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RollIt!

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List of Figures

List of Tables

Contents

Abstract

Automation in food processing has seen a surge of interest due to its ability to enhance speed, precision, and consistency. This project focuses on the design of an automated sushi production line, addressing the growing demand for efficient and customizable food preparation solutions.This machine takes all the steps in sushi production-from rice spreading to rolling-so as to provide consistency in quality and considerable savings in time. By inputting user preferences, it gives an option for personalized service and reduces chances of human error, which is vital for restaurants and catering services.

The system's design emphasizes the integration of hardware components, including stepper motors and DC motors for precise movements, drivers, H-bridge, and relays for motor control, an Arduino Mega controller for centralized coordination, and an ESP32 module with Wi-Fi for app connectivity. The machine executes each step of sushi preparation sequentially: spreading rice evenly, compressing the rice onto the seaweed paper, adding fillings, rolling, and cutting. Rigorous testing is conducted to ensure stable performance, seamless operation, and adherence to functional specifications.

While existing sushi-making machines require manual intervention for adding ingredients and lack customization options, this project introduces full automation combined with user-input features. Users can select their preferred fillings and sauces, setting this system apart from other machines on the market. This innovative approach demonstrates how robotics and automation can

enhance productivity in the food industry while meeting consumer demands for speed, precision, and personalization.

The project's significance lies in its potential to reduce labor costs, improve efficiency, and deliver a seamless user experience. By bridging the gap between automation and customization, this system represents a scalable solution for commercial use in the evolving food industry.

1 Introduction

1.1 Background

Automation in food processing has become one of the crucial areas of innovation due to its very high demand in the culinary industry for efficiency, accuracy, and scalability. With the global popularity of the sushi food products increasing, the sushi sector is particularly booming because of the consumer expectations for personalization and high quality in food. The traditional way of making sushi is artisan-type work, time-consuming, and prone to human error. The difficulty represents that there is an opportunity for automated systems that give consistent results while being able to customize.

1.2 Objectives

The primary objective of this project is to design and develop an automated sushi production line that combines efficiency, precision, and customization. The machine is designed to facilitate the production of sushi by decreasing the time for preparation but working at the same time to maintain the quality of the products. This is achieved through user preference input, allowing the user to choose fillings and sauces, ensuring personalized service. Apart from that, the project looks at the viability of robotics and automation in providing solutions to problems encountered with food preparation, scalable for restaurants, catering services, and related commercial applications.

1.3 Significance

The importance of this work lies in its ability to address market demands for faster, high-quality food preparation with minimal labor costs. With consumer demands consistently swinging toward speed and custom orders, automation within the food industry will experience a wide growth. Studies show that the world is coming to rely more on automated systems to increase productivity and minimize human error. Existing machines to make sushi are available, though not very helpful, considering that they do not automatically and fully prepare the sushi and personalize the ingredients. Instead, this project aims to fill that gap. By providing a delicate balance of automation and customization, this system offers a solution, addressing these dynamic requirements with the possibility of translating more technologies like this into the food industries.

1.4 Organization of the Report

This report is organized into several sections to provide a comprehensive overview of the project. The Design and Methodology section details the hardware components, such as stepper motors, DC motors, H-bridge, relays, an Arduino Mega, and an ESP32 module with Wi-Fi, along with their integration into the system. The Results and Testing section discusses the machine's performance and its adherence to functional specifications, including rigorous testing outcomes. The Discussion section analyzes the significance of the findings and their implications for the food industry, while the Conclusion and Future Work section summarizes the project's achievements and outlines potential areas for improvement and expansion.

2 Theoretical Background and Previous Work

2.1 Theoretical Background

Automation in food processing involves the integration of various technologies, including robotic systems, and control systems. These technologies are designed to streamline processes, increase efficiency, and improve overall productivity. The use of robotics in food production, such as in sushi preparation, enhances precision and consistency, allowing for uniform product characteristics and packaging.

2.2 Previous Work

2.2.1 Existing Sushi-Making Machines

Previous attempts at automating sushi have resulted in commercial machines that streamline parts of the process. For example, Suzumo's Maki Maker automated rolling and cutting but requires human intervention for ingredient placement and rice spreading. While these systems are efficient, they are limited by human operators and not scalable or consistent.

2.2.2 Food Automation Innovations

Beyond sushi, the food industry has seen many innovations towards full automation. Pizza robots use robotic arms and conveyor belts to assemble, bake and slice pizzas. Automated sandwich makers use ingredient dispensers and precision actuators to customize sandwiches based on user input. These systems show the importance of incorporating user input into the automation process, which is what this project aims to do and improve for sushi preparation.

2.2.3 Integration of Robotics and Customization

A big leap in food automation is combining robotics with user input. Studies have shown that integrating human-machine interfaces (HMIs) with robotics enhances user experience and allows for greater flexibility in product customization. For instance, a study by Smith et al. (2021) demonstrated the feasibility of using app-controlled systems to tailor food preparation processes in automated kitchens. This is the concept behind this sushi making system where users can select their preferred fillings and sauces through a mobile app connected to the machine via Wi-Fi.

2.2.4 Existing System Challenges

Despite all these, there are still challenges in existing systems. The lack of hardware-software integration is causing inefficiencies and downtime. Many systems are also limited in customization options and expensive, not suitable for small to medium enterprises. This project solves these gaps by providing a cost effective, fully automated solution with many customization options.

3 Methodology

3.1 Hardware components

In order to build this project, we used many hardware components:

3.1.1 Microcontrollers

- **Arduino Mega 2560 :**

The Arduino Mega 2560 is a microcontroller board built with the ATmega2560 chip. It has 54 digital input/output pins (15 can be used for PWM), 16 analog inputs, 4 serial communication ports, a 16 MHz clock, a USB connection, a power jack, a programming header, and a reset button. Its many features make it a great choice for our project. Since we need to connect many devices, the Arduino Uno was not enough, so we chose the Arduino Mega 2560 as our main microcontroller.

