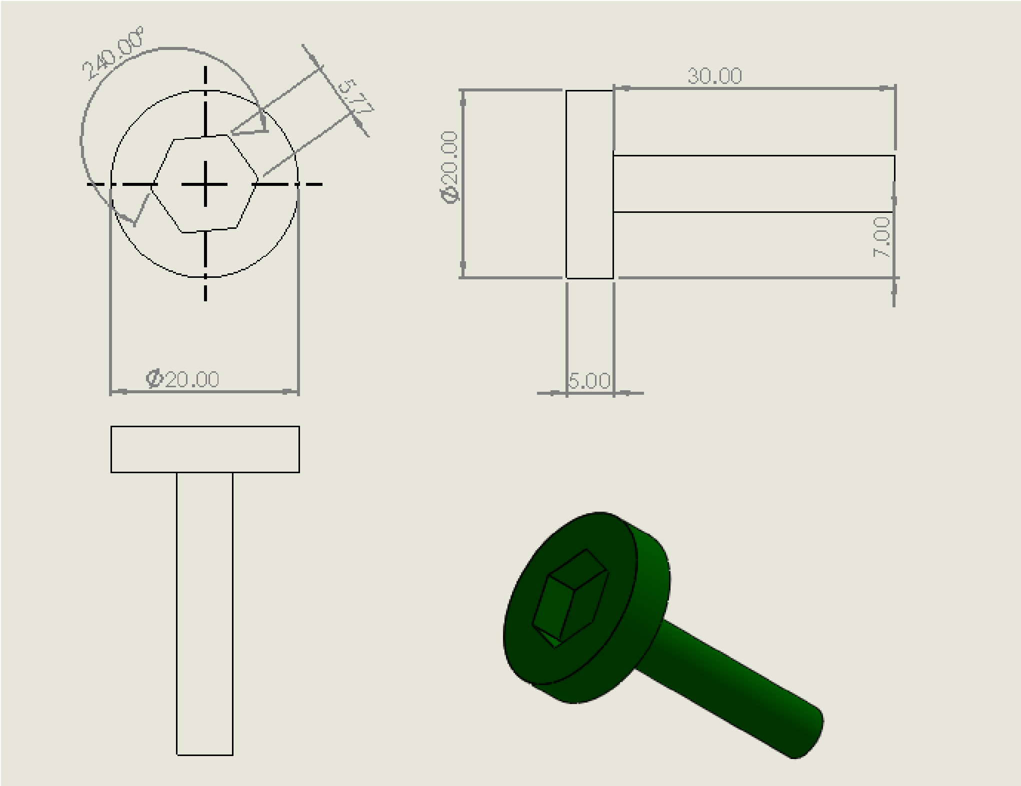
The motor coupling mechanism shown in Fig.3.6plays an important role in ensuring the stability and functionality of the beverage dispensing machine. Comprising two essential components, it facilitates the seamless operation of the stack within the machine. The first component, connected to the spiral rod securely housed inside the stack, is designed in the shape of a hexagon. Its counterpart, affixed to the motor, complements the first component with its hollow hexagonal configuration. When the motor rotates, these interlocking components synergize to transmit motion to the spiral rod, enabling it to revolve within the stack. This coupling mechanism ensures the precise and synchronized movement required for efficient powder dispensing and beverage preparation.

3.2.6 Slide Rails

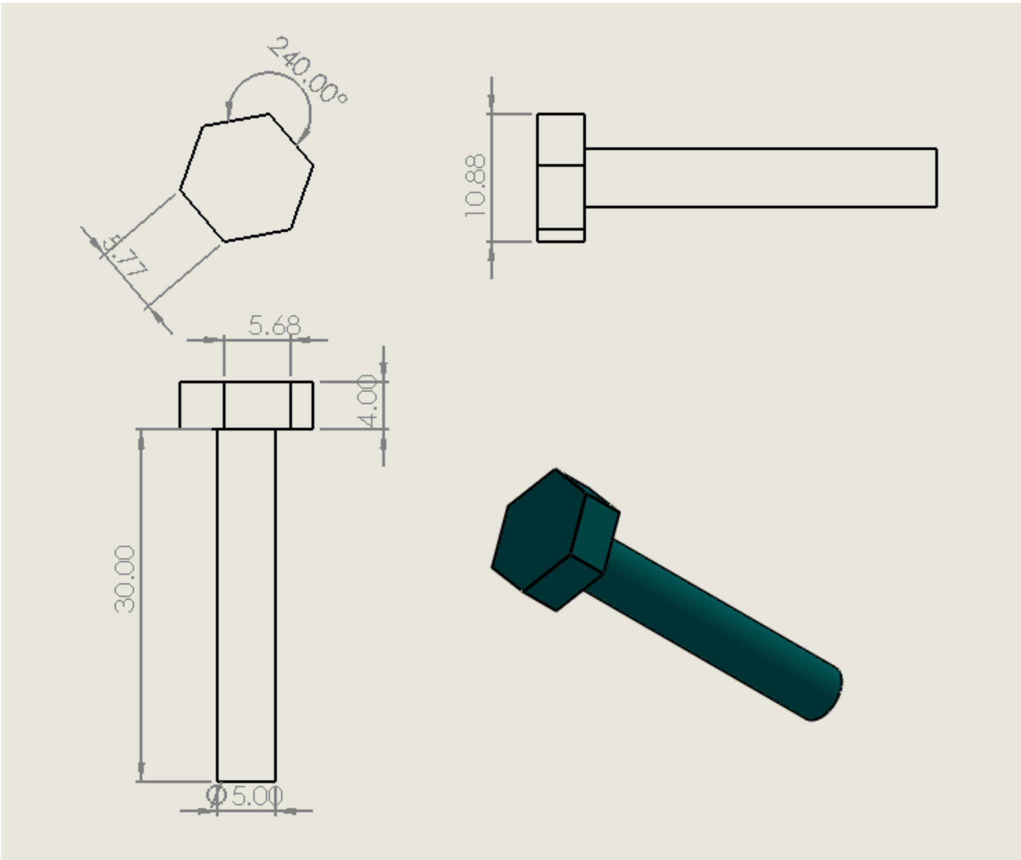
The slider rails shown in Fig.3.7 play a crucial role in the design by enabling the easy cleaning of the stacks. They allow the stacks to extend out of the frame, simplifying maintenance and ensuring efficient operation.

3.2.7 Stirring Gear

The stirring gear shown in Fig.3.8 is strategically positioned directly above the spiral rod to continuously agitate the powders, preventing clumping or moisture accumulation. Its rotational motion is synchronized with the machine's operation, ensuring consistent mixing and optimal powder dispensing throughout the beverage preparation process.



(a) Part 1



(b) Part 2

Figure 3.6: Interlocking System Made Using SolidWorks 2022

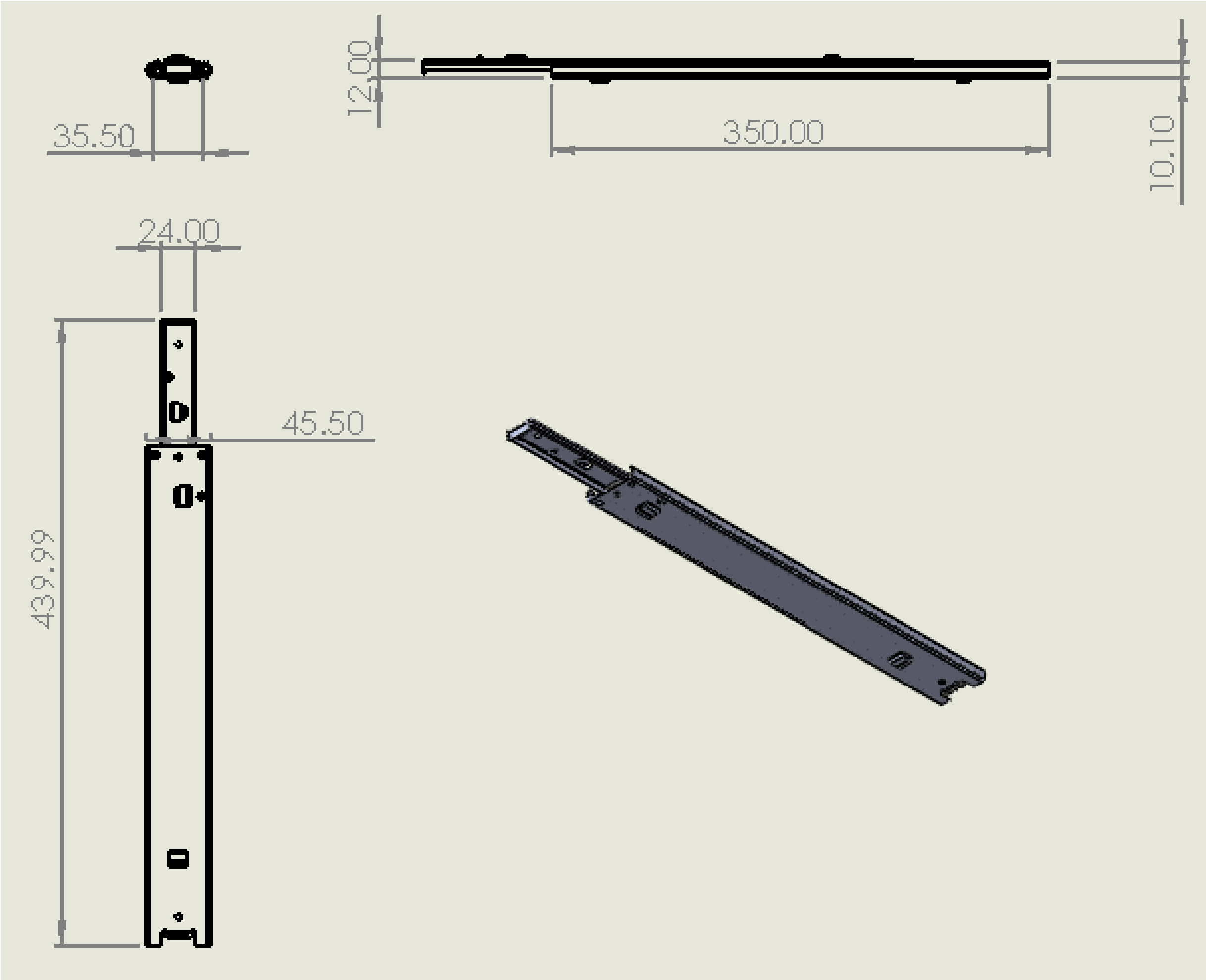


Figure 3.7: Slide Rails Design Made Using SolidWorks 2022

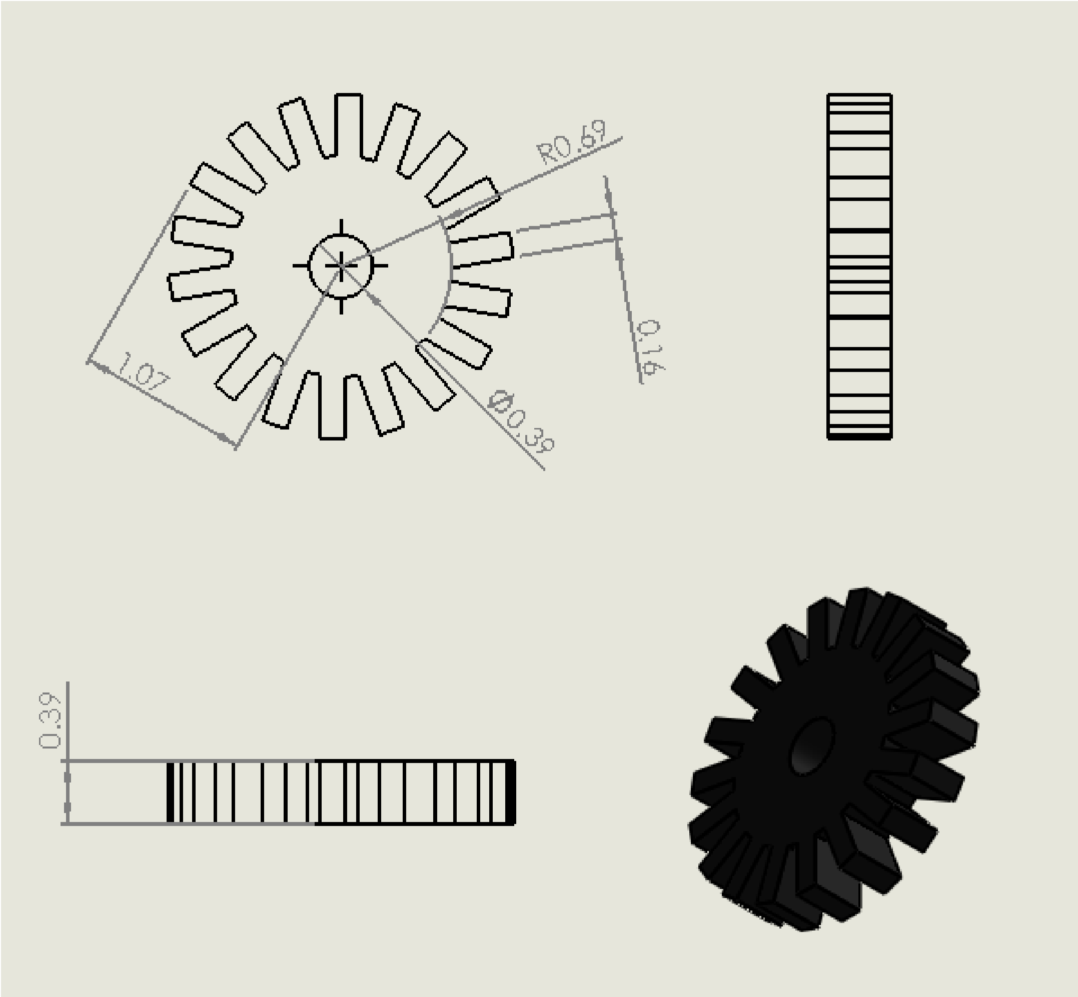


Figure 3.8: Stirring Gear Made Using SolidWorks 2022

3.2.8 Hot Water Pipe

The outlet pipe in Fig.3.9, an integral component of the beverage dispensing machine, is strategically connected to the boiler's outlet and features a distinctive curved design tailored to sit atop the edge of the cone. This curvature facilitates optimal positioning and ensures efficient water distribution during the beverage dispensing process. Along the curved section of the pipe, a series of holes are meticulously crafted, extending along its length and culminating at the closed end.

These holes serve a dual purpose: first, to ensure thorough dispersion of hot water across the cone's surface, preventing any residue or leftover ingredients; second, to facilitate the machine's cleaning function. In response to user input via the touchscreen interface, activating the wash option triggers the release of hot water exclusively through these perforations, facilitating a comprehensive cleaning cycle focused on the cone area. This thoughtful design feature underscores the machine's commitment to hygiene and user convenience, ensuring a consistently high standard of beverage quality and operational performance.

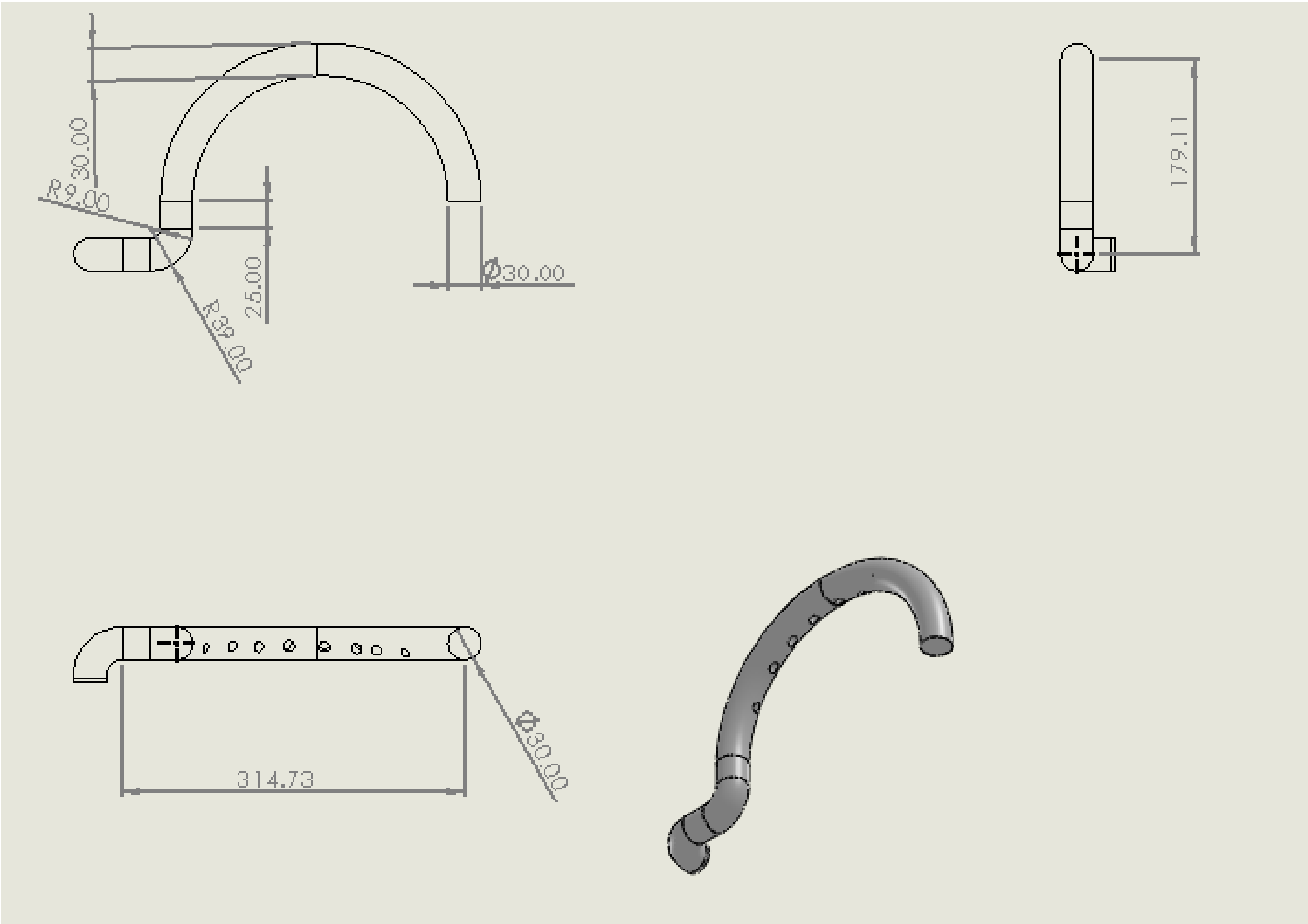


Figure 3.9: Made Using SolidWorks 2022

3.2.9 Water Tank

The water tank shown in Fig.3.10, a fundamental component of the beverage dispensing system, serves as the primary reservoir for supplying water to the boiler. With dimensions of 10x20x20 cm, it is meticulously engineered to accommodate a generous 4-liter capacity, ensuring ample supply for sustained machine operation. Strategically positioned directly beneath the boiler, the tank optimizes space utilization within the machine while facilitating seamless water flow to the heating element.

