An-Najah National University

Faculty of Engineering & Information Technology

Computer Engineering

Graduation Project

The Nail Polish Robot

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Contents

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Abstract

The Polish Nail Robot represents a significant innovation in the beauty and personal care industry, addressing the need for precision, efficiency, and convenience in nail care. With the increasing demand for personalized beauty services, this project aims to revolutionize the traditional manicure process by automating nail painting, drying, and removing nail polish. The goal is to design an intuitive interface for ease of use by individuals, thus providing a consistent and high-quality manicure experience.

The methodology involves several key phases. First, comprehensive research is conducted to understand the requirements and challenges in automating the manicure process. The robot's design includes sensors to detect and track finger motion, an OAK-D camera to capture and process images, and an Arduino Mega for control. A Delta mechanism with three stepper motors (NEMA17) is used to precisely control the movement of the nail polish brush in x, y, z coordinates. Additionally, a fan is incorporated to dry the nail polish quickly and safely, while a DC motor is employed to remove nail polish efficiently.

To enhance the user experience, the system includes an RGB light strip that changes color based on the selected nail polish, an LCD, keypad, RFID for secure operation, and a speaker for audio feedback. The user interface is being built to allow users to easily control the robot. This project is unique, as no existing applications or robots at An-Najah National University automate the entire manicure process, including painting, drying, and removal of nail polish.

Introduction

3.1 Background

There is no doubt that beauty and personal care represent a big part of our lives as girls, it is not just a luxury but a way to express ourselves and take care of our appearance. With the development of technology and the increase in our interest in studying science and engineering, it was natural to combine our passion for beauty with our interest in developing modern technologies that serve our daily needs.

In this project, we succeeded in designing a nail polishing robot that combines technological precision with an aesthetic touch, making nail care easier and more enjoyable. This robot is the result of our passion and creativity, and represents the fruit of our efforts to combine what we have learned in the field of technology with our love of beauty.

The core of the system is built around user comfort and high-quality results. The robot integrates an advanced Delta mechanism, which consists of three arms that move in three dimensions, to precisely control the polishing brush, ensuring that each nail is polished with extreme precision. We also added the OAK-D camera, which adds an additional layer of intelligence by detecting the position of the user's finger and accurately calculating the width of the nail, to determine the number of brushes to use based on the size of the nail, in real time. This ensures that the robot adapts to individual nail sizes, providing a personalized experience for each user.

Security is also a key element of the design. The RFID system restricts access to authorized users only, ensuring that only those with registered cards can operate the robot. This system is ideal for personal use or in beauty salons, where security and control are paramount. Upon successful authentication, a voice system greets users, enhancing the experience with a personal touch of interaction.

Choosing a color is facilitated via a keypad connected to a stepper motor-controlled rotary system. Each keypad button has a specific nail polish color, and when the user selects the desired color, the rotary system moves to place the appropriate bottle of polish in the correct spot. The robot then picks up the desired color and prepares it for use. For added visual interaction, the RGB lighting colors change to match the chosen polish color, adding a fun and engaging touch.

The robot does more than just apply nail polish, it also includes a nail drying and cleaning unit, ensuring that the entire nail care process is completed from start to finish. This integrated system eliminates the need for additional tools or manual steps, as the robot takes care of everything from color selection to drying and cleaning, making nail care a seamless and enjoyable experience.

Constraints, Standards and Earlier Coursework

4.1 Standards

In designing the nail polishing robot, we adhered to several engineering and safety standards to ensure both functionality and user safety. The key standards include:
Safety of Machinery: This standard was followed to ensure the robot is safe to operate, especially in a salon environment where users may not have a technical background. Precautions such as restricted access through RFID and safety measures when handling nail polish chemicals were implemented to meet these guidelines.
Electrical Standards: The safety and dependability of the electrical parts utilized in the delta mechanism machine are guaranteed by adherence to electrical standards, such as those established by the Institute of Electrical and Electronics Engineers (IEEE). This covers electromagnetic compatibility, power distribution, and wiring standards.
Mechanical Standards: The project complies with standards for mechanical engineering,The choice of materials, structural integrity, and adherence to accepted standards for mechanical components are all taken into account.