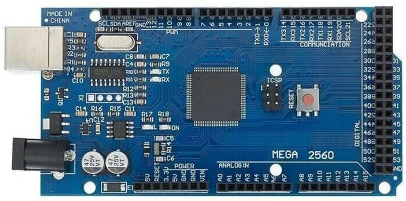


Figure 3.1: Arduino Mega

- **ESP32-WROOM-32 :**

The ESP32-WROOM-32 is a versatile Wi-Fi and Bluetooth module with a dual core processor, integrated Wi-Fi (802.11 b / g / n) and multiple GPIOs, enabling seamless communication and control for IoT projects. Its low-power modes and platform compatibility make it ideal for real-time applications.

ESP32-WROOM-32 has been used in our project to create a client-server communication bridge between our Blynk application and the Arduino. The Wi-Fi module on this module allowed for wireless connection on the application, which allowed buyers to make their own sushi orders directly into the application. ESP32 would hence send data to Arduino once a particular order is placed. The Arduino would then execute the order according to the procedure defined in the hardware. This knit has allowed an efficient interaction between

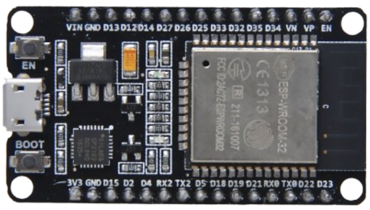


Figure 3.2: ESP32

hardware and applications in making the system very interactive and easy to use.

3.1.2 Sensors

- **IR Sensor :**

In order to achieve the highest transparency of the sushi production line, Two IR sensors are well equipped. The first sensor, located under the rice container, when it detects the belt with the paper, the rice motors start working to evenly distribute rice on the seaweed paper as the belt with the paper above moves. The second one detects when the sushi holder reaches the end of the belt, stopping the forward motion, starting the rolling and cutting processes, and then reversing the system to restart the cycle. The completion of the task is read by all three sensors working in one direction to automatically perform the task with the fullest efficiency.

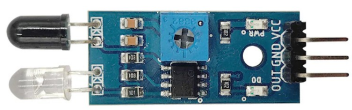


Figure 3.3: IR Sensor

- **LDR Light Sensor Module :**

We used multiple LDR sensors to control the movement and functionality of the project. Three LDR sensors are placed below the ingredient dispensers. These sensors ensure that ingredients are distributed only when the seaweed paper filled with rice is properly aligned under them.

Figure 3.4: LDR light sensor module

- Laser diode :

There are three lasers positioned in front of the LDR sensors, and they send out beams to measure the position of a seaweed paper. As the seaweed passes through a sensor, the respective laser beam becomes blocked, indicating its presence under the designated sensor. This systematic positioning allows for high accuracy of timing and orientation for all phases of seaweed harvesting.

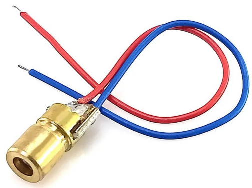


Figure 3.5: Laser Diode

- **Ultrasonic Sensor :**

Ultrasonics are used to monitor the amount of ingredients that are still left in the containers. These sensors provide feedback on the amount of ingredients, alerting if a container is empty and needs refilling or if it is overfilled. It makes sure that ingredient levels are maintained at tolerable levels, ensuring that there would be no depletion of ingredients or overfilling.

Figure 3.6: Ultrasonic Sensor

3.1.3 Motors and Drivers

- **J-5718HB2401 Stepper motor and YS-DIV268N driver:**

Stepper motors convert electricity into rotation. Not only do they convert electrical power into rotation, but they can also be very accurately controlled in terms of how far they rotate and how fast. They are called "stepper motors" because each pulse of electricity turns the motor one step. They are controlled by a driver, which sends pulses to the motor, causing it to turn. The number of steps the motor takes is equal to the number of pulses fed into the driver. The motor spins at a rate determined by the frequency of those pulses.

Stepper motors possess input pins or contacts which allow the current from a supply source to enter the coil windings of the motor. Pulsed waveforms in the appropriate sequence can then be applied to generate the electromagnetic fields needed to drive the motor.

In our project, the stepper motor bipolar four wire four five API was used, and more specifically the J-5718HB2401 model was selected owing to its high accuracy, strength and efficiency to carry out a wide range of tasks, here we used a total of five motors and each motor had its own driver.

Two stepper motors were used for dispensing rice. Each motor connected with a cylinder, and they faced one another with a small gap to allow for rice to flow through here and spread evenly on the seaweed. By rotating in opposite directions, the motors guaranteed that a thin, uniform layer of rice was formed with the precise dispensing amount.. To achieve precise control of their movement, we relied on 5A YS-DIV268N drivers.

We used the other three stepper motors to handle the rotating paddles in the ingredient dispensers. Instead of controlling the whole container, they worked with 3D-printed parts inside to pour the ingredients over the seaweed and rice. The steps of the motors allowed us to control exactly how much of each ingredient was added. With each motor paired to its own driver, everything stayed accurate and consistent.

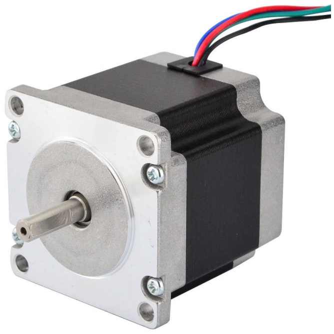


Figure 3.7: Stepper motor

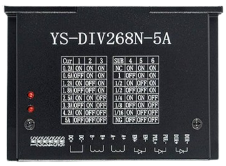


Figure 3.8: Driver 5A

- **Servo Motor :**

Servo motors provide high precision when it comes to position, speed, and torque control and thus are found across most machinery and equipment where movements must be accurate and controlled.

A servo motor usually consists of a small DC motor, a gearbox, and a control circuit in which the movement of the motor is regulated. The control circuit gives feedback to ensure that the motor turns to an exact position according to input signals, then holds that position with great accuracy, usually a few degrees.

In our project, we have incorporated two servo motors; they control the dispensing of sauces: soy sauce and Mayo. Each sauce has its servo motor for dispensing. The servo is attached to a wooden piece that will tilt to pour the chosen sauce. When the servo motor is activated, it lowers the sauce container, allowing the desired sauce to be dispensed.