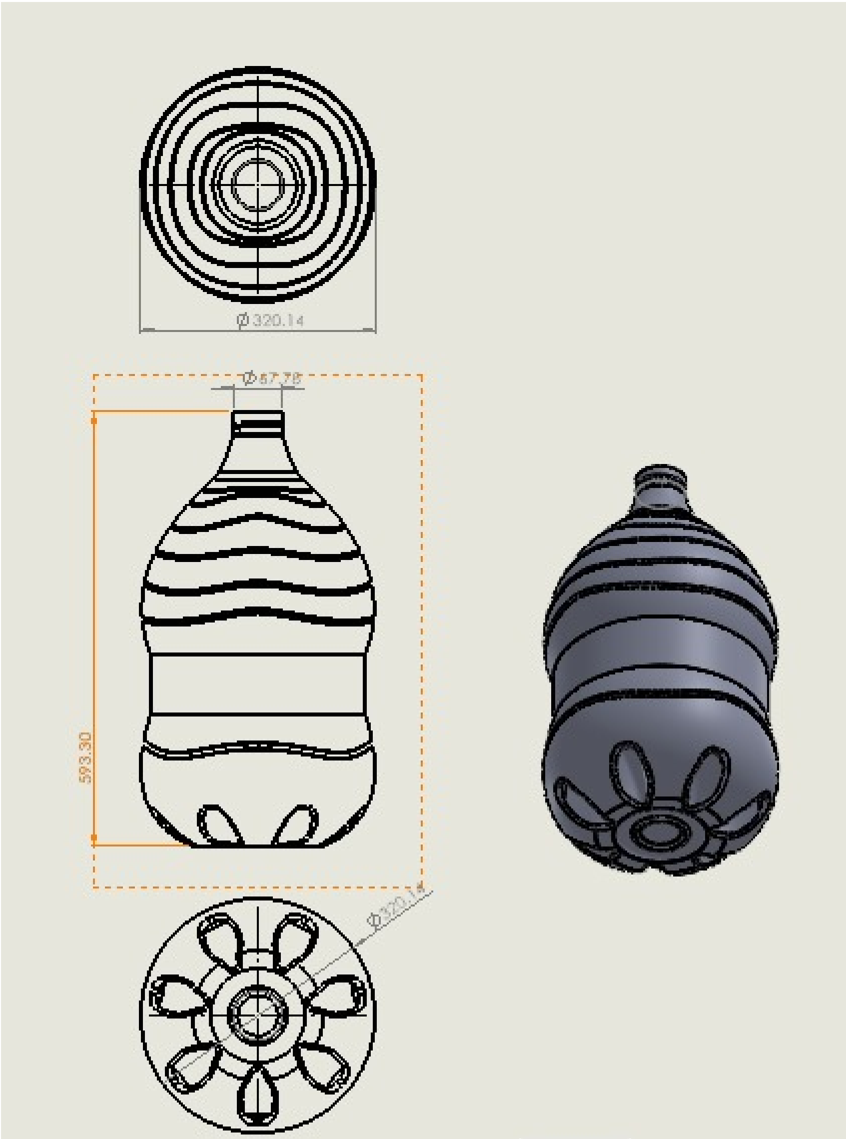


Figure 3.10: Water Tank

3.2.10 Biscuits Shelf

The steel shelf design shown in Fig.3.11 is designed to showcase and accommodate up to 10 packets of biscuits for user selection. Easily removable for convenient restocking and maintenance, this sturdy shelf ensures efficient organization and presentation of available biscuit options.

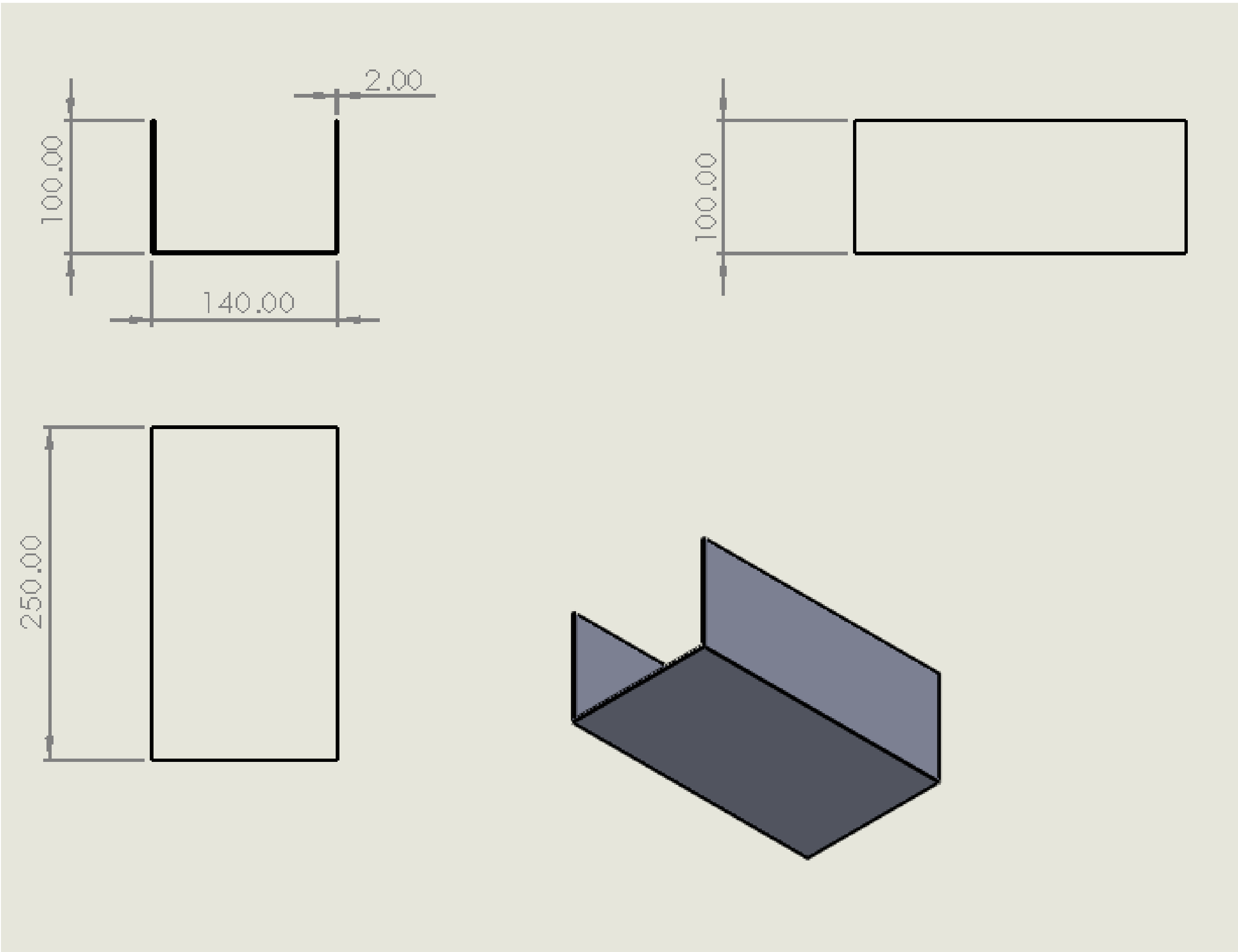


Figure 3.11: Biscuits Shelf Made Using SolidWorks 2022

3.2.11 Compression Spring

The biscuit spring shown in Fig 3.12 features a dual-ended design: one end is straight and linked to a spring motor, while the other end is spiral-shaped and open. As the stepper motor rotates, the spiral end of the spring facilitates the controlled dispensing of biscuits. With each rotation, the spring moves forwards and backwards, ensuring consistent and precise delivery of biscuits to the user.

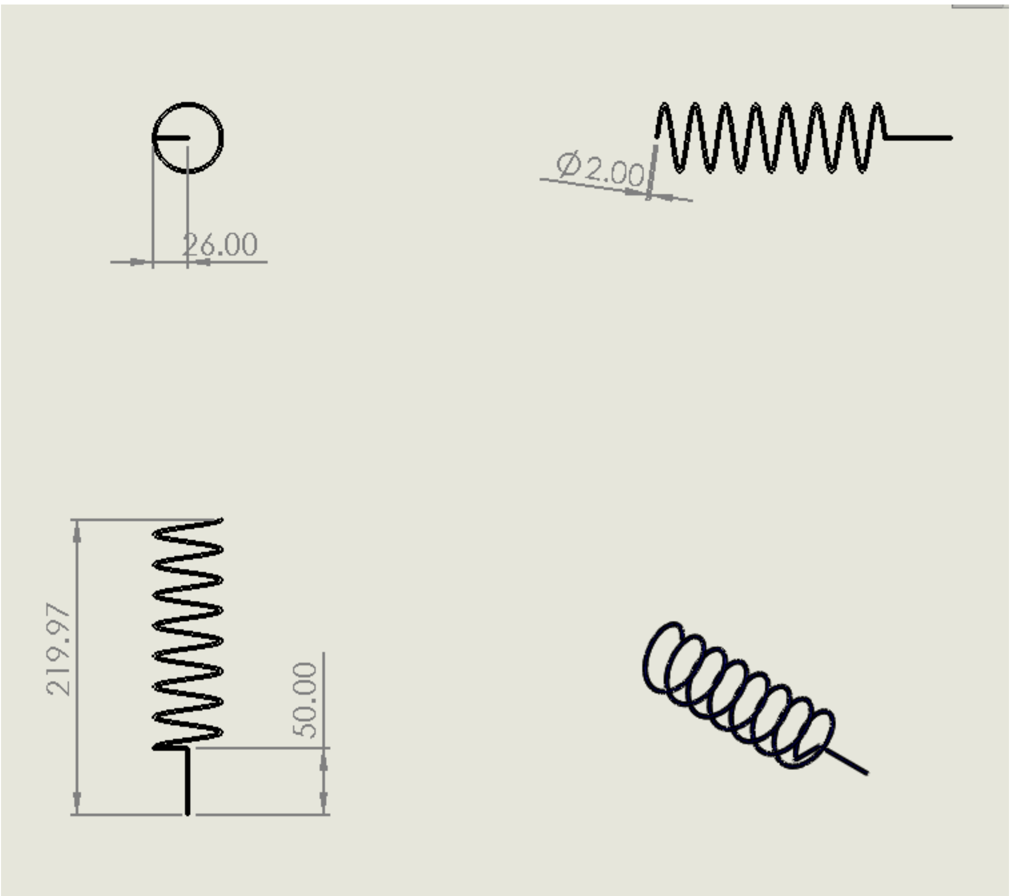


Figure 3.12: Compression Spring Made Using SolidWorks 2022

3.2.12 Biscuits Pick Up Shelf

Below the biscuit dispensing mechanism, there is a lower shelf specifically designed for easy access to the dispensed biscuits Fig 3.13. Once the motor completes its rotation, a packet of biscuits drops onto this shelf, providing a convenient location for users to retrieve their selected snacks.

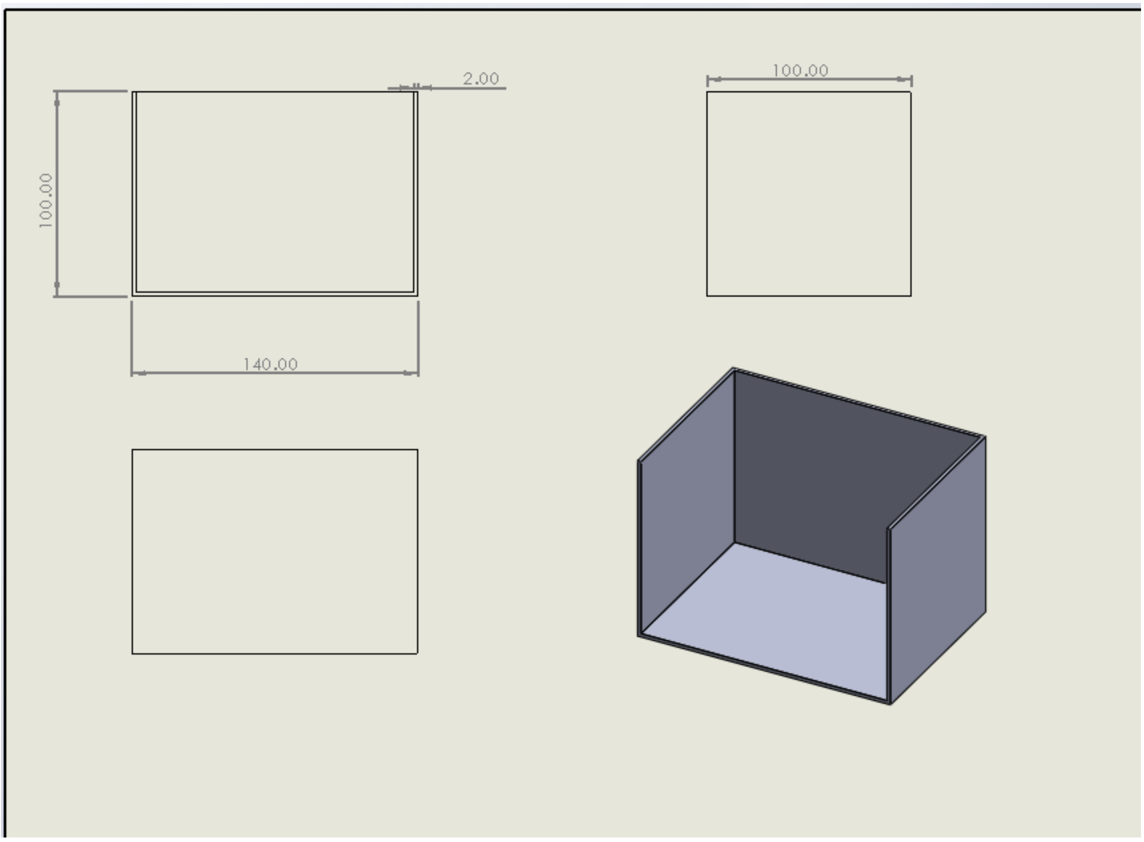


Figure 3.13: Biscuits Pick Up Shelf Made Using SolidWorks 2022

3.2.13 Slotted Rod

The slotted rod design shown in Fig 3.14, crafted from durable steel, serve as integral components within the machine's frame structure. Steel, renowned for its robustness and resilience, provides the ideal material for constructing sturdy and reliable framework elements.

These rods feature strategically positioned slots along their length, ingeniously designed to form a versatile track system. This innovative configuration enables the effortless attachment of various components and accessories without the need for drilling additional holes. By offering flexibility and adaptability in component placement, the slotted rods facilitate seamless customization and optimization of the machine's layout, ensuring optimal functionality and ease of maintenance.