4.2 Constraints

Developing this nail polishing robot involved overcoming several challenges and constraints:
Novelty of the Idea: One of the primary constraints is that this concept of an automated nail polishing robot had not been developed before, which meant that there were no existing designs or models to reference. This required extensive research and experimentation in designing the system from scratch, including the integration of various hardware components like the Delta mechanism, OAK-D camera, and RFID system.
High Costs: The cost of high-precision components, including the stepper motors, sensors, and the design of the Delta mechanism, presented a significant financial constraint. The Delta mechanism, in particular, required specialized components for precise motion control, which

increased the overall expense. Balancing cost-efficiency with the need for accuracy and quality in the robot's performance was a challenging aspect of the design process.

User Customization: The robot had to be designed to cater to a wide range of nail sizes, shapes, and colors. Achieving this level of customization required the use of advanced technology like real-time image processing with the OAK-D camera and adaptive motion control with the Delta mechanism, which added complexity to the design.

4.3 Earlier coursework

We are required to take a few courses that are essential for advancing our expertise and completing this project.

- PIC and Arduino Lab.
- Arduino course.
- Online python course.
- Robotics movement.

Literature review

The use of robotics in personal care and beauty spheres has witnessed rapid growth in the recent past. The developing market of hair and beauty application robotic systems for hair and beauty treatments is due to a high necessity for automated solutions for hair dressing, make-ups, and nail care application among others. These robotic systems are expected to provide increased efficiency in terms of speed, and uniformity, while minimizing the risks related to human involvement. Liu et al. [1] focused on the introduction of robots in the beauty industry and discussed the key problem areas including personalization, safety, and accuracy. Much innovation in the field of robotics in beauty services offers a new dimension of technology oriented to the requirements of the consumers.

The delta mechanism, which is known for its precision and speed, is widely used in applications requiring accurate control of movement. This mechanism is particularly beneficial in the beauty industry, where precision is paramount for tasks such as nail polishing. Chen et al. [2] explored the advantages of delta robots in cosmetic applications, emphasizing their ability to provide consistent results with minimal error. For the nail polish robot project, using a delta mechanism allows for fine control of the brush movement, ensuring high-quality results with minimal manual intervention.

Concerns such as security and user authentication are of utmost importance when it comes to the development of modern robots designed to be used in a shared way in places like beauty salons. The application of Radio Frequency Identification (RFID) technology has been demonstrated as an effective approach to control the restricted areas within every robotic system. Gupta et al. [3] examined the contribution of RFID technology in the field of robotics and confirmed its usefulness in restricting the use of a robot to only the permitted operators. In our project, RFID is implemented to forbid access to users' registered cards only concerning the nail polish robot since this increases security and privacy of the users.

Recently, RGB lighting systems have also been incorporated in robotic systems to allow for presentation purposes and interaction with users. In this project, the RGB system indicates the colour in which a specific nail polish will be painted after the user has made a choice of the actual colour. Zhao and Rahman [5] described the use of color in human-robot interactions in terms of an interaction toolkit comprising synthetic systems interfacing with people, stressing that such feedback enhances user experience. The use of RGB lighting in the process of the nail polish robot not only contributes to the enhancement of the user experience but also provides the necessary beauty to the process.

Methodology

6.1 Hardware parts :

- Arduino Mega 2560
- Computer power supply
- NEMA 17 stepper motors and A4988 Driver
- Connecting wires
- LCD 16*2 with I2C
- Limit Switches
- GT2 belt , gears , bearings and chromium smooth rod
- bolts and nuts
- OAK-D camera
- servo motor
- Keypad
- LED RGB strip and MOS Module
- RFID and buzzer
- Speaker , DFPlayer Mini MP3 Player and 16G SD card
- DC motor
- Relays
- H-Bridge
- PIR Motion Sensor
- DC Fan
- TM1637 Digit Display

6.2 Description

In this section we will talk about each of the hardware components that we used

Arduino Mega 2560

The Arduino Mega serves as the core controller that orchestrates the interaction between various subsystems in the nail polish robot. It manages RFID authentication, controls the stepper motors for the delta mechanism, processes keypad inputs for color selection, regulates RGB lighting, and handles audio feedback via the DFPlayer Mini. Additionally, it interfaces with the OAK-D camera to retrieve the width of the user's finger. If the camera detects no finger, the system triggers an audio alert to inform the user. Conversely, if a finger is detected, the Arduino Mega determines whether a single brush or two brushes are needed based on the measured nail width. This allows the system to provide precise and customized nail polishing, while ensuring real-time responses to user interactions and environmental inputs.