Figure 3.9: Servo Motor

- **DC Motor with gear box :**

1. **DC Motor 12V 45RPM GB37 with gear box connected to L298N H-Bridge :**
   The DC 12V 45RPM GB37 Geared Motor is extraordinarily dependable and is meant to serve the industrial place. This is a 37 mm gearbox with an eccentric shaft-pushed motor designed to give high-torqued low-speed (45 RPM) moves with maximum precision and control of movements. Built using full copper parts ensure durability, efficiency, and stable performance. It is indeed a good motor for robotics, automation, and other mechanical designs that need smooth low-speed motion.

   This DC motor is used at the beginning of the process for handling seaweed. The moment the motor is switched on, it rotates the wheel that is coupled to it to bring down the seaweed paper for the beginning of the process. Such a motor is controlled using an L298N H-bridge that allows speed control via the enable pin driven by the Arduino's PWM pins. In addition, this motor possesses two input pins that are connected to the Arduino and configured to provide directional control to the motor.

Figure 3.10: DC 12V

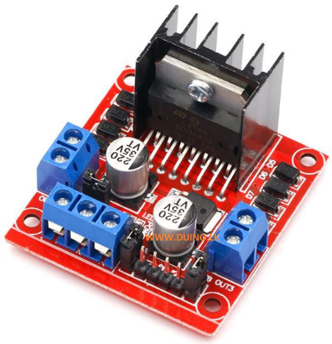


Figure 3.11: L298N H-Bridge

2. **DC 12V Gear Motor with Encoder :** The DC 12V Gear Motor with Encoder is a heavy-duty motor best suited for applications requiring systems working with iron and metal. High torque and durability enable this motor to take on heavy-duty, large machines, ensuring reliable operation in the heaviest working conditions. The inbuilt encoder provides real-time feedback for precision positioning and control, making it well suited for the most arduous industrial machines and other heavy-metal systems.

   Five motors have been included in this project, with each serving the following functions:

   (a) Rice Mixing Motor: The strength of rice mixing is ensured by this motor which rotates a metal piece inside the rice container to ensure there is even distribution of rice and helps in pour. Control of motor is achieved through a 2-channel relay that pushes this metal piece forward and backward in mixed rice with the seaweed paper placed underneath the container.

   (b) Rod and Sushi Transport Motor: This motor moves a heavy wooden piece across the entire system using a chain mechanism.This was chosen due to the strength and smooth operation that this should work with under heavy loads. For speed and direction control, IBT2 Motor Driver H-Bridge BTS7960 43A was used to make precise adjustments in the forward and backward motion as required during the process.

(c) Rolling Motors: For shaping rectangular prismatic sushi two motors are used. Each motor is connected to one side of the rolling mechanism.
The motors lift the poles that lift the frame of metals, thus shaping the sushi as per the desired form. They both connected to two IBT2 Motor Driver H-Bridge BTS7960 43A to control their speed, movement and direction.

(d) Cutting Motor: This is responsible for cutting the already shaped rolled sushi. The motor is provided with three pizza cutters and is controlled through the use of a 2-channel relay. This allows the motor to move in both directions on command; when activated, the motor in turns spins the pizza cutters around, slicing the decently-sized portions of sushi properly.

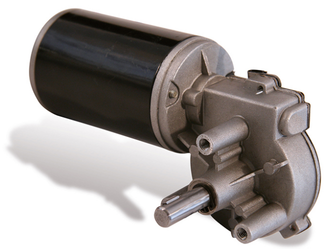


Figure 3.12: DC 12V

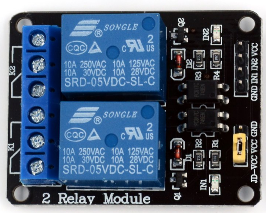


Figure 3.13: 2 Relay 2-channel

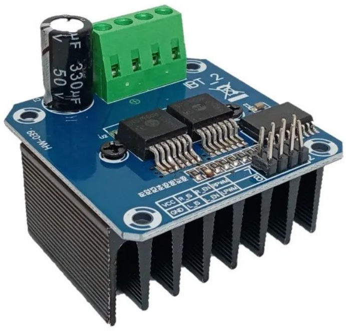


Figure 3.14: IBT2 Motor Driver HBridge

3.1.4 Input/Output Devices:

- **Keypad :**

Keypad is a set of buttons arranged in the matrix form so that each button is classified by coordinates made up of a row and column. Keypads are usually used for input in microcontroller-based systems, like those based on the Arduino platform.

In this project, we are using 4x1 keypad as an input device. The customer orders sushi by selecting the type from the menu list, and the sauce from the menu list that will be displayed on the LCD. And then, the customer confirms their selection using the keypad.

Figure 3.15: Keypad

- **LCD and I2C :**

An I2C interfaced LCD (Liquid Crystal Display) is an LC display module that offers the simple and straightforward feature of an

I2C communication interface alongside the functionality of a normal LCD.
I2C is two-wire communication serial data which links many devices onto a single bus, thus minimizing the number of pins required by micro controllers/controllers and reducing wiring efforts.
In our project we used LCD with I2C to display:

- **Order Taking**: The LCD is used to display the options for selecting sushi ingredients.
- **Sauce Selection**: It shows the available sauce choices for the sushi order.
- **Process Progress**: The LCD displays the percentage of completion during the sushi-making process, letting the user know how far along the system is in preparing the sushi.

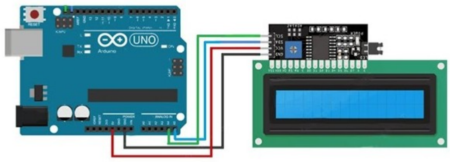


Figure 3.16: LCD and I2C

3.1.5 Power Devices

- **Power Supply :**

We decided to use a computer power supply due to the 5 volts output for many devices and 12 volts output for drivers and stepper motors because it caters for these voltage demands. Additionally, the power supply offers a sufficient current output that meets our project's demands.

Figure 3.17: Power Supply

- **Arduino Power Cable :**

The Arduino Power Cable is a kind of cable used to connect an Arduino board with a power supply such as the USB port of a computer or a wall adapter. primary function is to provide power to the board, while also facilitating programming and data transfer. In our project, we used the Arduino power cable to ensure that the Arduino board received a stable 5-volt power supply, which was necessary for proper functioning of the board.