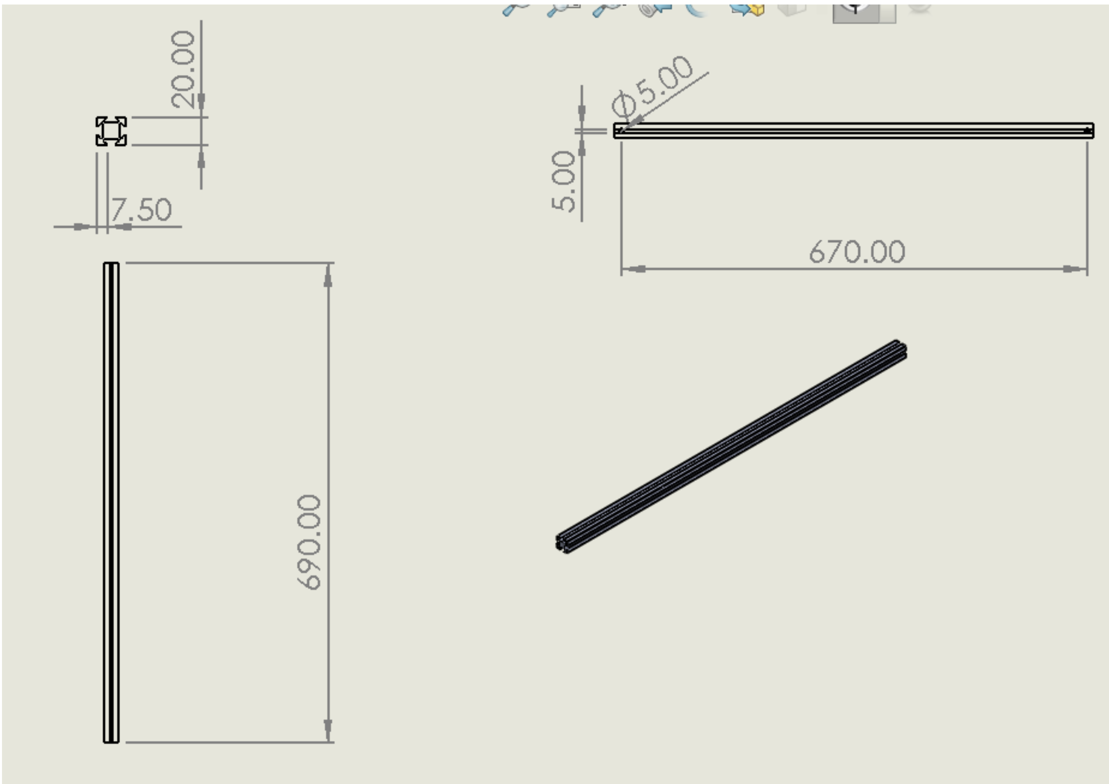


Figure 3.14: Slotted Rod Design Made Using SolidWorks 2022

3.2.14 Linkage

Crafted from sturdy steel, the 90-degree linkage shown in Fig 3.15efficiently connects rods together, enhancing structural integrity. Its streamlined design requires only two bolts for secure attachment, simplifying assembly while ensuring stability. This pivotal component enables precise alignment of rods at right angles, ensuring reliable performance and longevity.

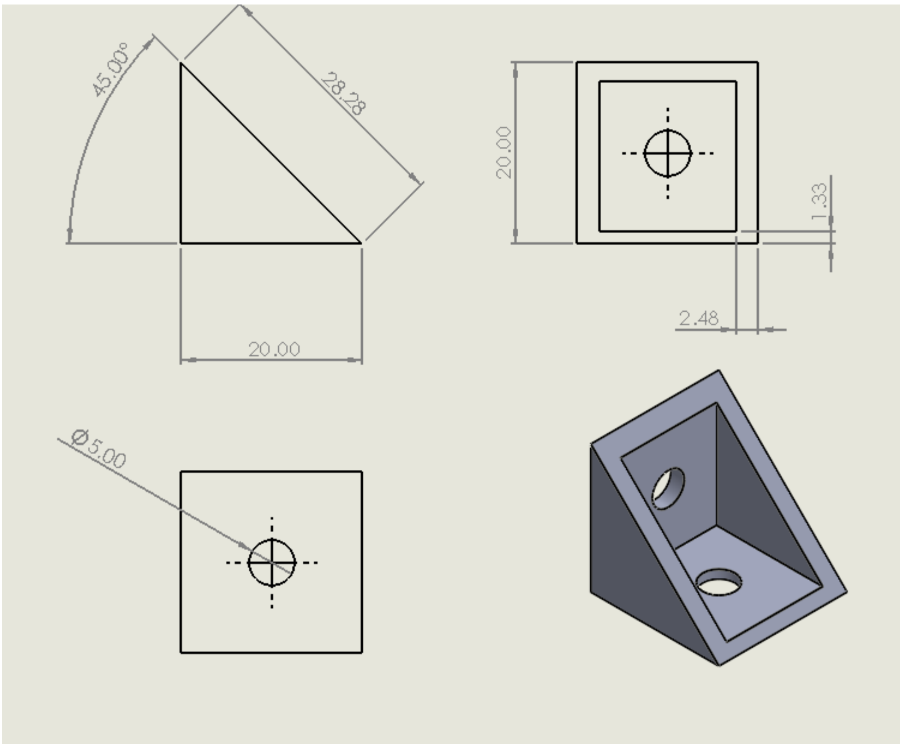


Figure 3.15: Linkage Design Made Using SolidWorks 2022

3.2.15 Bolt

The Bolt shown in Fig 3.16 is made of steel and their sizes complements the holes in the linkage.

3.2.16 Table

The steel table shown in Fig 3.17 serves as the foundation for the machine's structure frame, providing stability and support. Additionally, it features ample space for holding disposable cups, ensuring convenience for users. With a square edge along the top, the table securely holds the frame in place, preventing it from sliding out and allowing for easy lifting when necessary.

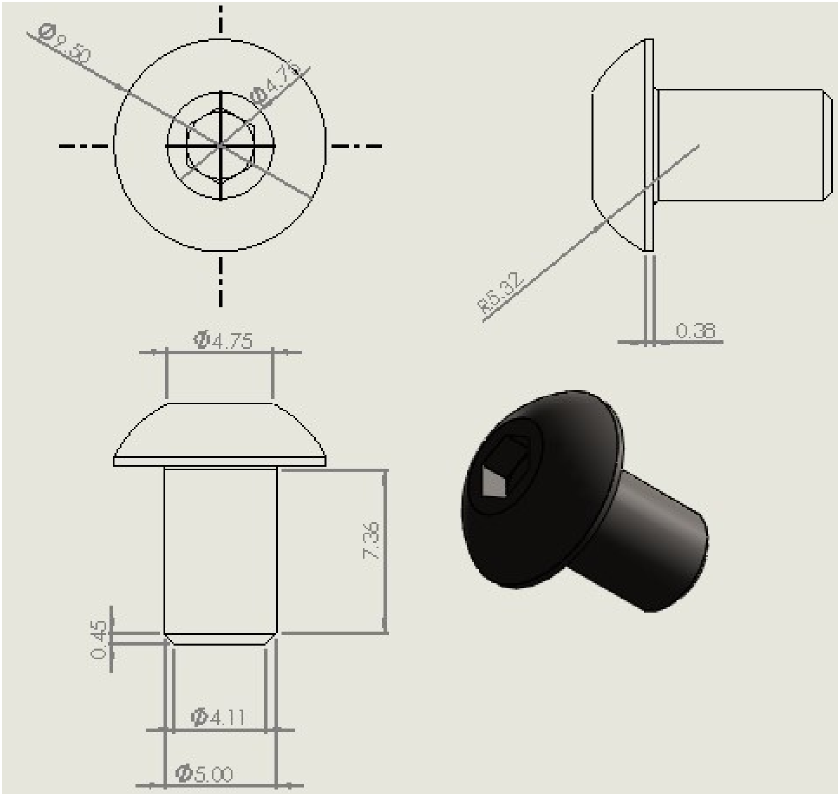


Figure 3.16: Bolt Design Made Using SolidWorks 2022

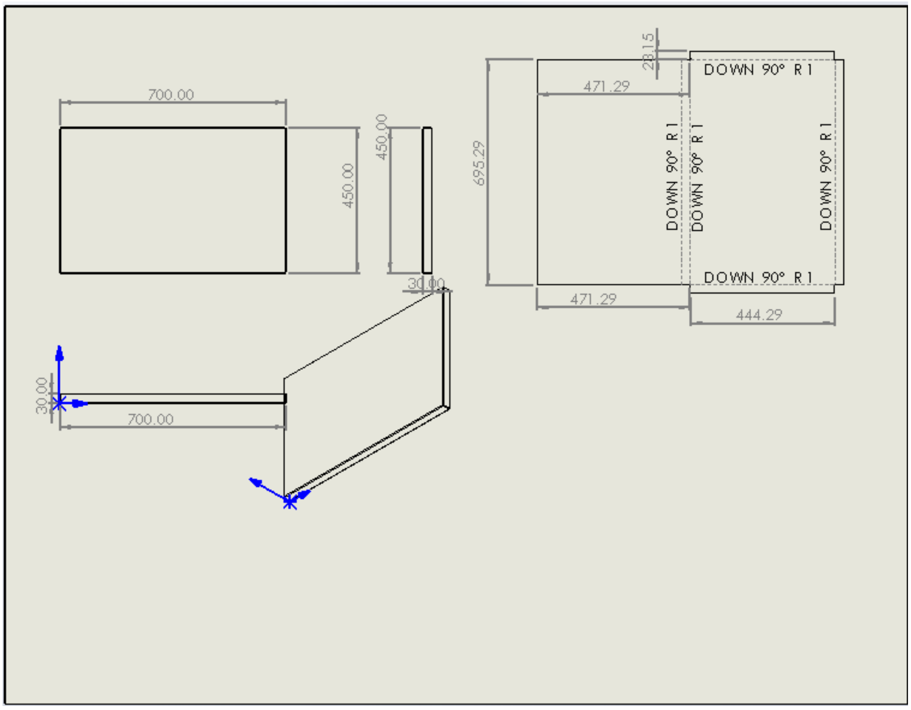


Figure 3.17: Table Design Made Using SolidWorks 2022

3.2.17 Wheels

The wheels design shown in Fig 3.18 is made to be attached to the legs of the table facilitate the movement of the machine, allowing for easy transportation and repositioning as needed.

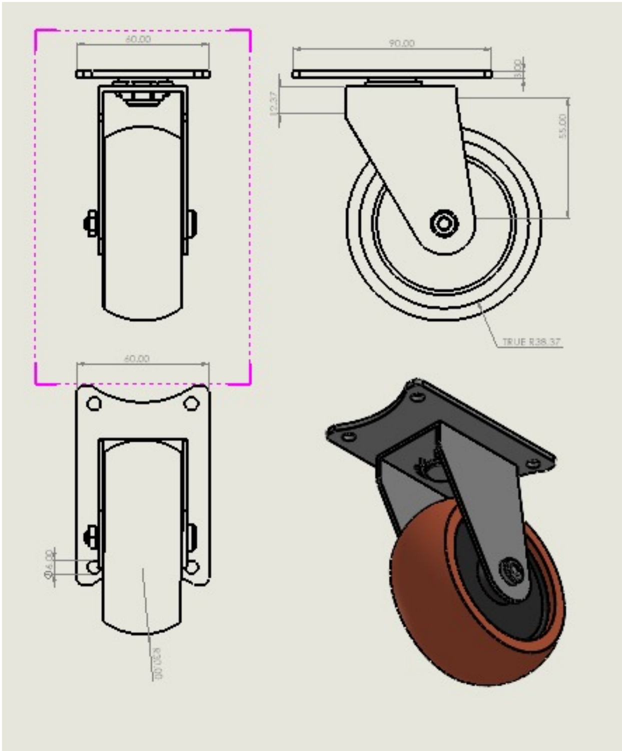


Figure 3.18: Wheels Made Using SolidWorks 2022

3.2.18 Cup Drain Holder

This component shown in Fig 3.19 serves as a visible indicator for users to know where to place their cup. It features a hole to accommodate the sensor and tracks for the cup's drain to ensure proper positioning.

3.2.19 Cup Drain

The drain shown in Fig 3.20 is positioned on tracks, enabling smooth movement for ease of access and maintenance. Its perforated design ensures efficient drainage of any liquid residue, enhancing cleanliness and hygiene within the machine.

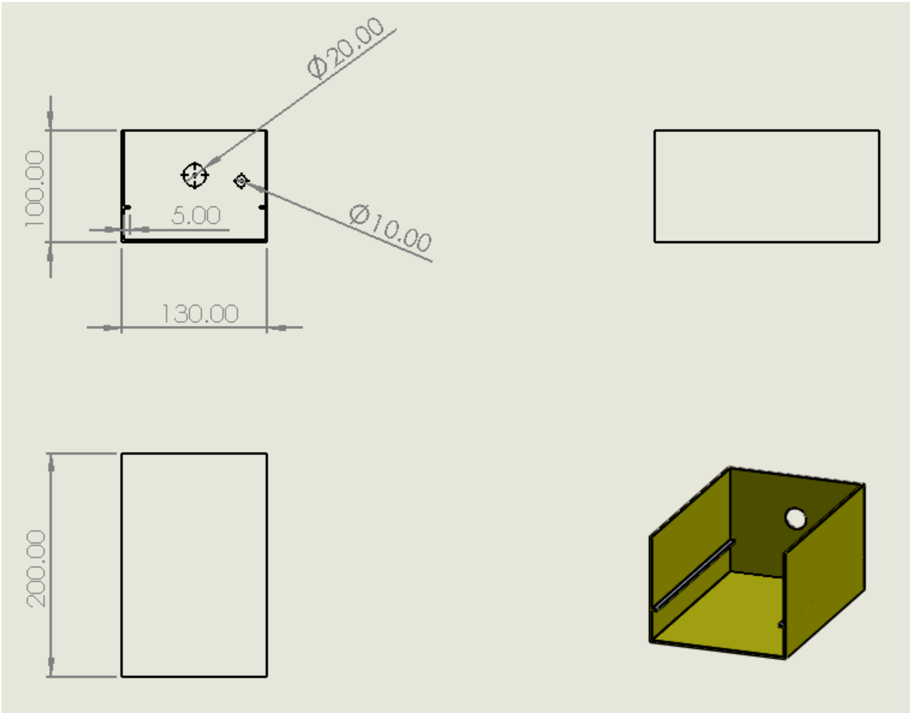


Figure 3.19: Drain Holder Design Made Using SolidWorks 2022

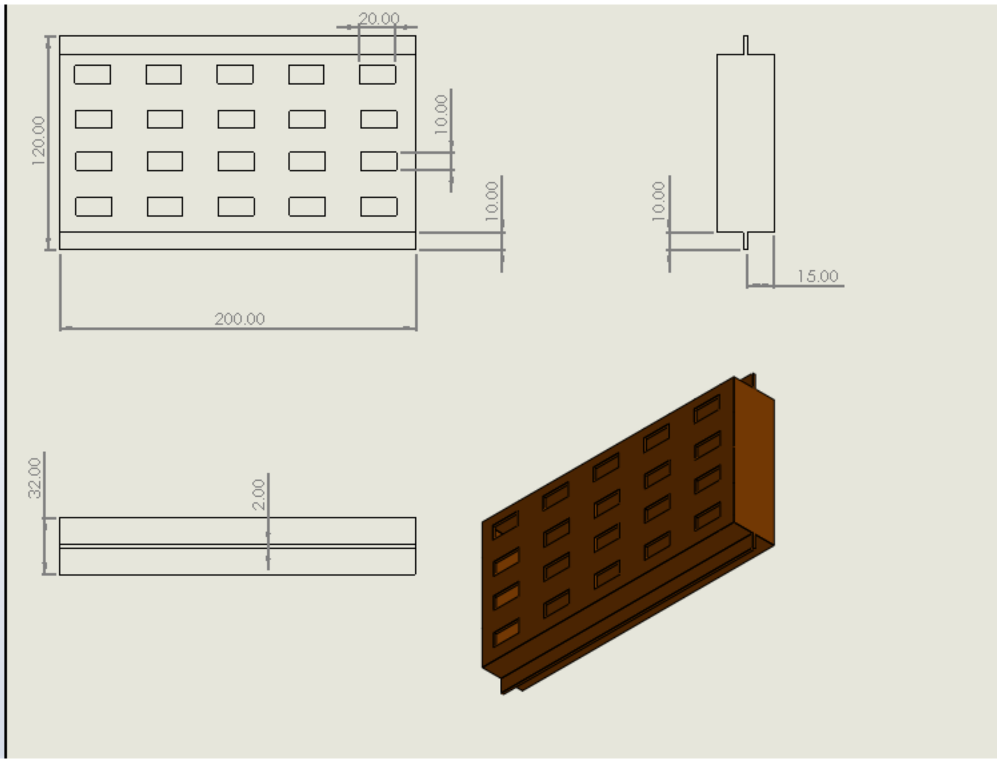


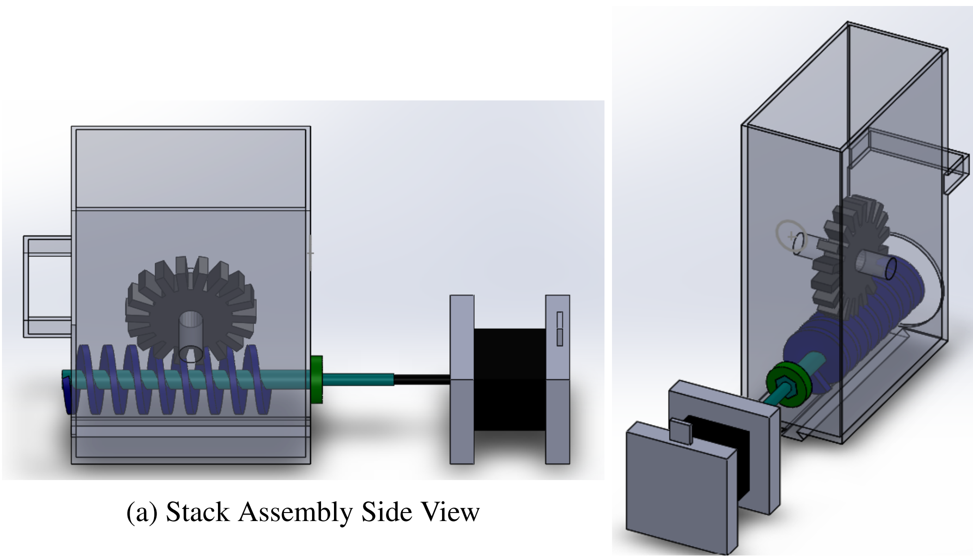
Figure 3.20: Drain Design Made Using SolidWorks 2022

3.3 Assembly

This section will present the assemblies made to form the whole machine. Table 3.4 shows the sequence of assembling.