Computer power supply

We utilized a computer power supply in our project to provide stable and reliable power to various components and modules. We used it due to its robustness and ability to deliver sufficient power across multiple voltage rails.

NEMA 17 stepper motors and A4988 Driver

We used three NEMA 17 stepper motors to achieve precise movement in three dimensions. These motors allow the polishing brush to be positioned precisely, allowing it to move smoothly across the nail surface. The stepper motors were chosen for their high torque and precise control capabilities, which are essential for the delicate task of polishing nails with precision. We also used it to rotate the nail polish base to align with the selected color. This motor adjusts the position of the nail polish bottle holder according to the user's choice, ensuring the correct color is applied.
A4988 stepper motor driver converts digital inputs into exact steps to govern and control the movement of stepper motors. By controlling the electrical pulses that power the stepper motors, this driver improves the precision and guarantees a smooth and controlled application of nail polish

Limit Switches

A limit switch is an electromechanical device designed to trigger an action when an object reaches a predefined position or limit. In our project, we employed three limit switches, each connected to a corresponding stepper motor. These switches serve as reference points, ensuring that the motors stop precisely when they reach their designated starting positions. By integrating limit switches, we guarantee that the stepper motors reset accurately to their home positions, enhancing overall precision and preventing mechanical over-travel or potential damage to the system.

Mechanical Components in the Delta Mechanism

To construct the Delta mechanism, we used a combination of precision mechanical components and custom 3D-printed parts.**Bolts and nuts** were essential in securely fastening the various parts, including **smooth rods, bearings, and gears**, to ensure stability and structural integrity. The use of a **3D printer** allowed us to design custom parts such as the frame and arm supports, which were tailored to fit the dimensions and requirements of the Delta mechanism. Each smooth rod was aligned and fixed in place with the help of nuts and bolts to provide a stable guide for the moving arms. **Belts** were looped around gears, transmitting the rotational motion of the stepper motors into linear movement. Bearings reduced friction in the joints, allowing for smooth and precise motion of the arms, ensuring that the end effector, which holds the nail polish brush, can move accurately to the nail's surface.

The final structure is a balanced combination of off-the-shelf components and custom-designed 3D-printed parts, resulting in a well-functioning Delta robot capable of precise movements needed for high-quality nail polishing.

(a) GT2 belt.

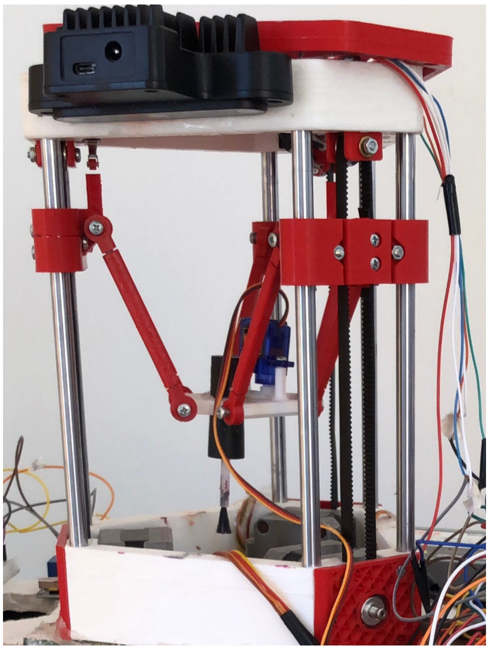
(b) Smooth Rod.

(c) Bearing.

(d) Gears.

Mechanical Components

These features combine to create a mechanically efficient delta machine as shown in below picture, capable of providing precise, repeatable motion for perfect nail polish.