Figure 3.18: Arduino Power Cable

- **AC Adapter :**

It was rather that the project's power supply from the computer would not be able to drive the motors along with the rest of the project; hence two AC adapters were using for powering the 12V DC motors instead.

Figure 3.19: AC Adapter

3.1.6 Other Devices

- **Wires:**

We used multiple types of wires for the connection between components:

- Female to Male/ Male to Male
- Intercom
- Headphone wires

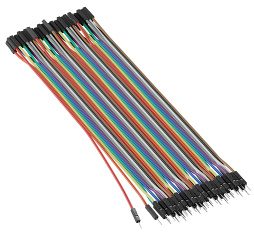


Figure 3.20: Wires

- **Wire Connectors:**

Figure 3.21: Wire Connectors

3.1.7 Mechanical components:

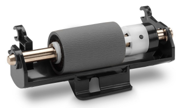
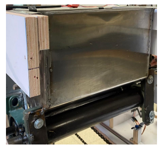
Component Name	Component Description	Component Image
Printer Rollers	These were used for dispensing the seaweed paper and were connected to a 12V DC power supply.	
Rice Mixer	A stainless steel rice mixer equipped with two rollers designed to deposit rice features a stainless steel hoop on the inside to thoroughly mix the rice.	
Coupler	The coupler iron allows the motors to be connected to objects, promoting the sending of the rotation from the motor to the object and thereby movement.	
Smooth Rods	The smooth rods have an utmost necessity to ensure the straight sliding and keeping of the parts.	
Rod Holders	Rod holders are essential in securely mounting smooth rods in place, ensuring stability and alignment within a system.	

Table 3.1: Table of Components

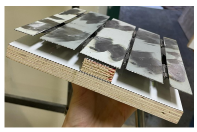
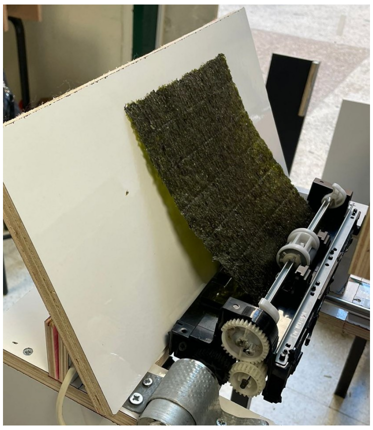
pulley	The pulley system allows equal movement through all stages. One pulley is driven by a motor and connected to a belt; the belt rotates the second pulley, which runs the escalator chain without a hitch.	
Escalator chain	The escalator chain holds the wooden part securely and moves them smoothly across all production stages.	
Bearings	Bearings in the rice mixing mechanism hold the iron hop securely while enabling smooth and efficient rotation.	
3D Printed Item with container for ingredients	A stepper motor drives the 3D printed element keeping it in motion during the dispensing process with accurate dispensing of ingredients in sushi making.	
Rolling Module	The unit that is responsible for rolling sushi. When the two sides are lifted, it can mold the sushi into a rectangular parallelepiped shape.	
Cutting Module	This component is responsible for cutting the rolled sushi into slices.	

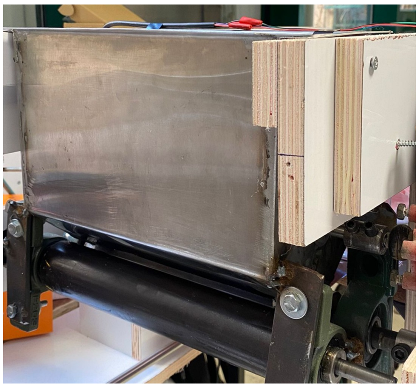
Table 3.2: Table of Components

3.2 Mechanism of action

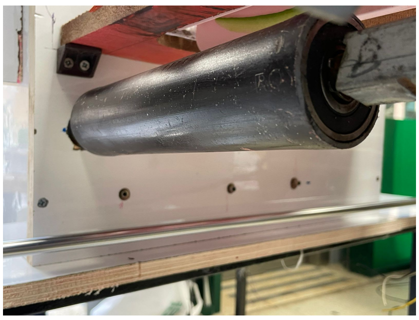
1. This is the first part where the seaweed paper descends on the belt.



2. This is the rice-spread part.

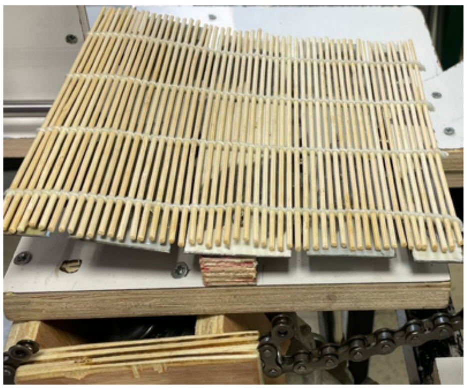


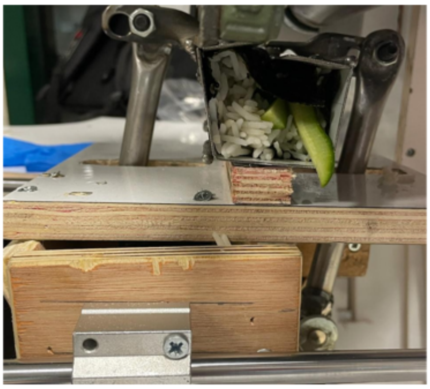
3. In this part, the rice is pressed down by the cylinder.