3.3.1 Powder Dropping Mechanism Assembly

The powder dropping mechanism assembly shown in Fig 3.21a showcases the integration of mechanical components to efficiently perform its designated function. As depicted in the figures, the spiral rod is firmly secured within the stack and connected to one part of the interlocking mechanism, while the other part is linked to the motor. This arrangement allows the spiral rod to be attached to the motor yet easily removed from the machine, leaving the motor in place. Additionally, the design includes provisions for accommodating electrical components, such as a designated space for positioning the sensor, ensuring seamless integration of mechanical and electrical elements for optimal functionality.



(a) Stack Assembly Side View

(b) Stack Assembly Back View

Figure 3.21: Stack Assembly Made Using SolidWorks 2022

3.3.2 Boiler Assembly

The boiler assembly design shown in Fig 3.22 is meticulously crafted to accommodate various electrical components, including temperature sensors and switches. Positioned prominently at the front are the inlet and outlet solenoid valves, strategically placed for efficient water flow control. Additionally, the design incorporates space for seamlessly integrating electric elements, ensuring optimal functionality and operational efficiency.

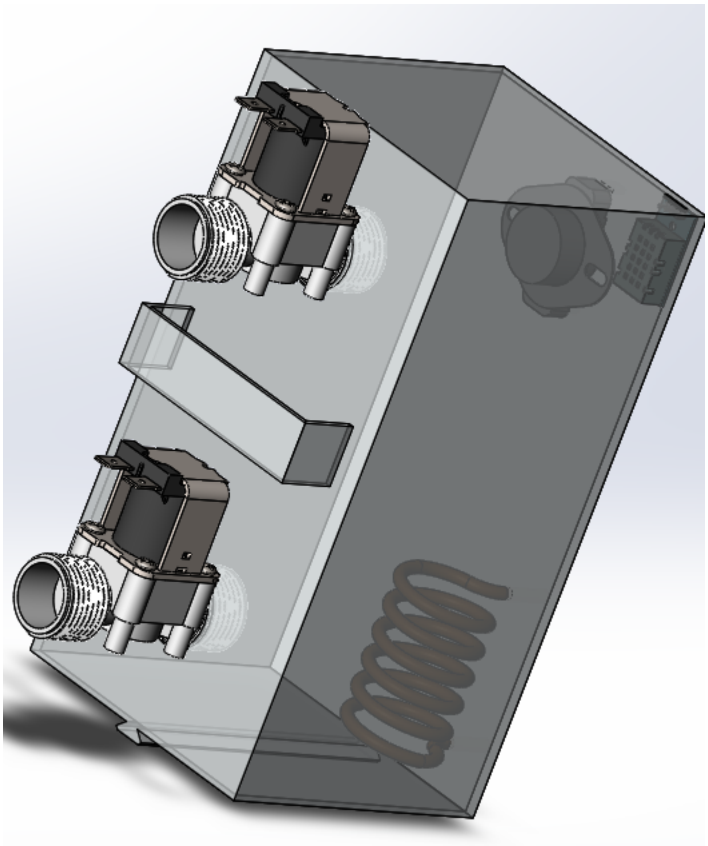
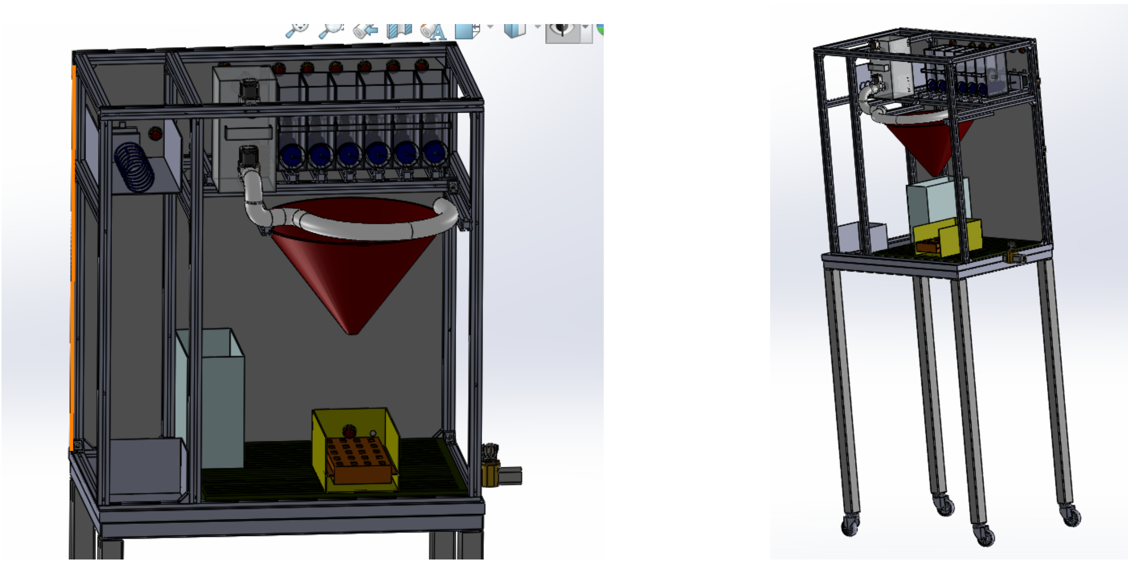


Figure 3.22: Boiler Assembly Made Using SolidWorks 2022

3.3.3 Frame Structure Assembly

The frame structure shown in Fig 3.23 is meticulously assembled using slotted rods, firmly joined together by linkages and bolts. These rods serve dual purposes, forming tracks for both the ingredient stacks and the heater assembly. The frame comprises three distinct levels: the first level serves as a showcase for biscuits, houses the water boiler, and accommodates the ingredient stacks. On the second level, mixing occurs with the aid of the perforated hot water pipe and the cone. Finally, the third and lowest level facilitates user pickup of both the beverage and biscuits, ensuring a seamless user experience.



(a) Frame Structure Front View

(b) Frame Structure Side View

Figure 3.23: Frame Structure Assembly Made Using SolidWorks 2022

3.3.4 Machine Cover Assembly

The machine cover shown in Fig 3.24, resembling a box, fulfills dual roles. It grants users access to retrieve their beverages or biscuits and facilitates cup placement. With openings on select sides, accessible via handles, it offers entry to the control room. The front panel can be opened for ingredient stack removal and boiler washing. Moreover, it includes a designated area for the touchscreen, ensuring visibility to users.

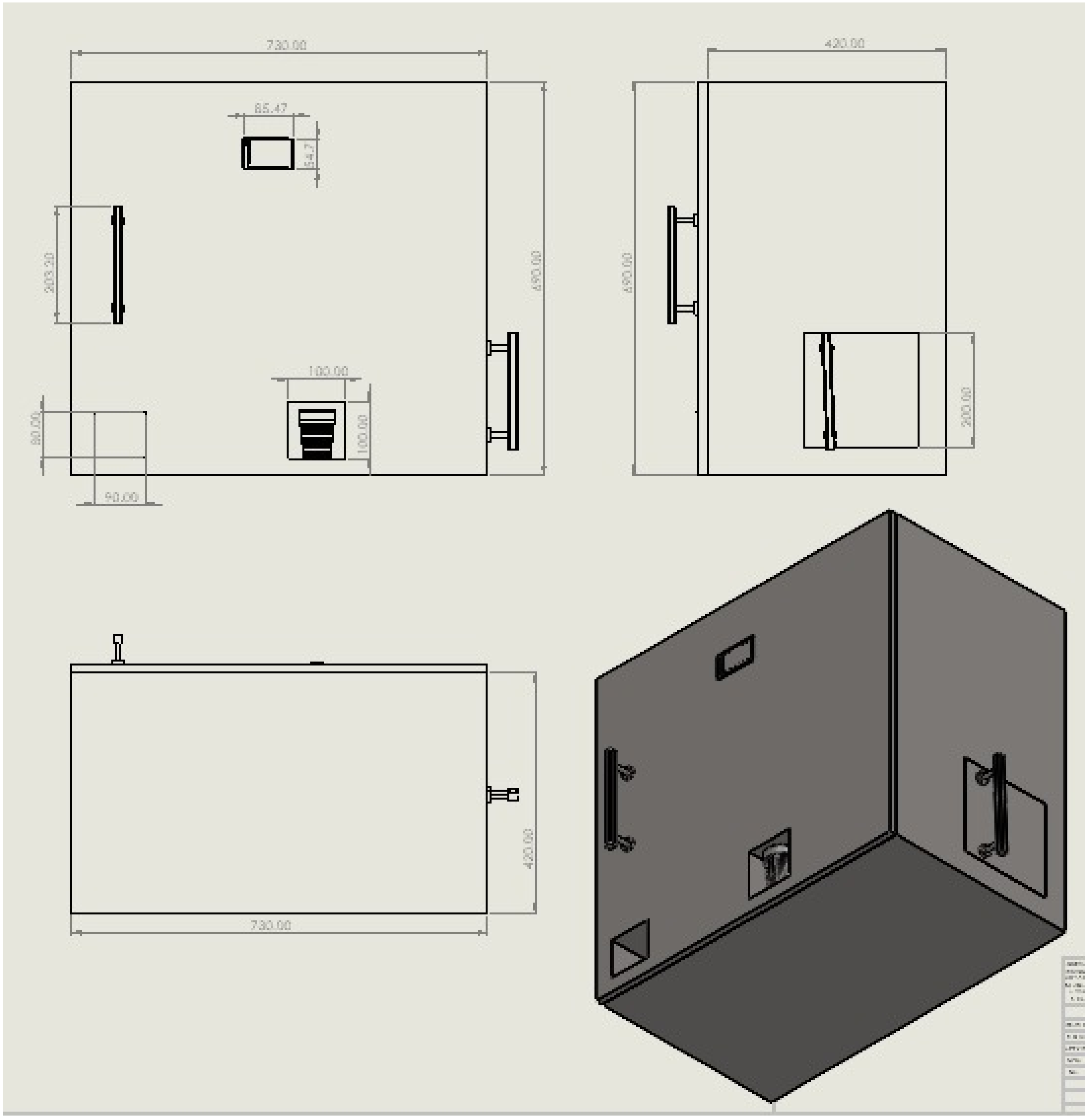


Figure 3.24: Machine Cover Assembly Made Using SolidWorks 2022

Component Name	Material	Quantity
Stack	Stainless Steel	5
Boiler Stack	Stainless Steel	1
Cone	Stainless Steel	1
Slotted Rod 1	Aluminum	2
Slotted Rod 2	Aluminum	10
Slotted Rod 3	Aluminum	4
Slotted Rod 4	Aluminum	6
Linkage	Aluminum	22
Slide Rails	Steel	6
Hot Water Pipe	PVC	1
Spiral Rod	PTFE	5
Part 1 of Interlocking Mechanism	PTFE	5
Part 2 of Interlocking Mechanism	PTFE	5
Water Tank	Plastic	1
Compression Spring	Steel	1
Biscuits Shelf	Steel	1
Pick Up Shelf	Steel	1
Cup Drain Holder	Steel	1
Cup Drain	Steel	1
Table	Steel	1
Wheels	Steel and Rubber	4

Table 3.2: Quantity and Materials of Mechanical Components

Component Name	Manufacturing Process
Stack	Laser Cutting, Bending, Welding
Heater Stack	Laser Cutting, Bending, Welding
Table	Laser Cutting, Bending, Welding
Part 1 of Interlocking System	Turning
Part 2 of Interlocking System	Milling
Biscuits Shelf	Bending, Welding
Biscuits Pick Up Shelf	Laser Cutting, Bending, Welding

Table 3.3: Manufacturing Processes

Sequence	Name of Assembly
1	Frame Structure Assembly
2	Stack Assembly
3	Heater Assembly
4	Cup Place Assembly
5	Inner Machine Assembly
6	Machine Cover Assembly

Table 3.4: Assembly Sequence

Chapter 4

Electrical and Control Design

This Chapter focuses on the electrical components of the Smart Beverages Dispensing Machine. It delves into the various electric devices utilized, their connections, and how they're managed through an Arduino Mega microcontroller. This section provides insight into the intricate electrical setup of the machine, shedding light on its control mechanisms and operation.

4.1 Control Sequence and Program Flow

This section presents the control logic of the machine and the sequence of operations the machine go through to dispense a drink.

4.1.1 The logical sequence of the machine

The logical sequence of the machine as shown in Fig 4.1 above is as follows:

- If ”eat” is selected:
  - The stepper motor rotates to release a packet of biscuits.
- If ”drink” is selected:
  - The user is presented with a list of drink options (coffee, latte, tea, tea with milk, hot chocolate).
  - The user selects their desired drink.
  - After selecting a drink, the user is presented with options for the quantity of sugar (up to 3 tablespoons).
  - The user selects the desired quantity of sugar.
  - The stepper motors corresponding to the ingredients of the chosen drink, along with the sugar dispenser, are activated simultaneously.
  - Hot water is sprayed over the cone to mix the ingredients.

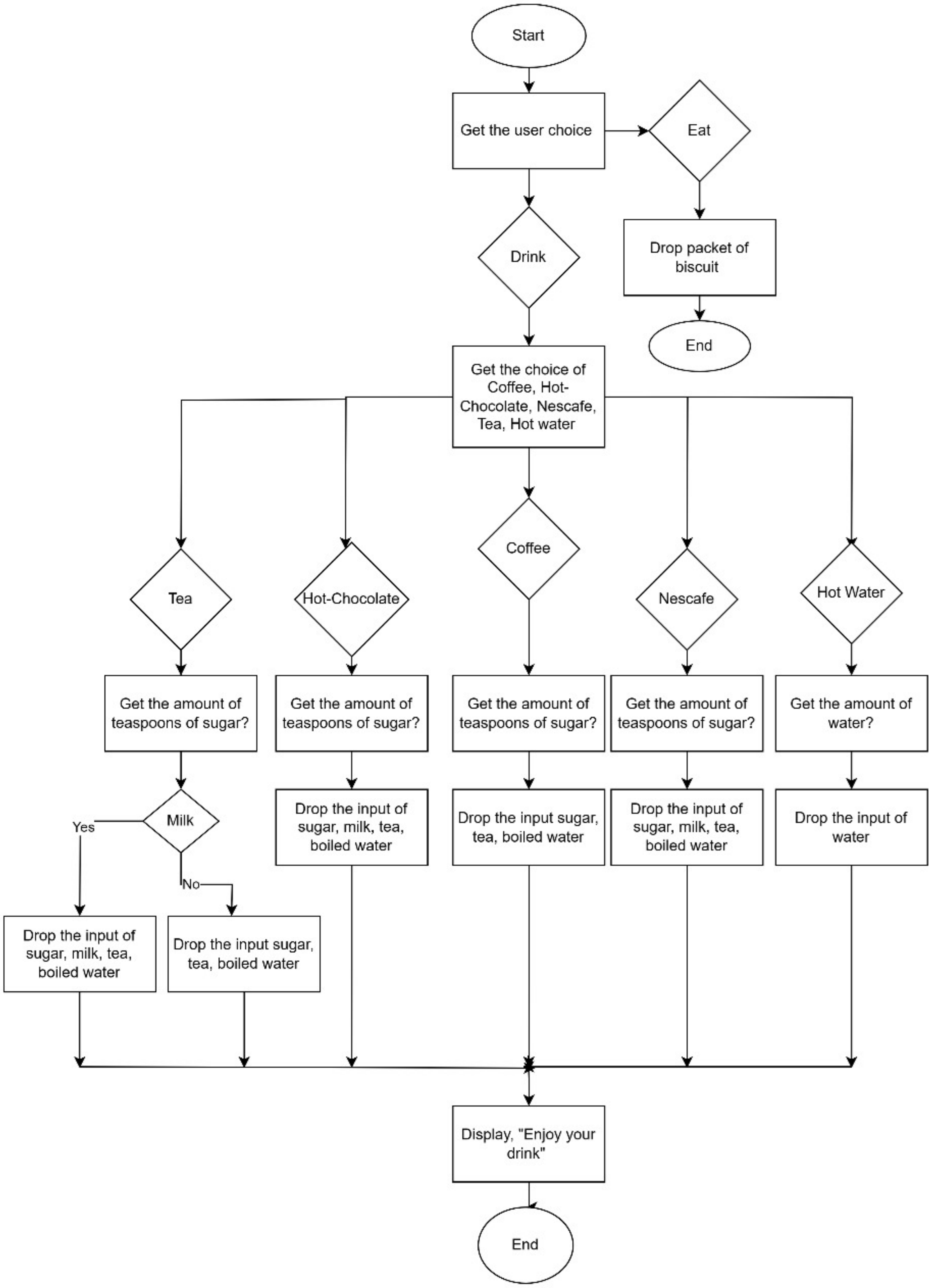


Figure 4.1: Control Flowchart

4.1.2 Ideal State and Error Messages

Once the Smart Beverages Dispensing Machine is plugged in and activated, it initiates a series of checks and prompts shown in Fig 4.2 to ensure smooth operation:

1. Cup Check:
    - The machine's infrared (IR) sensor scans the designated area for the presence of a cup. If the sensor detects no cup, indicating that the user has not placed one yet, the system prompts an error message on the machine's display screen. This message notifies the user to insert a cup before proceeding with their order, ensuring that beverages are dispensed into a container.
2. Ingredients Check:
    - Next, the machine conducts a thorough check of its ingredient levels. Sensors strategically positioned within the machine monitor the levels of water and various beverage ingredients, such as coffee beans, tea leaves, or chocolate powder, in their respective storage compartments. Should any of these levels fall below a predetermined threshold, indicating an insufficient supply, the machine displays an error message on the screen. This prompt notifies the user of the shortage and prompts them to refill the necessary ingredients to ensure uninterrupted service.
3. Water Temperature Check:
    - Additionally, the machine verifies the temperature of the water in its boiler system. It ensures that the water is adequately heated to the optimal temperature for preparing hot beverages. If the water temperature is found to be below the desired level, signifying that the boiler needs more time to reach the required temperature, the machine displays a message on its interface. This message advises the user to wait patiently until the water reaches the appropriate boiling point before placing their beverage order, ensuring that the dispensed beverages are of the desired quality and temperature.