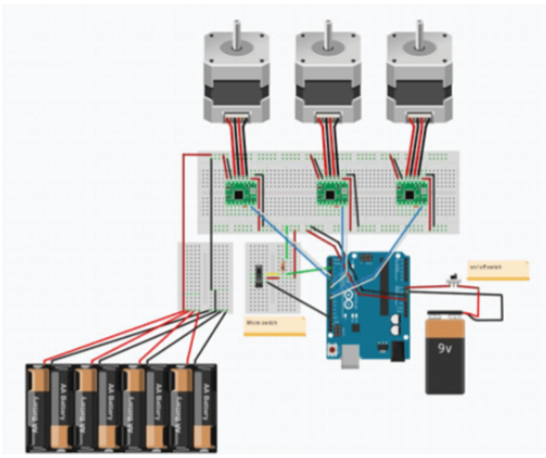


Arduino Mega to precisely control the movement of three NEMA17 stepper motors through A4988 drivers.

In this setup, an Arduino Mega is used to control the three NEMA17 stepper motors, each of which is driven by an A4988 driver. The stepper motors are responsible for the precise movement of the Delta mechanism in the x, y, and z axes.

Each A4988 driver is connected to the Arduino Mega to receive control signals for motor movement. The connections are as follows:

1. **Power Supply:** The A4988 drivers are powered by an external power source, providing sufficient current to drive the NEMA17 stepper motors. The VCC and GND of each A4988 are connected to the power supply.
2. **Motor Connections:** Each NEMA17 motor is connected to its respective A4988 driver through four motor output pins (2B, 2A, 1A, 1B), which control the motor's step and direction.
3. **Control Signals (Step and Direction):** The step and direction pins of each A4988 driver are connected to the designated digital output pins on the Arduino Mega. The step pin controls the movement step size, while the direction pin controls the rotation direction of the motor.
4. **Enable Pin:** The enable pins of all A4988 drivers are connected to a single digital pin on the Arduino Mega, allowing all motors to be enabled or disabled simultaneously.
5. **Microstepping Control:** The microstepping control pins (MS1, MS2, MS3) on the A4988 are set according to the required precision of the stepper motors. These pins allow for fine control of the motors' stepping resolution.

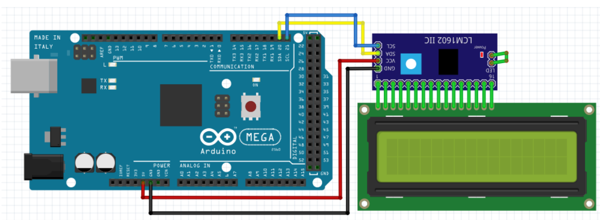


By coordinating the signals sent from the Arduino Mega, the stepper motors move the Delta mechanism smoothly and precisely, ensuring accurate control over the nail polishing process.

OAK-D Camera

We utilize the OAK-D camera to measure the width of the nail by processing both RGB and depth data. A custom code was deployed on the camera to analyze this information, determining whether the nail requires one or two brushes for the polishing process. If no finger is detected in the designated area, the machine remains inactive. Once the nail is detected, the camera sends the width data via serial communication to the Arduino, which then controls the movement of the machine accordingly. In addition, A red horizontal line is displayed in the live feed to indicate the starting position where the user should place their finger. This ensures accurate nail detection and helps guide the user for precise placement.

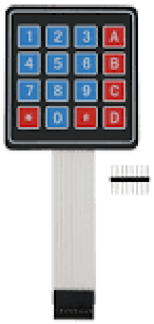
LCD 16*2 with I2C

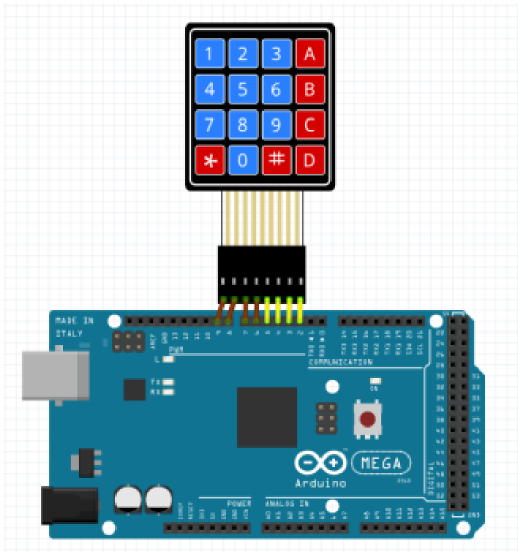


LCD with I2C Connection with arduino

LCD 16*2 with I2C

We integrated an LCD 16*2 display with I2C communication protocol into our system to visualize various inputs and outputs. This setup allowed us to display user settings and interact with them based on keypad inputs, displaying them on the LCD for user convenience and interaction.