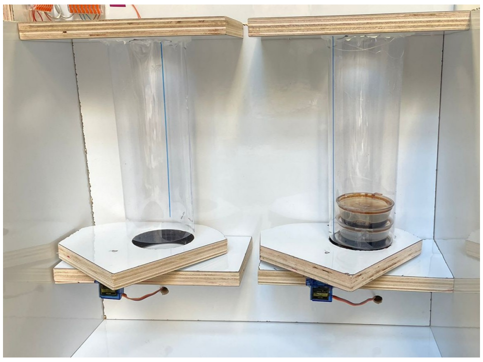
4. The ingredients part

5. This is the rolling part

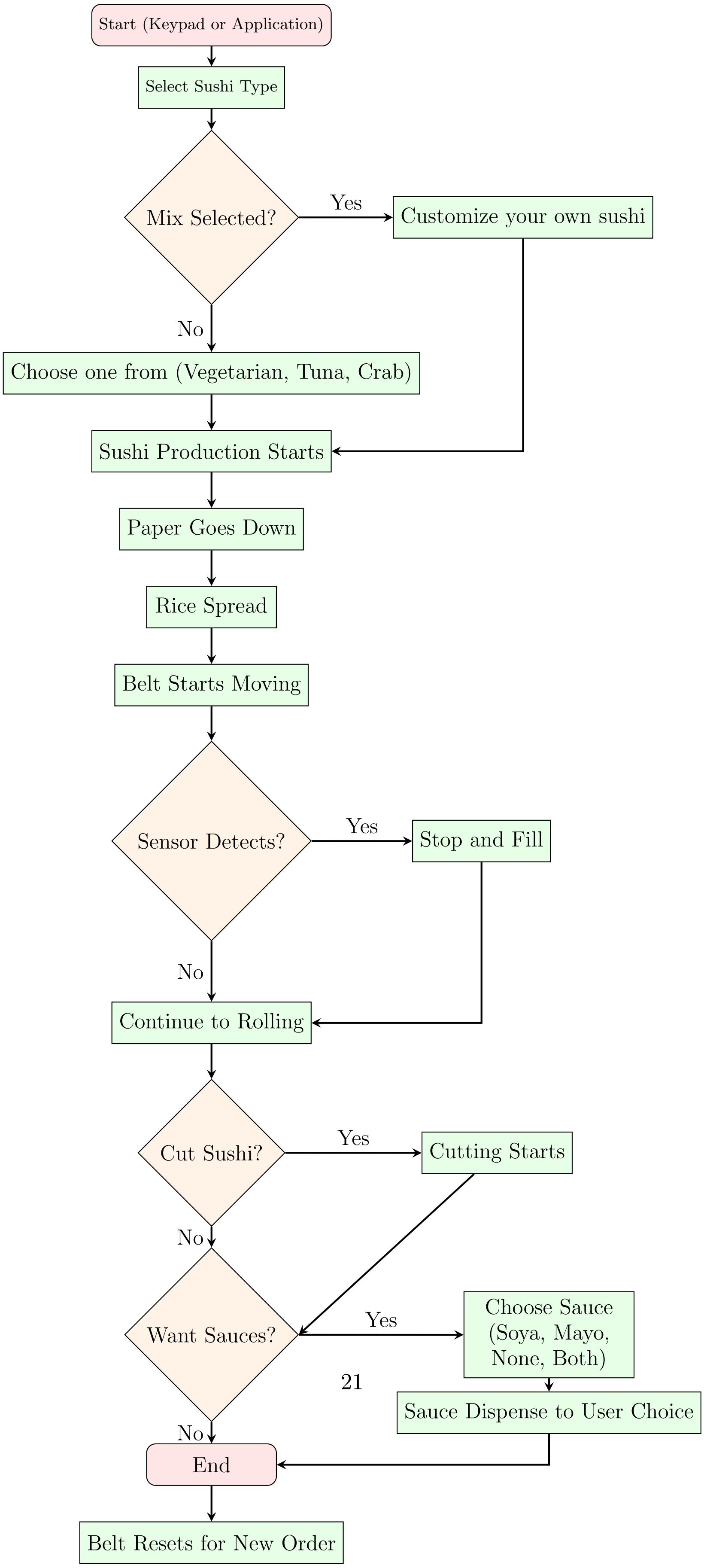




6. Sauces part



3.3 Software implementation



3.4 Mobile Application

We developed a very simple application on blynk to order with customized needs. We connected blynk to the ESP32 and then to the Arduino.

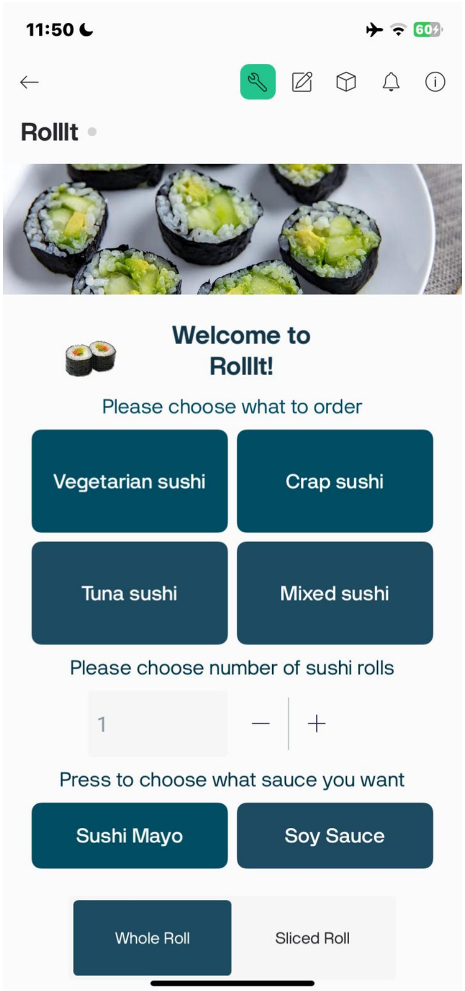


Figure 3.22: Application UI

3.5 Constraints

1. We needed a series of the DC motors (DC 12V Gear Motors with Encoders), which are conventional for damaged cars. However, sourcing them proved to be very difficult. Some had to be sourced from another city, an exercise that took a long time owing to road restrictions and other logistical hurdles.

2. Our project put more emphasis on mechanical applications for us but it was hard for us to get hold of it.

3. The overall cost of our project was significantly high since we relied on specialized and uncommon components.

4. We were working with new and unconventional components, making it extra difficult to familiarize themselves for a good use. In addition, several customized items had to be designed; for example, couplers and hubs. Finding capable suppliers or workshops to manufacture these specialized items took a lot of time and energy.