By conducting these checks and providing informative prompts, the Smart Beverages Dispensing Machine ensures that users have a seamless and enjoyable experience while using the system, minimizing errors and maximizing customer satisfaction.

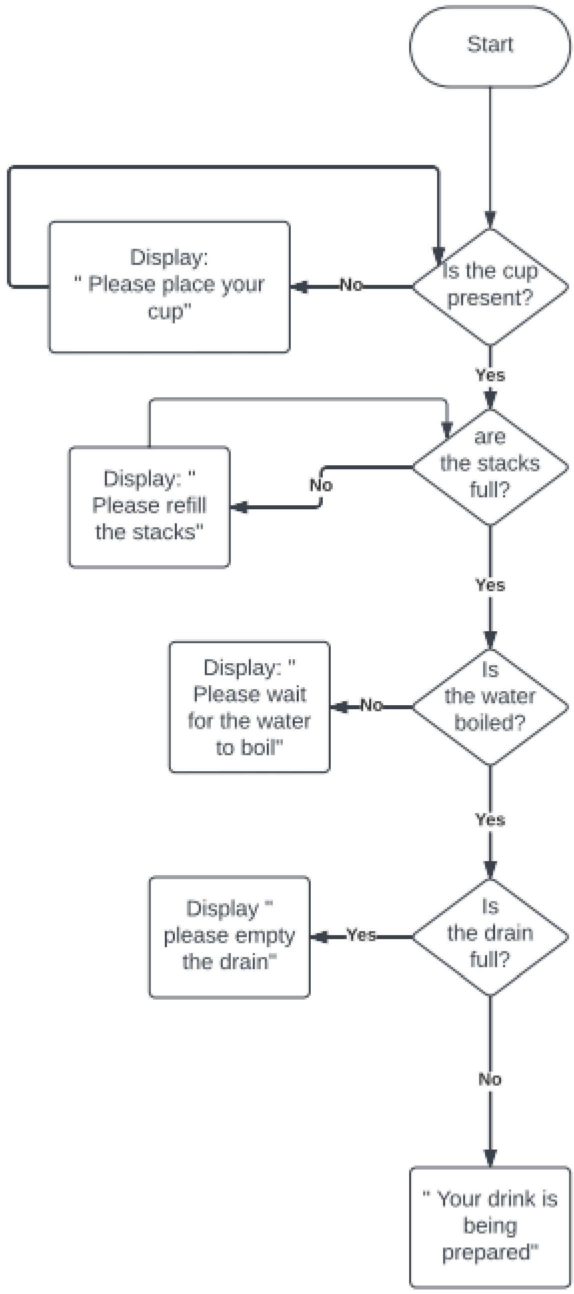


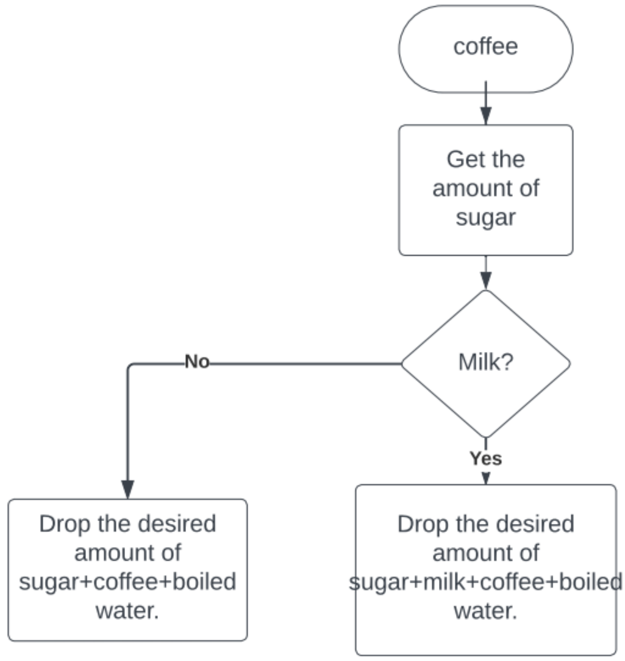
Figure 4.2: Ideal State Flowchart

4.1.3 Sequence of Dispensing the Drink

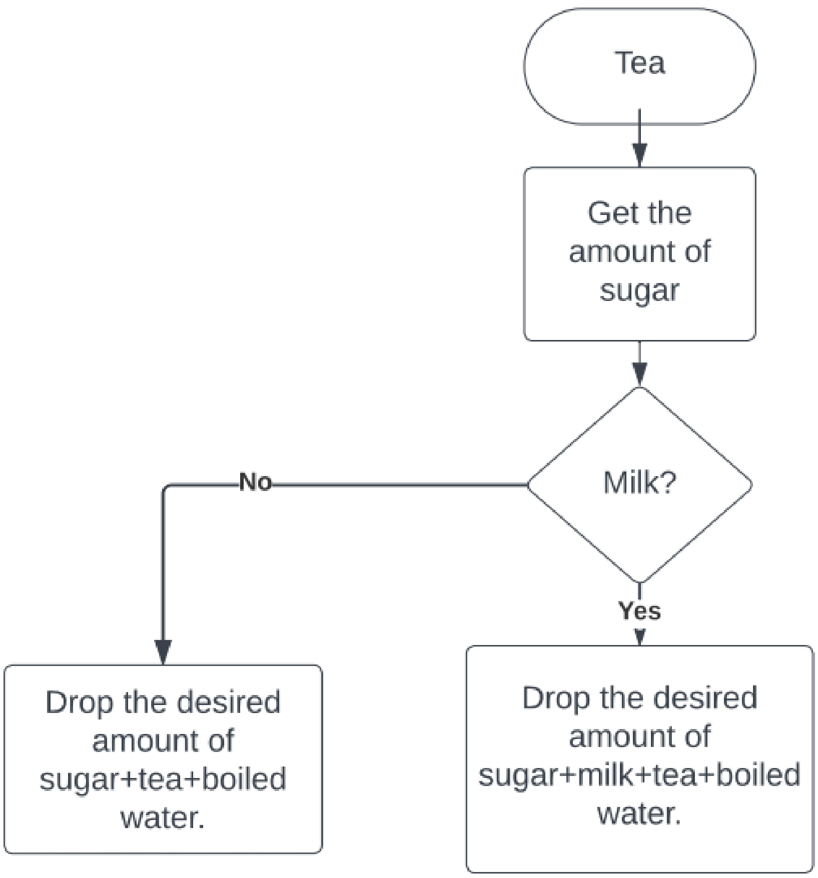
In the depicted scenarios presented in Figure 4.3, it is evident that the crafting of every beverage entails a meticulous journey through a sequence of personalized customization steps. Within this process, each beverage affords the consumer the opportunity to specify whether milk is to be included or omitted, along with the precise quantity of sugar desired. Subsequently, after gathering these individualized preferences, the machine undertakes the task of precisely dispensing the beverage, carefully incorporating the selected ingredients. This tailored approach ensures that each beverage is uniquely crafted to cater to the specific tastes and preferences of the discerning consumer, thereby enhancing their overall satisfaction and enjoyment of the beverage experience.

4.1.4 Microcontroller

The choice of the Arduino Mega 2560(Fig 4.4) for this project was deliberate, as it offers the speed and reliability required for precise control operations, particularly for the stepper motors used in the system. Furthermore, its extensive pin count makes it suitable for a wide range of applications, from manufacturing and robotics to actuation systems in industrial and laboratory settings [8]. Table4.1 discusses the advantages of using Arduino rather than other available controllers.

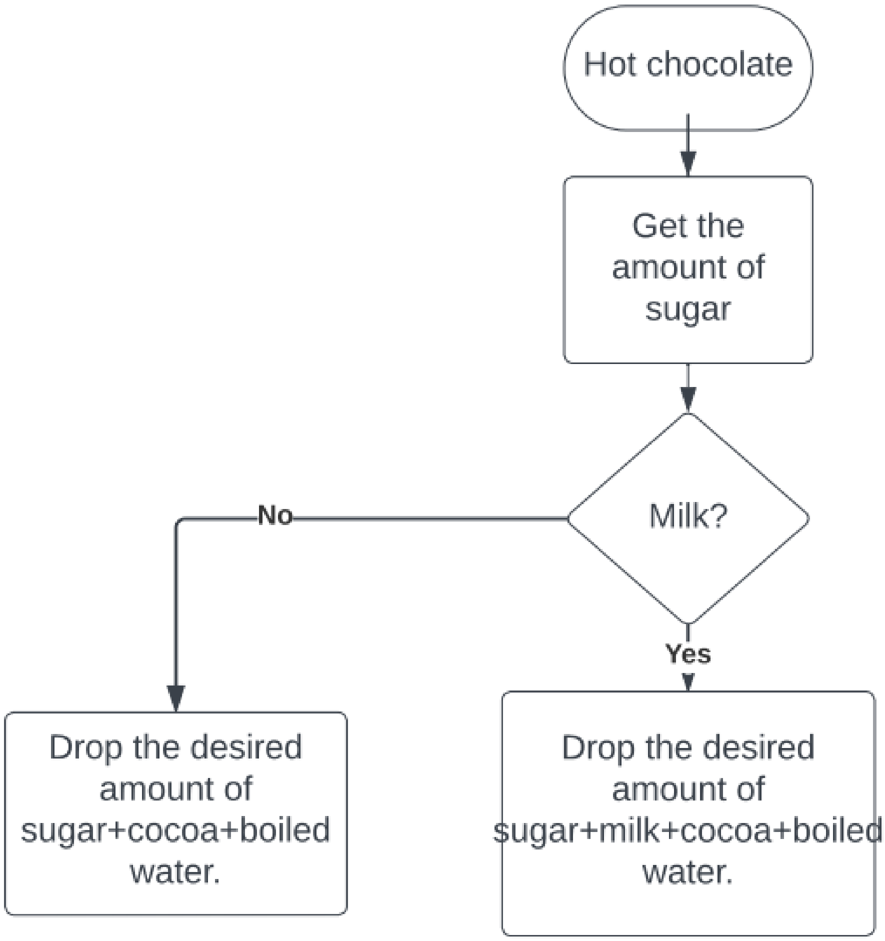


(a) Sequence of dispensing coffee



(b) Sequence of dispensing tea

Figure 4.3: Dispensing the drink: Sequence of operation



(c) Sequence of dispensing hot chocolate
Figure 4.3: Dispensing the drink: Sequence of operation (continued)

Figure 4.4: Arduino Mega 2650

Arduino	**Other Microcontollers like: Raspberry pi and ESP 32**
Cost	Relatively low compared to other options.
Programming Language	Arduino uses C++, which is easy to learn.
Community Support	Arduino has a vast and active community.
Flexibility	Arduino can be used for a wide range of projects.
Performance	Arduino is powerful enough for most projects.
Compatibility	Arduino can work with many other devices and components.

Table 4.1: Comparison between Arduino and Raspberry Pi/ESP32

4.1.5 PCB

Virtually every electronic product is constructed with one or more printed-circuit boards Printed Circuit Board (PCB)s. The PCBs hold the ICs and other components and implement the interconnections between them. PCBs are created in abundance for portable electronics, computers, and entertainment equipment. They are also made for test equipment, manufacturing, and spacecraft. Eventually, almost every EE must design a PCB, which is not something that is taught in school. Yet engineers, technicians, and even novice PCB designers can create high-quality PCBs for any and every purpose with confidence that the outcome will meet or exceed the objective. Also, these designs can be completed on schedule and within budget while meeting the design requirements[10]. Designers just need to mind the essential documentation, design steps and strategies, and final checks (Fig4.5).

The major reason why a PCB had to be implemented is that small components can be housed on a single simple PCB. Instead of using standard wires to connect these components, copper tracks are used. As a result, hundreds of components can be connected without concern for the size of the circuit board. These parts are often small like: Resistance, Capacitance and transistors. Because of this, ordinary cables can't link these components to one another. In essence, a simple circuit board offers a foundation for the effective placement of electronic components. This compactness makes it possible to design intricate electronic circuits without taking up much room[11].

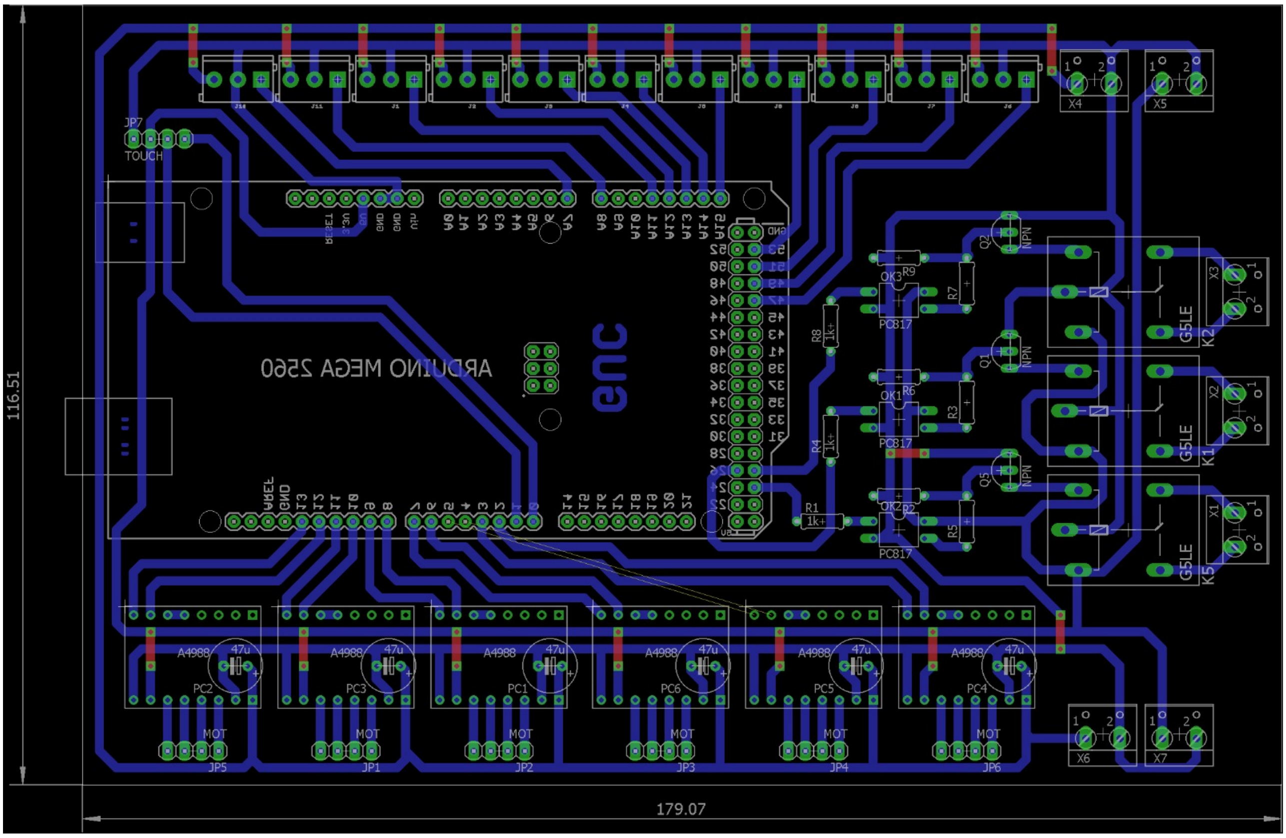


Figure 4.5: PCB Layout made By Proteus Professional 8

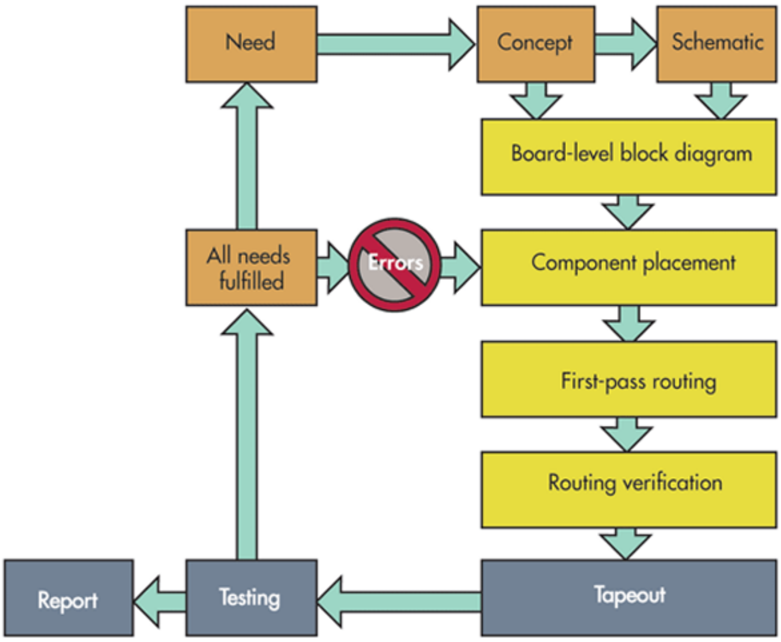


Figure 4.6: PCB Design Block Diagram

4.2 Electric Components

This section will discuss the electric components and their utilization in the machine.