KeyBad Connection with arduino

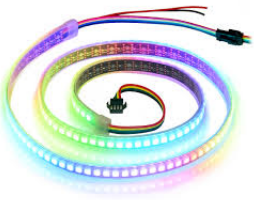
Keypad

We integrated a keypad into our system, where each button was labeled with a specific color using colored paper, allowing the user to easily select the desired nail polish color by pressing the corresponding key. Additionally, we added two special buttons: one labeled "Start", which initiates the nail polishing process, and another labeled "Clear", which triggers the cleaning mechanism to clean the brush before switching to a new color. This setup simplifies user interaction, making the process intuitive and straightforward.

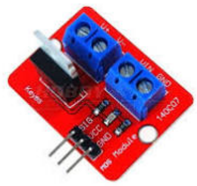
RGB LED strip and MOS Module

We integrated an **RGB LED strip** along with a MOS module to enhance user interaction through dynamic lighting. The system responds to the user's access status with the following color cues:

- If the user is unauthorized, the strip displays red.



RGB LED strip



MOS module

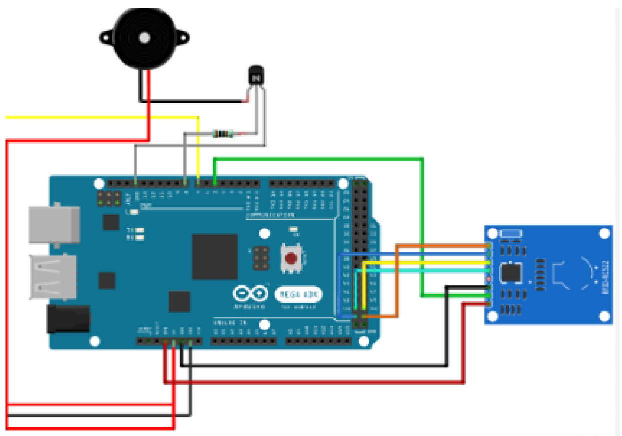
- If the user is authorized, it shows green.
- When the user selects a nail polish color, the strip changes to a color that matches the chosen polish.

The **MOS module** is used to precisely control the brightness and hue of the RGB strip, ensuring the lighting is well-coordinated with the selected nail polish color. This provides an interactive and visually appealing experience for the user.

RFID and buzzer

buzzer

RFID

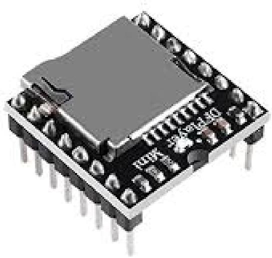


Connection

We used RFID technology to ensure security and privacy in the nail polish system. An RFID card is given to each authorized user, and when the user swipes the card in front of the reader, their identity is verified. If the card is valid, the buzzer emits a low frequency sound indicating that access to the system is allowed. If the card is not authorized, the buzzer emits a high frequency beep, providing an additional level of security and alert. All of this is controlled by an Arduino controller that manages the interaction between the RFID reader and the buzzer.

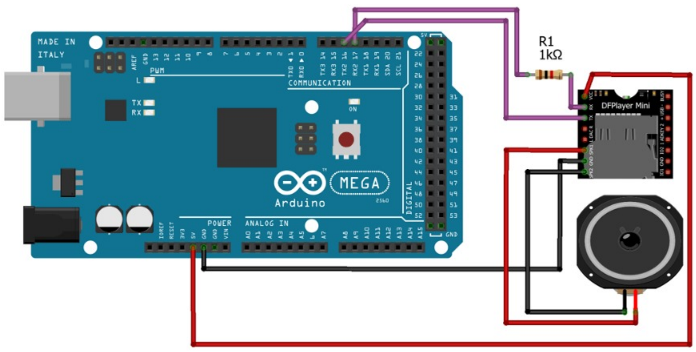
DFPlayer Mini MP3 Player, Speaker and 16G SD card