5. 3D printing was needed for certain aspects of the project; this entailed designing custom items, which required time both for design and printing.Compounding the issue, the person we consulted with for the 3D printing was located in another city, and the road scenario added more delays on this side of the project.

6. Since the majority of our project involved iron, it was very heavy, which created challenges in other areas. The weight made it difficult to find suitable components and also posed safety concerns, leading to a few minor injuries during assembly.

7. The mechanical work involving wooden parts was also challenging due to our lack of experience in this area. A significant amount of cutting and adjustments were required, as many wooden components were not customized from the start. We had to bring our own tools, such as an electric saw and power screwdriver, to cut and fix the wooden parts, adding to the complexity and effort needed for the project.

4 Results

By the end of this project, we successfully developed a fully automated sushi production line with the ability to make various types of sushi rolls based on users' preferences without human intervention. The system integrates various features, such as mobile app connectivity, an LCD and keypad interface for direct input, and ingredient-level monitoring with alerts for replenishment.

5 Discussion

5.1 Challenges and Solutions

These are some challenges and how they being solved:

1. **Automating the Transfer of Seaweed Paper to the Belt**
   Finding a reliable mechanism for passing the delicate seaweed paper of size **21 x 19 cm** onto the belt was one of the major challenges. The seaweed paper was small and thin, which made it susceptible to tearing, and thus careful operation during automation was required.

   Further trials led us to a HP LaserJet P1505 printer that served our needs. We successfully integrated its mechanism with a DC motor and gearbox to operate this system and hence the seaweed paper inside with great gentleness and efficiency. It resulted in smooth transferring of the seaweed paper without damage.

Figure 5.1: HP LaserJet P1505 printer

2. **Developing the Rice Spreading Mechanism**
   The rice spreading mechanism was unquestionably the most time-consuming part of the whole project. By nature, sushi rice is sticky due to the vinegar and sugar added to it, which made things a bit more complicated for automation. First, we thought of a CNC style system where a rice tube would dispense the rice. However, the sticky rice clumped together causing the slot to plug.

   To overcome these problems, iterative design improvements were made:

   - A stainless steel container was used to minimize stickiness, as the material's smooth surface reduced adhesion.

- To prevent the rice from clumping and blocking the slot, a mixing mechanism inside the container was incorporated. This mixer, connected to a **NEMA 17 stepper motor** stirring the rice with it constantly.

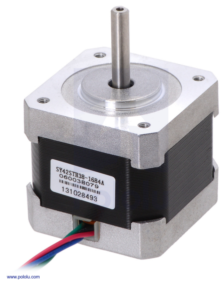


Figure 5.2: NEMA 17 stepper motor

The improved solution solved the problem, but it introduced a new one: the motor struggled to rotate when it was fully loaded with rice, the motor wasn't very responsive because of its weight; for this purpose, we switched over to a more powerful stepper motor, a **NEMA 23 stepper motor**, which offered greater torque. However, this motor was also not enough for heavy loads. Finally, we changed it to a **car wiper motor**, which is a high-torque DC motor controlled by a relay. This was the best among all that we tried, because it managed the load with no problem and allowed smooth mixing.

For dispensing the rice onto the seaweed paper, we designed a dual-cylinder system outside the container. One cylinder was connected to a **NEMA 23 stepper motor**, while the other cylinder, equipped with bearings, rotated passively as the first cylinder moved. This method allows rice to be spread onto the moving seaweed paper below.

With these improvements, yet another problem emerged-the rice output was not enough. To this, we attached both cylinders to two **NEMA 23 stepper motor**-one motor per cylinder-along with a **5A driver** and ensured rotation in the direction of the slot. This finally made the output of rice full, which was the final iteration of the rice container and spreading mechanism.

3. **Improving Rice Adhesion to the Seaweed Paper**
   Once the rice was laid out on the seaweed paper, the rice was rather loose and wasn't sticking to the paper at all. Because of this fact, it wasn't suitable for preparing sushi.

To solve this problem, we designed a compression mechanism. The moving seaweed paper with rice wrapped onto it was under a cylinder that comprised an iron pipe fitted with bearings, which rotated compressing the rice onto the seaweed paper as the latter passed under it. This will ensure rice strongly attached to seaweed with the proper texture and structure to prepare sushi.

This solution proved effective, producing a consistent and reliable bond between the rice and the seaweed paper, which is critical for the subsequent rolling process.

4. **Designing the Ingredients Dispenser**
One of the most difficult parts of manufacturing the ingredients dispenser was the special requirement for dispensing the long and thin slices of ingredients. Multiple versions of the dispenser were designed and tested in iterations, using a specific needs-driven 3D printing system.

First, the rotating paddle was measured and designed for a certain container. However, this container was too weak to hold up against the forces that would be generated by the motor driving this rotating paddle. Second, we moved to a stronger container. However, this rotating paddle with 4 wings released an excessively large amount of ingredients, which again was not appropriate in accurate dispensing.

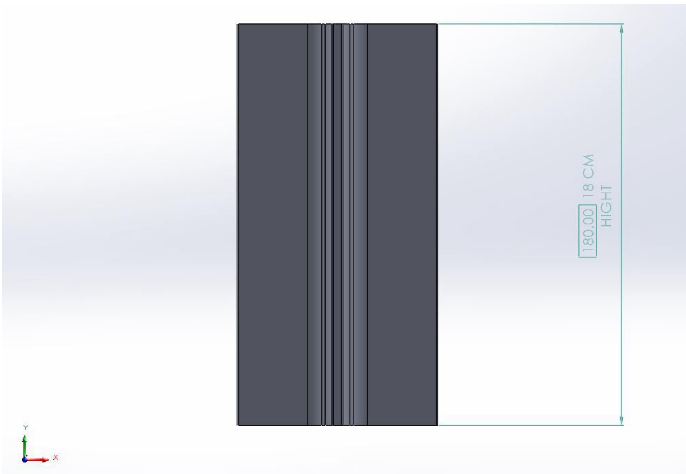


Figure 5.3: First design: 4-wing structure with rectangular edges

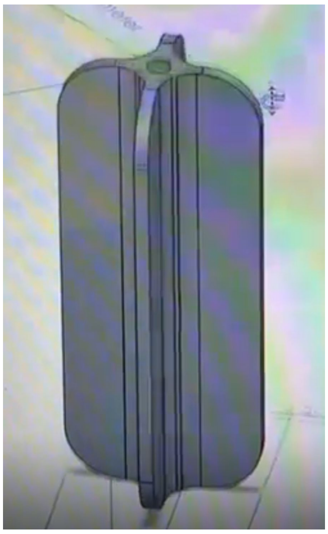


Figure 5.4: Second design: 4-wing structure with rounded edges

In the last remake, we redesigned the rotating paddle to include 8 wings. With the modification in that, flow was controlled so the correct quantity flows out at an instance. Now, the consistency and proper scattering of the ingredient in the sushi-making process.