4.2.1 Touch Screen

Nextion is a seamless Human Machine Interface (HMI) solution that provides a control and visualisation interface between a human and a process, machine, application or appliance. Table 4.2 lists the specifications of the screen.

Size	Resolution	Touch Panel	MCU	Flash	RAM	SKU
3.5”	480*320	Resistive Touch Panel (RTP)	48MHz	16MB	3584Byte	IM150918001

Table 4.2: NX4832T035 HMI Specifications

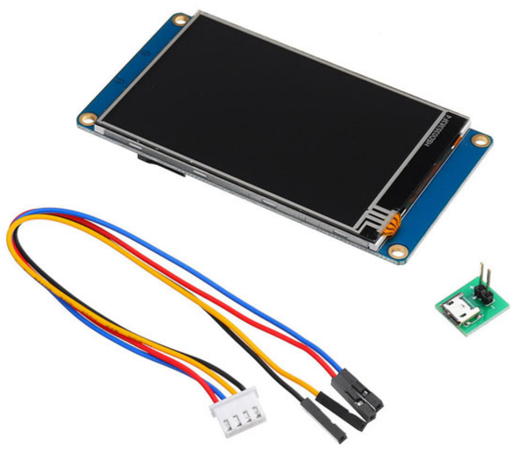


Figure 4.7: NX4832T035 HMI LCD 3.5

The HMI is programmed with four pages:

- Page 1: Offers the choices of ”eat” or ”drink”. Clicking on ”drink” navigates to the next page.

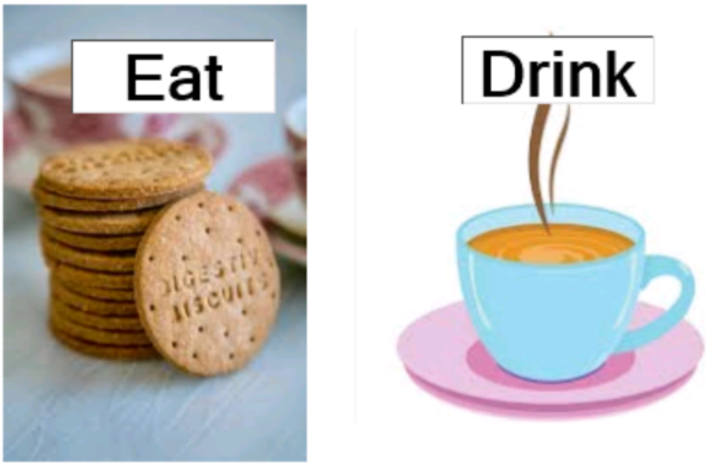


Figure 4.8: Page 1: Eat or Drink

- Page 2: Displays options to choose the desired drink.

Figure 4.9: Page 2: Choose Drink

- Page 3: Allows the user to select the number of teaspoons of sugar.

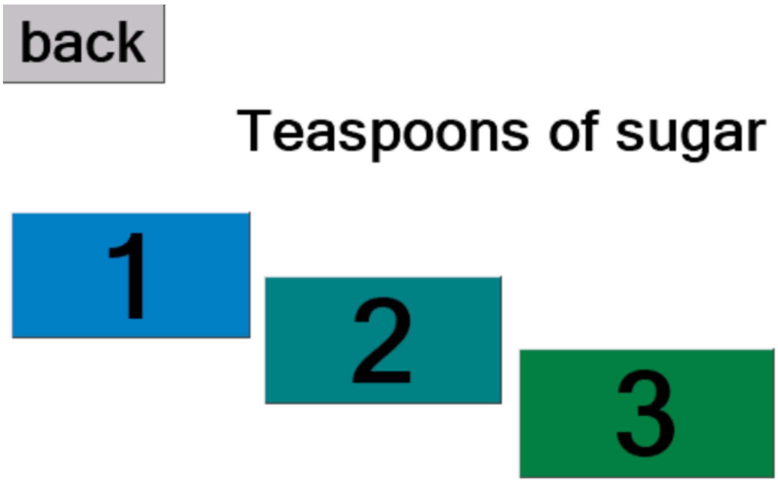


Figure 4.10: Page 3: Select Sugar Level

- Page 4: Shows a message for the user, presumably indicating that their order is being processed or providing some other relevant information.

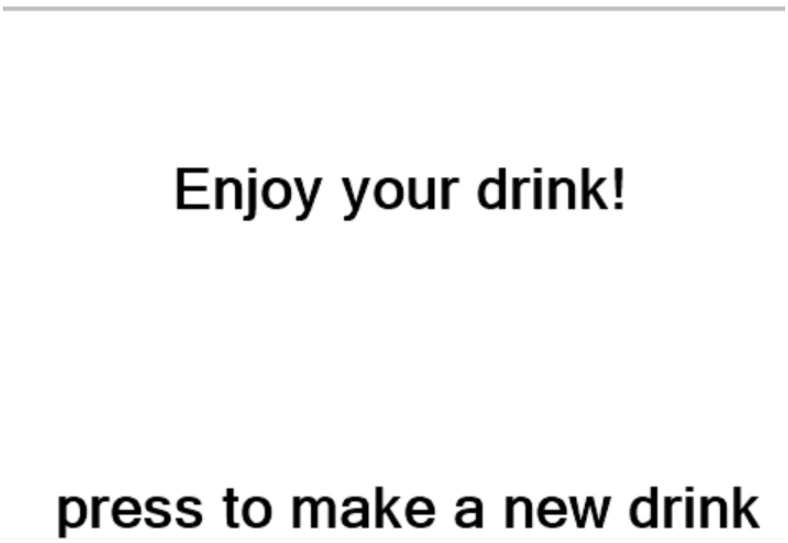
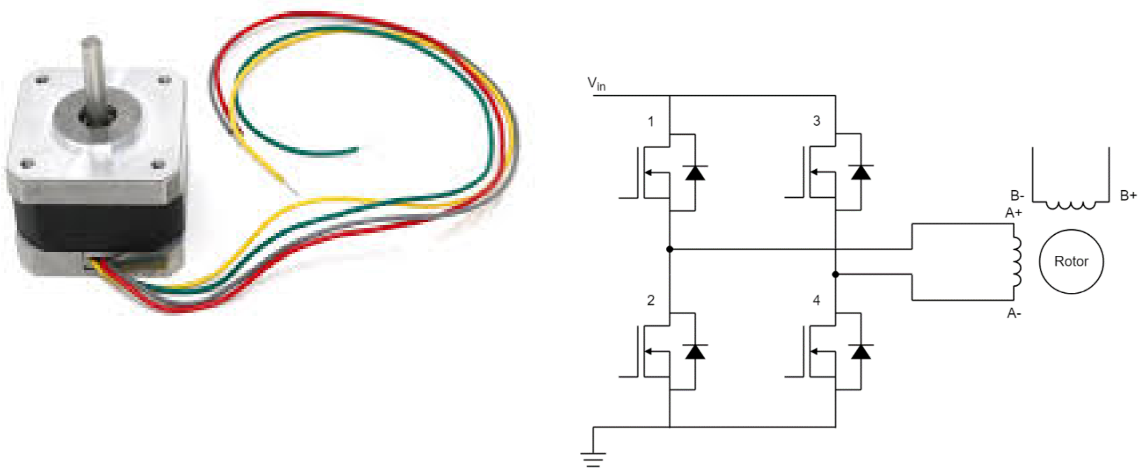


Figure 4.11: Page 4: User Message

4.2.2 Stepper Motors

Stepper motors are electromechanical devices that convert digital pulses into rotational motion. The motion of a stepper motor is controlled by energizing specific coils in a specific sequence. Each step of the motor corresponds to a fixed angular rotation, which is determined by the number of teeth on the rotor and stator [12]. Stepper motors come in different sizes, shapes, and specifications, and they require a specialized driver to operate.Stepper motors are widely used in many industrial applications especially in the applications that need high precise control position. Stepper motor is used in most applications which require discrete movement. Today most robotic systems, automatic digital camera focus and zoom functions, use stepper motors. Medically stepper motor used inside scanners, multi-axis stepper motor microscopic or nano-scopic motion control of automated devices, dispensing pumps, samplers, and chromatograph auto-injectors, and in aircraft sensors, stepper motors are used in antennas, scanning equipment etc.

In the project, the stepper motor used is the NEMA 17 Stepper motor (Fig 4.12).The stepper motors play a crucial role in the beverage dispensing process. When a user selects a drink, such as hot chocolate, each motor associated with the ingredients required for that drink receives a signal from the Arduino. Typically, for ingredients like milk powder and cocoa, the motor executes 200 steps, which corresponds to one revolution, dispensing the necessary amount of each ingredient. However, for customizable components like sugar, users have the option to choose the quantity, with up to four teaspoons available.



(a) NEMA 17 Stepper Motor (b) Stepper Motor Internal Circuit

Figure 4.12: NEMA 17 Stepper Motor

4.2.3 Stepper Motor Driver

The A4988 stepper motor driver shown in Fig 4.13 is a bipolar stepper motor driver that is capable of driving stepper motors with a maximum current of 2A per phase. It uses PWM to regulate the current flow through the stepper motor coils and can operate in full-step, half-step, and micro-step modes. The A4988 stepper motor driver consists of four main components: a pulse generator, a current regulator, a micro-stepping indexer, and an output driver. It can operate in micro step mode by using a technique called chopping and mixed decay to regulate the current flow through the stepper motor coils.

Additionally, the A4988 driver has built-in safety features to prevent damage to the motor and the driver itself. For example, it includes thermal shutdown protection, which disables the driver when the temperature exceeds a certain threshold. It also has over-current protection, which limits the current to prevent damage to the motor or driver in case of a fault. Table 4.3 presents the advantages of the A4988 stepper motor driver.

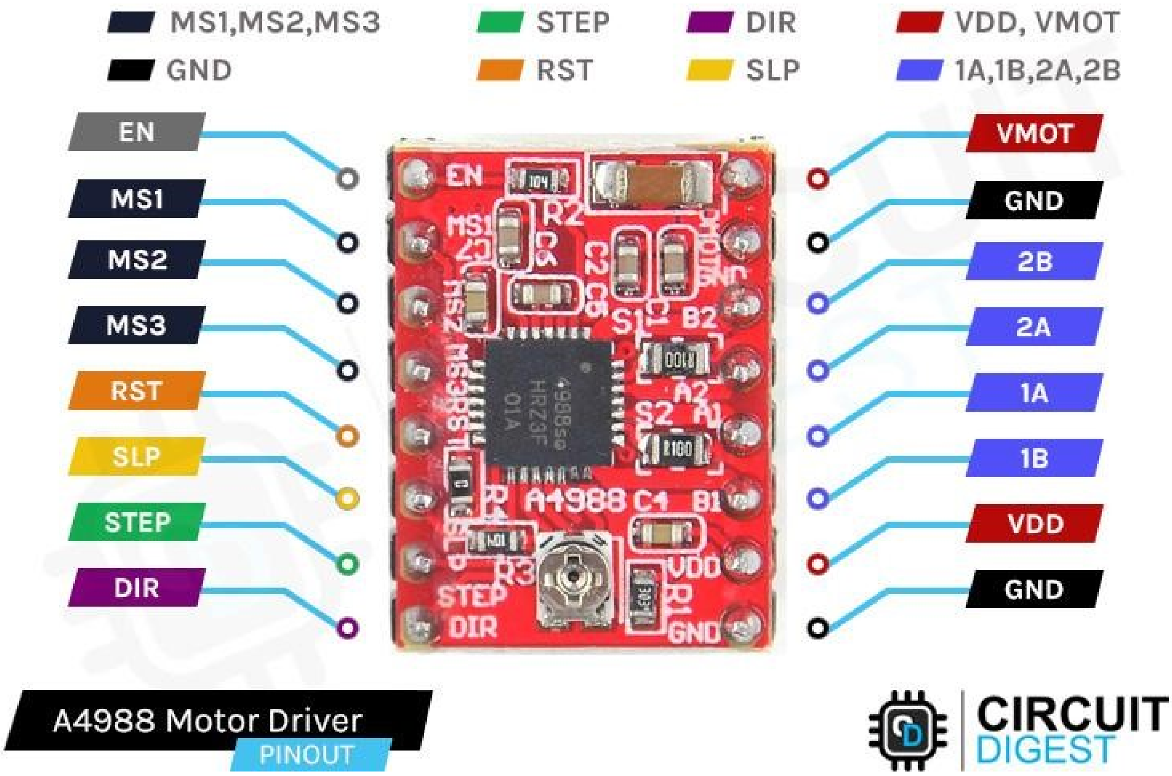


Figure 4.13: A4988 Stepper Motor Driver From Circuit Digest Website

Advantages of A4988 Driver
1. Maximum subdivision of 16
2. Maximum output current of 2A
3. Compatible with 8 to 36 volts
4. Load driving voltage of 5 35V
5. Compact size (Quad Flat No-leads (QFN)28 5x5 package)
6. Cost-effective
7. Can handle large vibrations
8. Minimizes high-frequency noise

Table 4.3: Advantages of A4988 Driver

4.2.4 Brushless Pump

Brushless Mini Direct Current (DC) water Pump refers to a machine that uses DC 4.5V 24V to drive a brushless motor to run, and the brushless motor rotation drives the impeller to rotate, thereby increasing the pressure of the liquid to achieve the effect of transferring liquid.The water pump is an Ultra-Quiet Brushless 12Vdc model with a flow rate of 240L/H. It features DC12V - 4.8W power consumption, approximately 1-meter head, and a maximum flow rate of 240 L/H. Additionally, it is submersible. In the case of this project, the pump had to be submersible because it is placed inside the water tank that supplies the boiler. Since the tank is located at a lower level than the boiler, this pump model is perfect as it can deliver up to 1 meter ahead.

Figure 4.14: Quiet Brushless 12Vdc Pump Model

The water pump is generally composed of pump body, motor stator, shaft, bearing, rotor (magnets and impellers) and so on (Fig 4.15). There are one inlet and one outlet on the pump body, water enters from the water inlet, and exits through the outlet. Any water pump that adopts this form and in small size is called brushless DC mini water pump. With the development of all walks of life and the progress of science and technology, some customers want to make the pump smaller and lower power consumption, even portable and can be powered by DC. Therefore, miniaturization of water pumps has become an inevitable trend.

Figure 4.15: Brushless Pump Structure

As you can see from the Brushless Direct Current (BLDC) PUMP structure diagram in Fig 4.14, the stator coil and circuit board are entirely isolated from the liquid and rotor by the isolation layer. Unlike the dynamic seal of the o-ring, this is a complete static seal. It guaranteed absolutely no leakage. In addition to preventing liquid leakage, this structure also brings another benefit: good heat dissipation, which allows the pump to have a longer service lifespan[13]. The pumping liquid medium cools the high-speed operation rotor, and the cooling efficiency is much better than the airflow cooling inside the traditional water pump. Because of this unique structure of the brushless DC pump, it is often called another name: magnetic drive pump.

4.2.5 Solenoid Valve

Solenoid valves find utility in controlling fluid flow automatically across diverse industries. Their usage is steadily rising in various plants and equipment. With a wide array of designs available, valves can be tailored to suit specific applications[14]. In our project, these valves are crucial for dispensing hot water. The selected design shown in Fig 4.16must be compatible with hot water and offer rapid response times. This ensures precise control, allowing the valve to open for a set duration before promptly closing.

Figure 4.16: 12Vdc Solenoid Valve

Parts of Solenoid Valve in Fig 4.17 Explained:

- **Diaphragm**
  - The diaphragm is a flexible material that isolates the solenoid assembly from the fluid.
  - It is designed to contain the pressure of the fluid.
- **Stem**
  - The stem is part of the valve where the core or plunger is attached.
  - As the core is attracted by the coil, the stem moves along with it, actuating the valve.
- **Disc**
  - The disc blocks the flow of fluid when the valve is closed.
  - In some solenoid valve designs, diaphragms, bellows, or pinch devices are used instead of a disc to block fluid flow.