speaker



DFPlayer Mini MP3 Player

SD Card



Connection

The system includes a DFPlayer Mini MP3 Player, a 16GB SD card for storing audio files, and a speaker for playback. When a user scans an unauthorized RFID card, the system plays a message saying ”You are not authorized to access” through the speaker. For authorized cards, the system plays a welcome message, ”Welcome to Nail Polish Robot,” from the SD card. When the user selects the correct color and presses the ”Start” button, the system prompts them with ”Put your finger at the beginning of the red line.” If the user’s finger is not detected, the OAK-D camera sends data to the Arduino, triggering a message, "No finger detected," to inform the user of the issue.

Nail drying and cleaning part

Drying Process

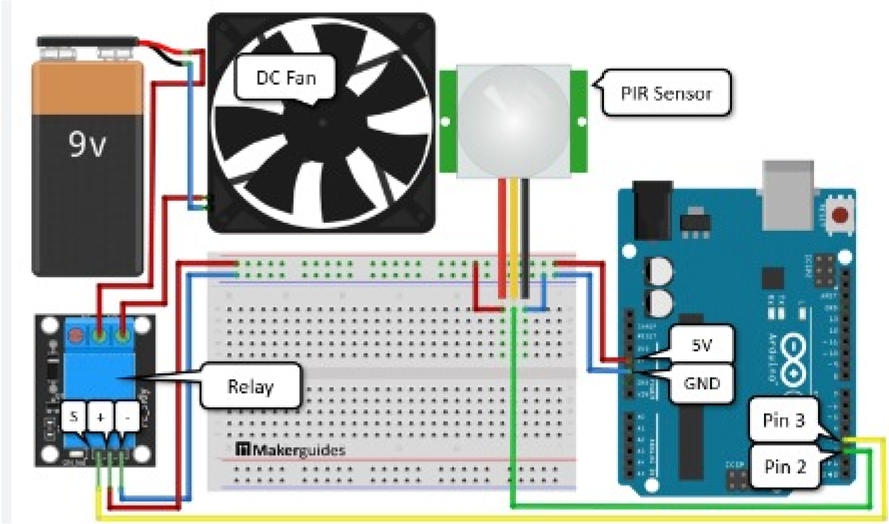
In the nail drying process, a **12-volt DC fan** is used with a **relay** and a **PIR motion detector sensor** to enhance drying efficiency. The DC fan provides airflow to speed up the drying of nail polish, while the relay controls the fan's operation, turning it on or off based on the sensor's input. The PIR motion detector sensor detects the presence of a hand or finger in the drying area, activating the relay to turn on the fan when motion is detected.
To provide users with a visual indication of the remaining drying time, a **TM1637 display** is used. The display shows the countdown of the remaining drying time for 15 seconds. During this period, users can easily see how much time is left before the drying process completes.

DC Fan

Relay

7-Segment Display TM1637

PIR seneor

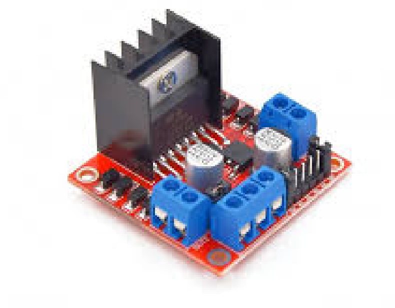


Connrction

Cleaning Process

In the cleaning process, we utilize a servo motor, a **DC motor** with an **H-bridge**, and a **PIR motion detector** sensor. The system features a small box containing a sponge soaked in acetone, which is mounted on the DC motor. A piece attached to the servo motor arm covers the box to prevent acetone from spilling. When the PIR motion sensor detects movement, the servo motor moves the cover piece to open the box, allowing the DC motor to rotate and clean the finger with the acetone-soaked sponge. The cleaning operation continues for 15 seconds, and the remaining time is displayed on a **7-segment TM1637 display** . This countdown informs the user of the time left before the system stops, ensuring efficient and controlled cleaning.