Figure 5.5: Lat design: 8-wing structure with rounded edges

5. **Motor Selection for the Rotating Paddle Mechanism**
   The requirement for the rotating paddle mechanism of the ingredient dispenser was a motor strong enough to bear the weight of the rotating paddle and its ingredients present in the dispenser. A **stepper motor NEMA 17** was initially being used along with an **L298N H-Bridge driver**; however, due to the length of the rotating paddle along with plenty of weight inside, it was felt that the NEMA 17 motor did not generate the required torque to turn on the paddle effectively.

   This problem was solved by replacing the motor with a **stepper motor NEMA 23** along with a 5A driver. The torque generated by NEMA 23 was an order of magnitude greater and was enough to efficiently turn the heavy paddle and the ingredients inside. This work was very much to the satisfaction of the dispenser requirements indeed, except one issue was the slight extra cost incurred due to the choice of the power motor. The NEMA 23 motor was finally chosen for use because of its excellent performance in this application.

6. **Handling the Seaweed Paper After Rice Spreading**
   The most challenging aspect of the entire project was how to deal with the seaweed paper once the rice had been spread on it: the rice made this seaweed paper softer and more fragile, added by its thinness, which could not easily be moved around without human intervention.

   In the original design, it was supposed to transfer the seaweed paper from one belt to another belt for the rolling mechanism. However, due to the delicacy of the paper and the intricacy in transferring, it turned out to be almost impossible.

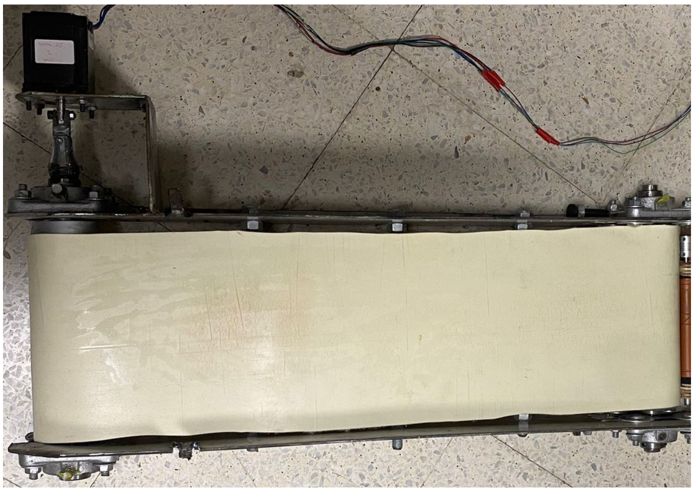


Figure 5.6: First design: Belt One, where the seaweed paper is placed with spread rice and ingredients on top

Figure 5.7: First design: Belt Two, which supports the rolling mechanism above

We finally managed to come up with an effective solution after multiple trials within the tight time constraints of the project. Instead of transferring the seaweed paper between belts, we integrated the rolling mechanism on the same belt. The mechanism was mounted onto two smooth rods, which provided the ability for it to be moved along the belt. Finally, we also connected the rolling part to an escalator chain system driven by a pulley, powered by a DC motor (car wiper motor). This was done to minimize the handling of seaweed papers between belts in such a process for smooth, fast, and effective flow.

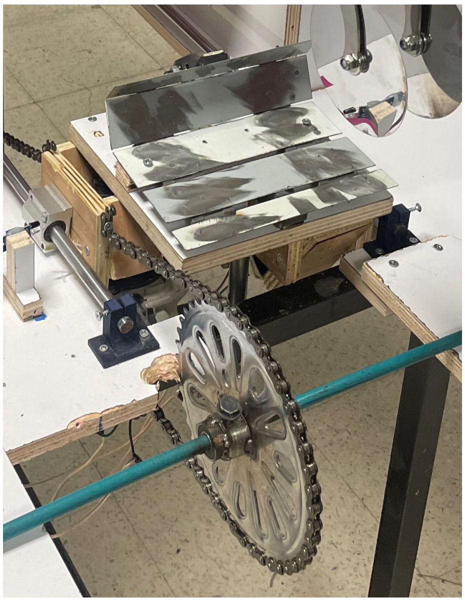


Figure 5.8: Final design: Rolling mechanism functioning as a belt

7. **Integrating the Rolling Mechanism into the System**
   Integrating the rolling mechanism into the system posed significant challenges due to the limitations of materials and the structural requirements. Initially, we attempted two different methods to implement the mechanism, but both failed due to their inability to handle the forces involved.

   After much trials, we came up with the design-a rectangle structure of the same size as the seaweed paper. The structure was split into five pieces that were attached: one base piece and two pieces on each side, attached by jacks. The jacks allowed the side pieces to move upward to roll the seaweed paper effectively.

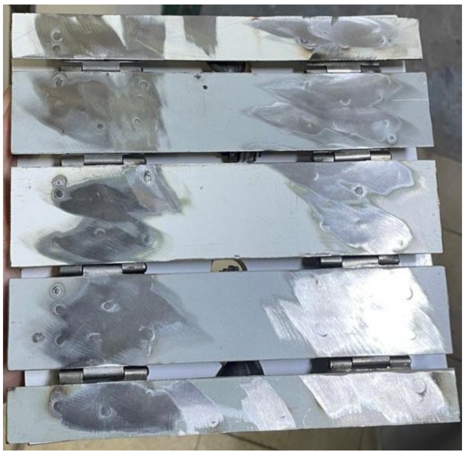


Figure 5.9: Rolling mechanism

Figure 5.10: Jack

However, moving the jacks proved to be difficult. We tried several approaches before determining that the mechanism required a powerful motor to lift the jacks. In the end, we used two DC motors (car wiper motors) that can provide the required torque to actuate these jacks. This solution was effective, though it introduced additional challenges, such as increased space requirements and difficulty sourcing the appropriate motors. Despite these obstacles, the final design successfully achieved the rolling mechanism's integration and functionality.