  - Depending on the application, the disc is usually made of corrosion and erosion-resistant materials such as PTFE or stainless steel.

- **Seat**
  - The seat is the orifice that presses against the disc when closing the valve.
  - Like the disc, the seat may not be present depending on the valve design.
  - The seat is also made of corrosion and erosion-resistant material.
  - Once the seat or disc is damaged, the valve will become passing and unable to stop flow.

- **Seal**
  - The seal, like the diaphragm, isolates the solenoid assembly and the external environment from the fluid.
  - Depending on the application and the process fluid, there is a variety of seal materials available such as PTFE, Fluoroelastomer (FKM), Nitrile Butadiene Rubber (NBR), and Ethylene Propylene Diene Monomer (EPDM).

- **Bonnet**
  - The valve bonnet seats at the top of the valve body.
  - The core tube and stem extend through the bonnet and into the valve.

- **Body**
  - The body is the main part of the valve which holds the diaphragm, disc, seat, and the inlet and outlet ports.

- **Bleed Orifice**
  - For indirect or semi-direct acting solenoid valves, a bleed orifice is installed on the diaphragm.

  - Some valve designs use an equalizing hole.
  - The bleed orifice enables the valve to use the line pressure to open or close the valve.

- **Pilot Channel**
  - For indirect acting solenoid valves, a pilot channel is included into the valve body.
  - This is where fluid flows from the top of the diaphragm and into the downstream side of the valve.

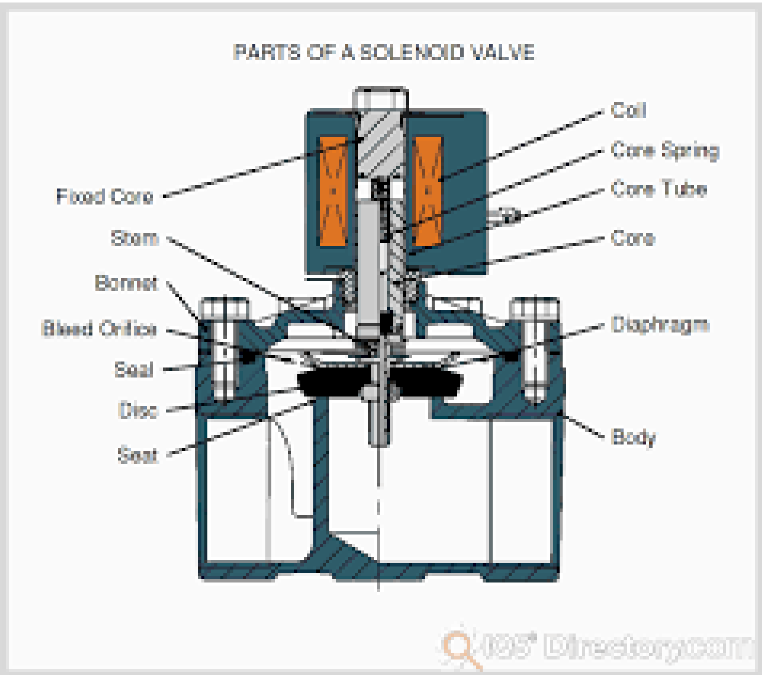


Figure 4.17: Solenoid Valve Configuration

4.2.6 Sensors

Sensors are essential components in modern technology, detecting and measuring physical quantities like temperature, pressure, light, and more. By converting real-world inputs into electrical signals, sensors enable machines to interact intelligently with their environment.

They're found in diverse applications, from automotive and industrial systems to consumer electronics and medical devices. As technology advances, sensors become more sensitive, accurate, and compact, driving innovation across industries. Understanding sensors' principles, types, and applications is crucial for engineers and researchers aiming to maximize their potential in various fields.

Infrared Proximity Sensor

Capacitive Proximity Sensor (CPS)s (Fig 4.18) have recently been a focus of increased attention because of their widespread applications, simplicity of design, low cost, and low power consumption.An Infrared (IR) sensor, or Infrared Sensor, is a device that detects and measures infrared radiation in its environment[15]. This sensor operates on the principle that all objects emit some form of infrared radiation as a function of their temperature. The IR sensor detects this radiation and converts it into an electrical signal.

This technology is incredibly versatile. You can use it to measure heat emitted by objects or even detect motion. The fundamental operation of an IR sensor revolves around an IR LED and an IR Photodiode. These two components form a crucial duo, working to detect infrared light. The IR LED emits infrared radiation, while the IR Photodiode acts as a receiver, sensitive to the LED's emitted IR light. When infrared light strikes the photodiode, it changes its resistance and output voltage, proportional to the intensity of the IR light received. This change is what the sensor interprets to provide valuable data.

Proximity infrared sensors play a crucial role in the machine, serving multiple functions. They are employed extensively, with one sensor allocated to each stack to monitor its fill level. When a stack is emptied, the sensor triggers a signal to be displayed on the touchscreen, prompting the user to refill it. Additionally, these sensors are utilized in the boiler to detect its status. Moreover, they are positioned to detect the presence of a cup, initiating the order-taking process on the screen.

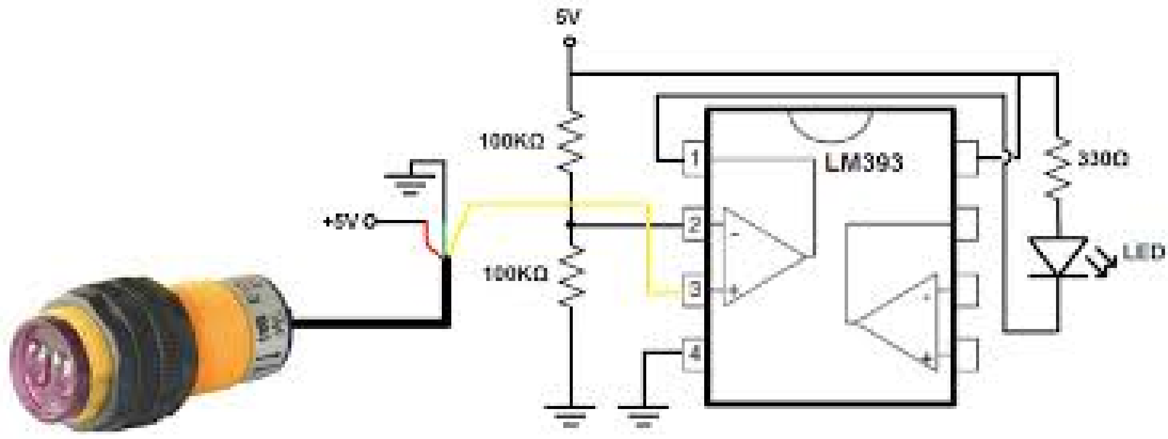


Figure 4.18: Capacitive Infrared Proximity Sensor

4.2.7 Isolation Circuit

To protect the Arduino from potential damage and isolate the control circuit from the power circuit, an isolation circuit (Fig 4.19) is implemented for the output pins of the Arduino. The primary objective of this circuit is to ensure that the Arduino remains unaffected by the external power supply required by some of the actuators in the machine, typically operating at 12V. This isolation helps maintain the integrity of the control system, safeguarding the Arduino from any potential harm or interference caused by fluctuations in the power circuit[16].

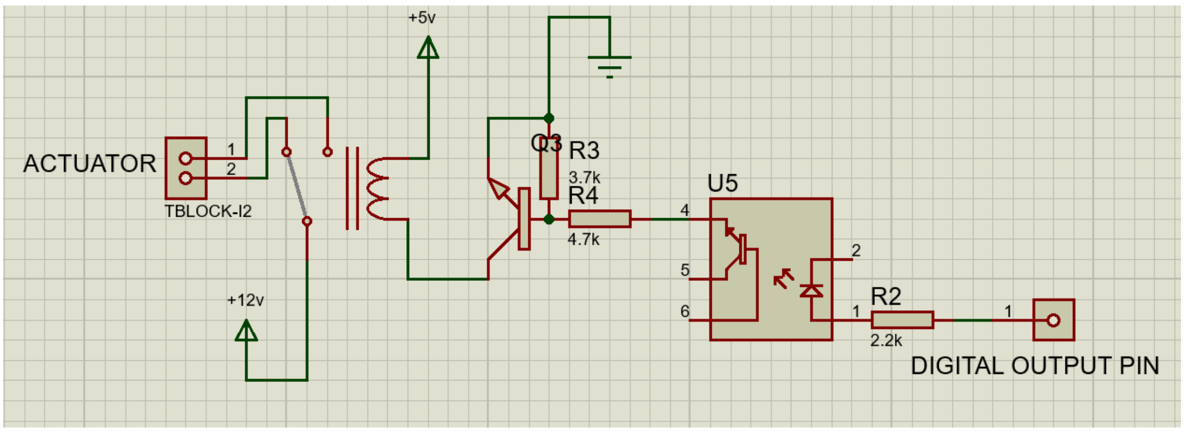


Figure 4.19: Isolation Circuit Schematic Done by Proteus Professional 8

Optocoupler

An opto-isolator (Fig 4.20) also called an optocoupler, photocoupler, or optical isolator, is an electronic component that transfers electrical signals between two isolated circuits by using light. Opto-isolators prevent high voltages from affecting the system receiving the signal[17]. An optocoupler typically consists of a light-emitting diode (LED) and a photodetector (such as a phototransistor or photodiode) enclosed within a light-tight package. The LED and photodetector are separated by a transparent isolation barrier. Here is the specifications of the PC817:

- Forward current (mA): 2.5 to 30
- Peak forward current: 1A
- Reverse voltage: 6V
- Power dissipation: 50mW

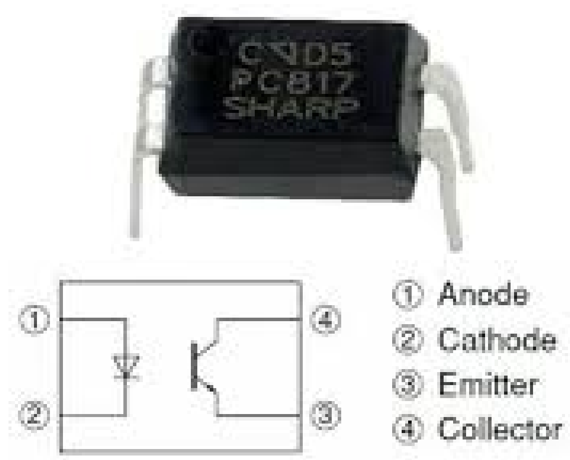


Figure 4.20: PC817 Optocoupler

Transistor

Transistors is a three-layer, three-terminal semiconductor device, which is often used in signal amplification and switching operations. As one of the significant electronic devices, transistor has found use in enormous range of applications such as embedded systems, digital circuits and control systems[18].

In the application of the isolating circuit the transistor is the 2N2222A Negative-Positive-Negative (type of bipolar junction transistor) (NPN) transistor (Fig 4.21) and it is used as a switch Based on the voltage applied at the base terminal of a transistor switching operation is performed. When a sufficient voltage (VIN more than 0.7 V) is applied between the base and emitter, collector to emitter voltage is approximately equal to 0. Therefore, the transistor acts as a short circuit. The collector current VCC / RC flows through the transistor.

When no voltage or zero voltage is applied at the input, transistor operates in cutoff region and acts as an open circuit. In this type of switching connection, load is connected to the switching output with a reference point. Thus, when the transistor is switched ON, current will flow from source to ground through the load.

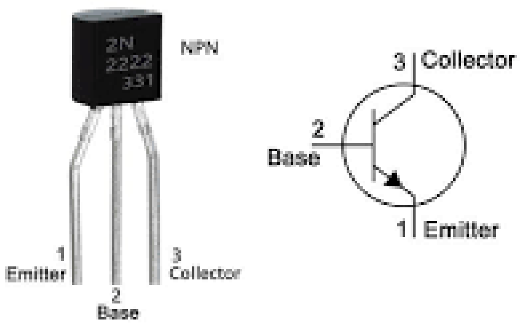


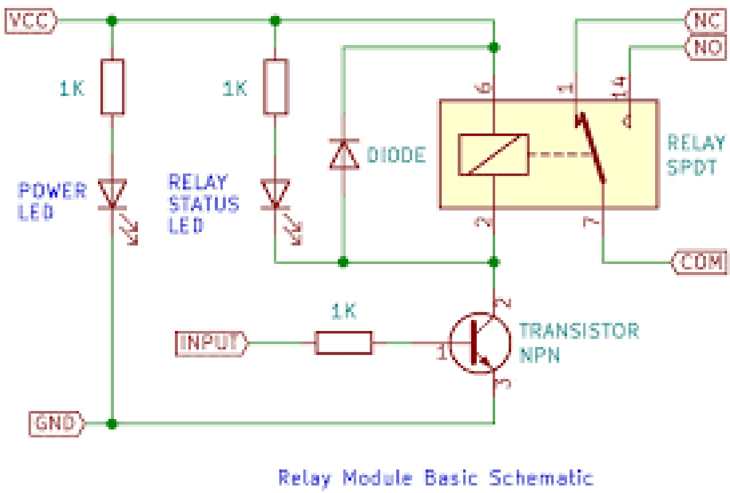
Figure 4.21: 2N2222A NPN Transistor

Relay

A relay is an electrically operated switch. It consists of a set of input terminals for a single or multiple control signals, and a set of operating contact terminals. The switch may have any number of contacts in multiple contact forms, such as make contacts, break contacts, or combinations thereof.

Relays are used where it is necessary to control a circuit by an independent low-power signal, or where several circuits must be controlled by one signal. In the case of the isolation circuit implemented, the 5Vdc relay (Fig 4.22) takes low power signal from the transistor and the common pin is connected to the power supply of 12V required to operate many some of the actuators in the machine. The relay in this context protect the optocoupler from the power circuit, consequently protecting the Arduino.

(a) 5Vdc Relay



(b) Relay Module Basic Schematic

Figure 4.22: SRD-05VDC-SLC Relay

4.3 Boiler's Circuit

The circuit depicted in Fig. 4.23 is The boiler circuit for the hot beverages dispensing machine consists of several critical components that work together to ensure proper temperature control and heating. These components include a temperature controller, a solid-state relay, a temperature switch, a temperature sensor, and an immersible water heater. The following subsections provide detailed descriptions of each component and their roles within the boiler circuit.

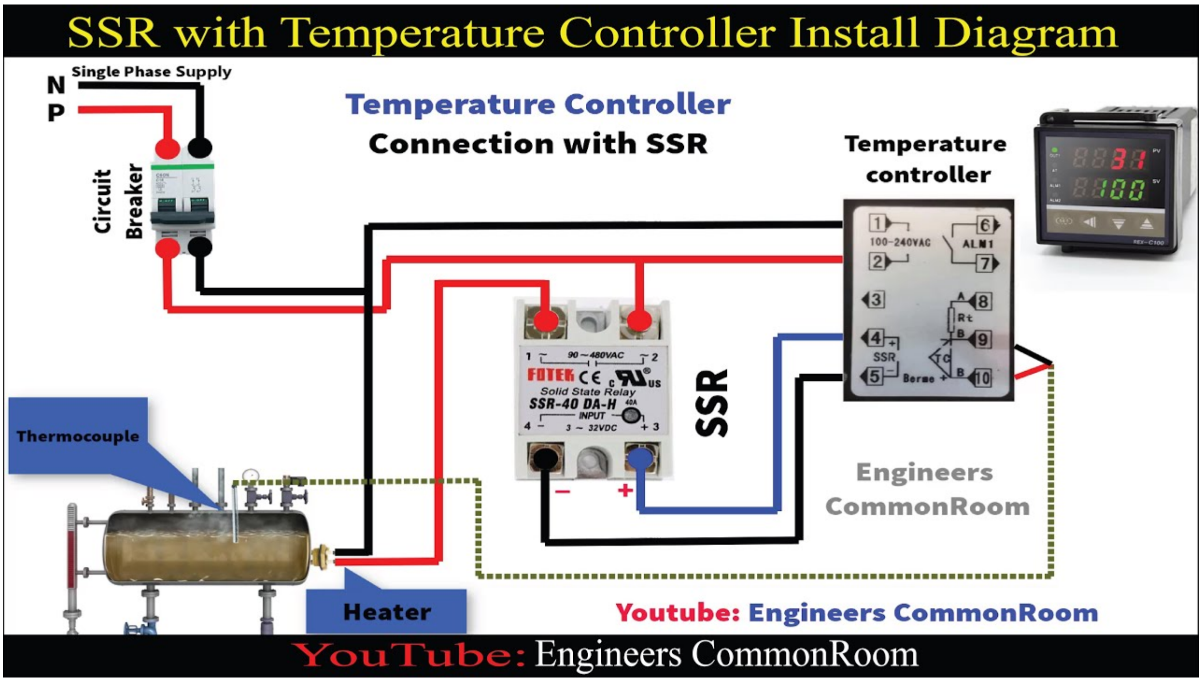


Figure 4.23: Boiler's Circuit illustration

4.3.1 Temperature Controller

The temperature controller shown in Fig 4.24 is responsible for maintaining the desired temperature within the boiler. It monitors the temperature readings from the sensor and adjusts the heating element's power output accordingly to achieve and maintain the set temperature.

Figure 4.24: Temperature Controller

4.3.2 Solid State Relay

The solid-state relay shown in Fig 4.25 acts as an intermediary between the temperature controller and the heating element. It allows the temperature controller to switch the high-power heater on and off with low-power control signals, providing efficient and reliable operation [19].