8. **Power Supply for DC Motors in the Rolling Mechanism**
   Since the jacks and other metal parts were hard to move, DC motors for the rolling mechanism required a lot of power. We first tried running the motors from the power supply computer. However, the power supply unit was inadequate to supply the high current the DC motors needed when under load.

   We solved this by using an external power adapter rated at 12 volts, 4.3 amperes, which could provide the adequate power that the motors needed to get them working effectively. With such a solution, the rolling mechanism will work reliably and address the limitation brought about by the original power supply, especially in meeting the high torque demand from the system.

9. **Controlling DC Motors in the Rolling Mechanism and Belt System**
   The DC motors (car wiper motors) used in the belt-like part to move the rolling mechanism forward and backward, as well as the two motors used for the rolling mechanism itself, initially posed challenges in control. At first, we tried using a 2-channel relay to operate the motors. However, this approach had significant limitations: we could not easily control the motors' speed, and changing their direction required a complex setup.

   In order to get over these issues, we started using the **IBT-2 Motor Driver H-Bridge**. It efficiently allowed us to control both the speed and the direction of the motors. Although the IBT-2 Motor Driver was more expensive and required multiple control pins from the Arduino, it granted us very precise and reliable motor control and thus was the best solution for the needs of the system.

10. **Sensor Implementation for Belt Movement and Position Control**
    Controlling the belt's movement and ensuring it stopped in the

correct position presented significant challenges, primarily due to the thin and lightweight nature of the seaweed paper and the rice. Initially, when the system used two belts (as discussed in Point 6), we tested various color sensors. Unfortunately, the translucent nature of the seaweed paper, along with the diverging ambient light conditions, made the color detection really hard, and therefore these sensors could not be depended upon.

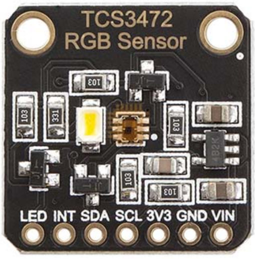


Figure 5.11: TCS3472 RGB Colour Recognition Sensor

To overcome this, we switched to **infrared (IR) sensors**, which when tuned to the right sensitivity could detect black and white surfaces very well. The white belt would be the contrasting surface when compared to the dark greenish black seaweed paper, which together with the white rice would enhance detection. This setup proved the IR sensors to be the best for this situation.

Later, with a design revision to a single belt system, things changed due to the introduction of a larger rolling part. This could be reliably detected using laser sensors and **light-dependent resistors (LDRs)**. The new setup brought with it its own set of problems, such as fine-tuning the sensors to stop precisely, but these were solved within the control code.

6 Conclusions & Recommendation

6.1 Conclusions

The aim of the project was to construct a sushi-making machine that is fully automatic that minimize human intervention during the critical work cycle of rice spreading, ingredient dispensing, and actual rolling. The entire automation of sushi production had been accomplished via the successful integration of different motors (stepper and DC), H-Bridge drivers, Arduino, and sensors. The system met the project's goal by controlling the complete process from spreading rice on seaweed paper to dispensing ingredients and rolling the sushi.

Key lessons learned from the project include:

- **Technical:** This relates to the importance of selecting the right motor controllers and sensors for the application and how to integrate them effectively into one cohesive system. The choice of stepper and DC motors with proper drivers and Arduino for control allowed for accurate movement and operation of the system.
- **Teamwork:** Communication and collaboration under tight time constraints were important in resolving the unexpected technical problems and in achieving the project's objectives.
- **Time Management:** The challenge was to balance the design with the iterative prototyping and the testing phases. Almost all phases were iterative, and a structured timeline was very important for identifying and fixing issues that came up during the development.

Achievements:

- Successful integration of hardware components, sensors, and control systems.
- Automation of key processes in sushi making, with reduction of human intervention.
- Design and implementation of mechanisms for rice spreading, ingredient dispensing, and sushi rolling.

6.2 Recommendation

While the project successfully attained its goals, recommendations for improvements in cost, performance, and efficiency are outlined below:

- **Cost Reduction:** While we were able to manage costs through negotiated deals on sensors, material reuse, and in-house design, there is potential to further reduce costs by selecting lightweight materials and minimizing the use of metal components without sacrificing system performance.
- **Simplification and Reliability:** Future iterations of the system should take a more modular design approach that will ease maintenance and upgrades. Using alternative materials that are lighter and more durable can reduce overall weight and stress on the motors, enhancing efficiency.
- **Future Work and Enhancements:**
  - **Precision Sensors:** The implementation of higher-precision sensors would improve the accuracy of ingredient dispensing and enhance the consistency of the sushi-making process.
  - **Advanced Materials:** Switching out metal components for lighter, less expensive alternatives would make the entire process very efficient.
  - **Advanced Features:** A more user-friendly interface or optimization algorithms using machine learning may serve to fully automate the process and enhance the overall experience.
  - **Ingredient Expansion:** Adding the option to include more ingredient choices would allow the machine to cater to a wider range of users, offering more sushi variations.
  - **AI Chatbot Assistance:** Implementing an AI-powered chatbot could help users, particularly those trying sushi for the first time, by recommending ingredient combinations based on preferences and dietary restrictions.
- **Open Problems and Areas for Future Research:**
  - **Sushi Transfer:** Key unreconciled issues lie in automating the transfer of the sushi from the machine to the plate without destruction. As such, the development has further testing ahead.
  - **Material Science and Motor Control:** An increasing amount of research into other materials and smarter strategies for control of motors will greatly improve the performance of this product and reduce power consumption.

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