Figure 4.25: Solid State Relay

4.3.3 Temperature Switch

The temperature switch shown in Fig 4.26 is a safety component that provides an additional layer of protection. It is designed to cut off power to the heater if the temperature exceeds a certain threshold, preventing overheating and potential damage to the system.

Figure 4.26: NC Thermal Switch

4.3.4 Temperature Sensor

The DS18B20 digital thermometer shown in Fig 4.27 provides 9-bit to 12-bit Celsius temperature measurements and has an alarm function with nonvolatile userprogrammable upper and lower trigger points. The DS18B20 communicates over a 1-Wire bus that by definition requires only one data line (and ground) for communication with a central microprocessor[20]. It has an operating temperature range of -55°C to +125°C and is accurate to ±0.5°C over the range of -10°C to +85°C. In addition, the DS18B20 can derive power directly from the data line ("parasite power"), eliminating the need for an external power supply. Table 4.4 lists the features of DS18B20.

The sensor plays a critical role within the boiler, its waterproof design allowing seamless integration into the system. Its primary function is to consistently monitor the temperature, ensuring it never dips below 90 degrees Celsius. This constant feedback loop guarantees that the water remains consistently hot, ready for dispensing at a moment's notice.

Figure 4.27: DS18B20 Temperature Sensor

4.3.5 Immersible Water Heater

The immersible water heater shown in Fig 4.28 is the main heating element within the boiler circuit. It directly heats the water to the desired temperature as dictated by the temperature controller. Its immersible design allows it to efficiently transfer heat to the water, ensuring rapid and uniform heating.

Feature	**Description**
Unique 1-Wire® Interface	Requires only one port pin for communication
Unique 64-Bit Serial Code	Each device has a unique 64-bit serial code stored in an on-board ROM
Multidrop Capability	Simplifies distributed temperature-sensing applications
No External Components Required	Requires no external components
Power Supply Range	Can be powered from data line; power supply range is 3.0V to 5.5V
Temperature Range	Measures temperatures from -55°C to +125°C (-67°F to +257°F)
Accuracy	±0.5°C accuracy from -10°C to +85°C
Thermometer Resolution	User selectable from 9 to 12 bits
Conversion Time	Converts temperature to 12-bit digital word in 750ms (max)

Table 4.4: Features of DS18B20

Figure 4.28: Immersible Water Heater

4.4 Final Circuit Schematic

Figure 4.29 illustrates the final electrical circuit schematic for the automated beverage dispensing machine. It encompasses the intricate connections, including isolation circuits for Arduino output pins, driver connections, and sensor connections. This schematic serves as PCB, guiding the assembly and operation of the machine.

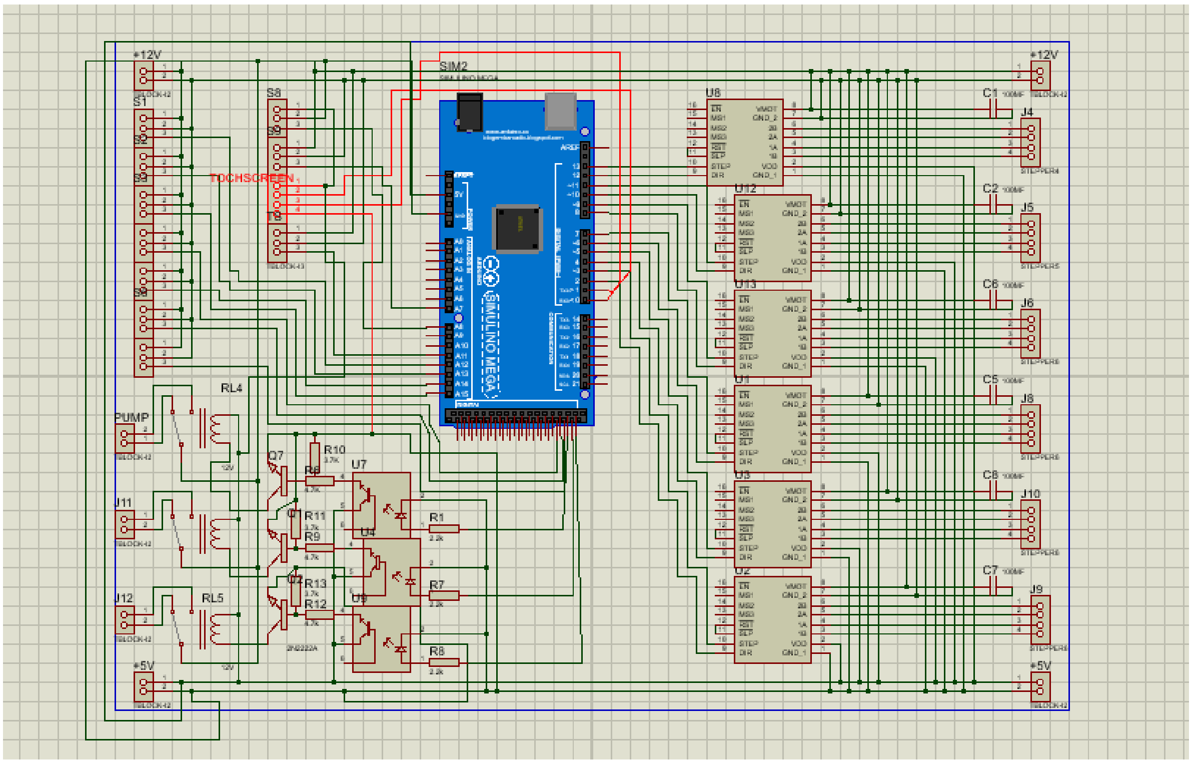


Figure 4.29: Final Circuit Schematic Made by Proteus Professional 8

Chapter 5

Summary and Future Recommendations

5.1 Summary

The Smart Beverages Dispensing Machine project is a commendable example of innovative engineering design and implementation. By integrating advanced engineering principles across mechanical, electrical, and user interface domains, the project has produced a prototype that meets the demands of modern consumers for enhanced functionality and customization options.

The utilization of a touchscreen interface represents a significant advancement over traditional vending machines, providing users with intuitive control and the ability to customize their beverage selections to suit their preferences. This interface not only enhances user experience but also facilitates ease of operation.

The selection of the Arduino Mega 2560 microcontroller for the machine is particularly noteworthy. Its ample number of digital I/O pins makes it well-suited for the diverse range of output options required by the machine. This choice demonstrates a thoughtful consideration of the technical requirements of the project and ensures the seamless integration of various components.

Moreover, the inclusion of a biscuits dispensing mechanism adds a unique and innovative feature to the machine, catering to modern consumer preferences for comprehensive service delivery. This novel addition enhances the machine's appeal and sets it apart from conventional vending solutions.

Overall, the Smart Beverages Dispensing Machine project represents a successful integration of advanced engineering principles to create a user-oriented automated beverage dispenser. With its comprehensive functionality, customizable options, and innovative features, the prototype promises to deliver enhanced consumer satisfaction in various settings.

5.2 Recommendations for Future Work

Absolutely, exploring further integration of internet connectivity or Bluetooth for remote monitoring and inventory management could greatly enhance the operational efficiency of the Smart Beverages Dispensing Machine. This would allow for real-time monitoring of inventory levels, automatic reordering of supplies when stocks are low, and remote troubleshooting and maintenance, reducing downtime and improving overall performance.

Expanding the range of beverage options, such as incorporating cold drinks or a wider variety of drinks, would also be a valuable addition to the machine. This would cater to a broader range of consumer preferences and increase the appeal and versatility of the machine in various settings.

Investigating alternative energy-efficient components and exploring scalability options are also promising avenues for future development. Implementing energy-efficient components could reduce power consumption and operating costs, while scalability options would allow for the customization and adaptation of the machine to different environments and usage scenarios.

Overall, these avenues of future work have the potential to further enhance the functionality, efficiency, and versatility of the Smart Beverages Dispensing Machine, ensuring its continued relevance and competitiveness in the market.

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Appendix

Appendix A

Arduino Code

”

include ¡Arduino.h¿ // Include Arduino core library

// Function prototypes void displayErrorMessage(String message); void rotate(int dirPin, int stepPin); void operatePump();

const int stepsPerRevolution = 200; // change this to fit the number of steps per revolution

bool coffee=false; bool nescafe=false; bool tea=false; bool cocoa=false; //bool sugar=false; //bool milk=false; bool teamilk=false;

//MOTORS SETUP define DIR$_{P}IN_{C}OFFEE3defineSTEP_{P}IN_{C}OFFEE2defineDIR_{P}IN_{S}UGAR5$

Serial.println(”hello world”);

// SET SENSORS INPUTS pinMode(CUP$_{S}ENSOR, INPUT); pinMode(BISCUT_{S}ENSOR, INPUT$

// initialize the serial port: Serial.begin(9600);

void loop()

// DISPLAY ERROR MESSAGES

if (digitalRead(CUP$_SENSOR) == LOW)//SendNextioncommandstogotopage5anddisplayerrorme$
$LOW)//SendNextioncommandstogotopage5anddisplayerrormessageforbiscuitsensordisplayErrorM$
$LOW)//SendNextioncommandstogotopage5anddisplayerrormessageforcoffeesensordisplayErrorM$
$LOW)//SendNextioncommandstogotopage5anddisplayerrormessageformilksensordisplayErrorMe$
$LOW)//SendNextioncommandstogotopage5anddisplayerrormessage$

for sugar sensor displayErrorMessage("PLEASE REFILL THE SUGAR"); else if (digitalRead(COCOA$_SE$
$LOW)//SendNextioncommandstogotopage5anddisplayerrormessageforcocoasensordisplayErrorM$
$LOW)//SendNextioncommandstogoto$

page 5 and display error message for tea sensor displayErrorMessage("PLEASE REFILL THE TEA"); else if (digitalRead(WATER$_SENSOR) == LOW)//SendNextioncommandstogoto$

page 5 and display error message for water sensor displayErrorMessage("THERE IS NO ENOUGH WATER PLEASE WAIT"); operatePump();

// Check for incoming data from Serial if (Serial.available()) // Read the incoming data from Serial String data$_from_display = Serial.readStringUntil(''); Serial.println(data_from_display); //Echob$

// Call sendData function with the received data sendData(data$_from_display)$;

void sendData(String data$_from_display)//Checkifthereceiveddatamatchestheexpectedcommandif(da$

// Delay to ensure the motor completes the revolution: delay(500);

if(data$_from_display == "coffee")$

coffee=true;

if(data$_from_display == "tea")$

tea=true;

if(data$_from_display == "teamilk")$

teamilk=true;

if(data$_{f}rom_{d}isplay == "cocoa")$

cocoa=true;

if(data$_{f}rom_{d}isplay == "nescafe")$

nescafe=true;

if(data$_{f}rom_{d}isplay == "one")$

if(tea==true) rotate(STEP$_{P}IN_{S}UGAR, DIR_{P}IN_{S}UGAR); //Delaytoensurethemotorcompletesthere$
$delay(500);$

rotate(STEP$_{P}IN_{T}EA, DIR_{P}IN_{T}EA); //Delaytoensurethemotorcompletestherevolution :$
$delay(500);$

operateValve();

else if(coffee==true)

rotate(STEP$_{P}IN_{S}UGAR, DIR_{P}IN_{S}UGAR); //Delaytoensurethemotorcompletestherevolution :$
$delay(500);$

rotate(STEP$_{P}IN_{C}OFFEE, DIR_{P}IN_{C}OFFEE); //Delaytoensurethemotorcompletestherevolution$
$delay(500); operateValve();$

else if(nescafe==true)

rotate(STEP$_{P}IN_{S}UGAR, DIR_{P}IN_{S}UGAR); //Delaytoensurethemotorcompletestherevolution :$
$delay(500);$

rotate(STEP$_{P}IN_{C}OFFEE, DIR_{P}IN_{C}OFFEE); //Delaytoensurethemotorcompletestherevolution$
$delay(500);$

rotate(STEP$_{P}IN_{M}ILK, DIR_{P}IN_{M}ILK); //Delaytoensurethemotorcompletestherevolution :$
$delay(500); operateValve(); elseif(teamilk == true)$

rotate(STEP$_{P}IN_{S}UGAR, DIR_{P}IN_{S}UGAR); //Delaytoensurethemotorcompletestherevolution :$
$delay(500);$

rotate(STEP$_PIN_TEA, DIR_PIN_TEA); //Delaytoensurethemotorcompletestherevolution :$
$delay(500);$

rotate(STEP$_PIN_MILK, DIR_PIN_MILK); //Delaytoensurethemotorcompletestherevolution :$
$delay(500); operateValve();$

if(data$_from_display == "two")$

if(tea==true) rotate(STEP$_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherev$
$delay(500); rotate(STEP_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevo$
$delay(500);$

rotate(STEP$_PIN_TEA, DIR_PIN_TEA); //Delaytoensurethemotorcompletestherevolution :$
$delay(500);$

operateValve();

else if(coffee==true)

rotate(STEP$_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevolution :$
$delay(500);$

rotate(STEP$_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevolution :$
$delay(500);$

rotate(STEP$_PIN_COFFEE, DIR_PIN_COFFEE); //Delaytoensurethemotorcompletestherevolution$
$delay(500);$

operateValve(); else if(nescafe==true)

rotate(STEP$_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevolution :$
$delay(500);$

rotate(STEP$_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevolution :$
$delay(500);$

rotate(STEP$_PIN_COFFEE, DIR_PIN_COFFEE); //Delaytoensurethemotorcompletestherevolution$
$delay(500);$

rotate(STEP$_PIN_MILK, DIR_PIN_MILK); //Delaytoensurethemotorcompletestherevolution : delay(500); operateValve(); elseif(teamilk == true)$

rotate(STEP$_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevolution : delay(500);$

rotate(STEP$_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevolution : delay(500);$

rotate(STEP$_PIN_TEA, DIR_PIN_TEA); //Delaytoensurethemotorcompletestherevolution : delay(500);$

rotate(STEP$_PIN_MILK, DIR_PIN_MILK); //Delaytoensurethemotorcompletestherevolution : delay(500);$

operateValve(); if(data$_from_display == "three")$

if(tea==true) rotate(STEP$_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletesthere$ $delay(500);$

rotate(STEP$_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevolution : delay(500); rotate(STEP_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevo$ $delay(500);$

rotate(STEP$_PIN_TEA, DIR_PIN_TEA); //Delaytoensurethemotorcompletestherevolution : delay(500);$

operateValve();

else if(coffee==true)

rotate(STEP$_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevolution : delay(500);$

rotate(STEP$_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevolution : delay(500); rotate(STEP_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevo$ $delay(500);$

rotate(STEP$_PIN_COFFEE, DIR_PIN_COFFEE); //Delaytoensurethemotorcompletestherevolution$
$delay(500);$

operateValve(); else if(nescafe==true)

rotate(STEP$_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevolution :$
$delay(500);$

rotate(STEP$_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevolution :$
$delay(500); rotate(STEP_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevo$
$delay(500);$

rotate(STEP$_PIN_COFFEE, DIR_PIN_COFFEE); //Delaytoensurethemotorcompletestherevolution$
$delay(500);$

rotate(STEP$_PIN_MILK, DIR_PIN_MILK); //Delaytoensurethemotorcompletestherevolution :$
$delay(500); operateValve(); elseif(teamilk == true)$

rotate(STEP$_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevolution :$
$delay(500);$

rotate(STEP$_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevolution :$
$delay(500); rotate(STEP_PIN_SUGAR, DIR_PIN_SUGAR); //Delaytoensurethemotorcompletestherevo$
$delay(500); rotate(STEP_PIN_TEA, DIR_PIN_TEA); //Delaytoensurethemotorcompletestherevolution$
$delay(500);$

rotate(STEP$_PIN_MILK, DIR_PIN_MILK); //Delaytoensurethemotorcompletestherevolution :$
$delay(500); operateValve();$

void displayErrorMessage(String sensorName) Serial.write(0xFF); Serial.write(0xFF); Serial.write(0xFF); Serial.print("page 5"); Serial.write(0xFF); Serial.write(0xFF); Serial.write(0xFF); Serial.print("t0.txt=Ërror: " + sensorName); Serial.write(0xFF); Serial.write(0xFF); Serial.write(0xFF);

void rotate(int STEP$_PIN, intDIR_PIN)$

digitalWrite(DIR$_PIN, LOW)$;

// Rotate stepper motor counterclockwise for one revolution for (int i = 0; i ¡ STEPS$_PER_REVOLUTION; i$
$+) digitalWrite(STEP_PIN, HIGH); //Steppulserisingedgedelay Microseconds(500); //Adjustthisdel$

void operatePump() // Open the inlet valve digitalWrite(INLET$_VALVE_PIN, HIGH)$;

// Operate the pump until the water sensor pin goes high while (digitalRead(WATER$_SENSOR) ==$
$LOW) digitalWrite(PUMP_PIN, HIGH); //Turnonthepumpdelay(3000); //Adjustdelayasneededforp$

// Stop the pump digitalWrite(PUMP$_PIN, LOW)$;

void operateValve() digitalWrite(OUTLET$_VALVE_PIN, HIGH); delay(2000); digitalWrite(OUTLET_V$
$false; coffee = false; nescafe = false; teamilk = false;$"