DC motor



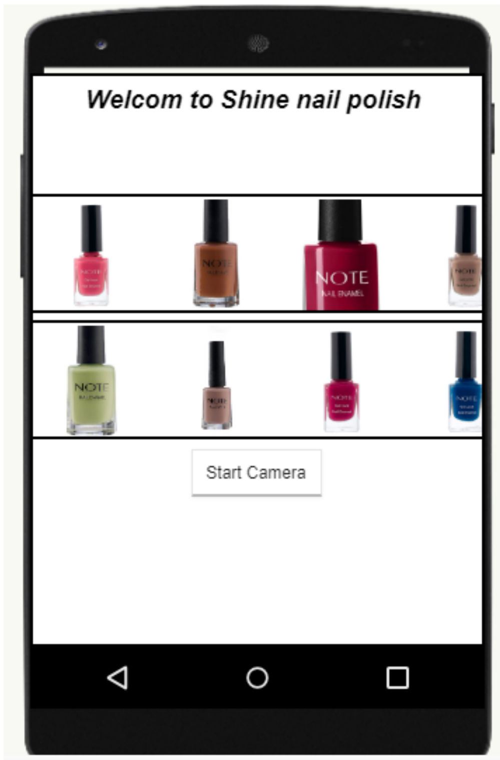
H-Bridge Motor Driver L298N

Servo motor

Application

We developed an application using App Inventor to send data to the ESP32, where the ESP32 receives this data from the application based on the user's choice of nail polish color. Then, the data is sent to the Arduino via the TX and RX interface. After receiving the data, the Arduino moves the stepper motor to the appropriate location based on the received signals, ensuring high accuracy in applying the chosen color to the nail.


ESP32



App

Results and Discussion

Final Desgin

Result

The final design of the nail-painting robot successfully achieved its intended purpose: automating the process of applying nail polish. As seen in the image above, the robot was able to apply the selected nail polish color evenly across the nails. Several key factors contributed to this outcome:

1. **Accuracy of Movement**: The use of stepper motors, limit switches, and smooth rods ensured precise control over the movement of the brush. The robot was able to accurately follow the contour of the nail and avoid overpainting.
2. **Nail Detection**: With the help of the OAK-D camera, the robot correctly detected the presence of the nail and determined its width. In cases where no finger was detected, the system did not proceed, enhancing error prevention.
3. **User Interaction**: The keypad and RGB LED strip enhanced the user interaction. The users were able to select their desired color using the keypad, and the LED strip visually confirmed the color choice by changing to the corresponding shade. The system provided additional feedback through audio alerts when necessary.
4. **Color Matching and Brush Control**: The integration of the MOS module ensured precise control of the RGB LED strip to match the selected nail polish color. Additionally, the system determined whether one or two brushes were needed based on the width of

the nail, ensuring an appropriate amount of polish was applied.

Overall, the robot demonstrated the ability to automate the nail polishing process effectively. While the results were promising, further refinement is needed to eliminate occasional smudges and improve the overall precision of the system.

Conclusion and Recommendation

Conclusion The development of the automated nail-painting robot has demonstrated significant progress in streamlining the nail polish application process. The integration of stepper motors, the OAK-D camera for nail detection, and the RGB LED strip for user interaction created a functional and interactive system. The robot was able to accurately detect nail width and apply polish based on the user's color selection. The design reduced human error, offered consistent polish application, and provided a smooth user experience.

While the overall performance was effective, some minor issues, such as slight polish imperfections and occasional misalignment, indicate that there is room for further optimization. However, this project lays a solid foundation for future enhancements in automation and robotics within cosmetic applications.

Recommendations

1. **Improvement in Precision**: Additional fine-tuning of the stepper motor control and the OAK-D camera's detection system can improve polish application accuracy. Implementing more advanced algorithms for better finger and nail recognition could also enhance precision.
2. **Brush Control**: Explore using different types of brushes or even more advanced paint-dispensing mechanisms to further improve the smoothness and evenness of nail polish application.
3. **Error Handling and Recovery**: Introduce a feedback mechanism that can detect when smudges or uneven application occur and automatically prompt the system to correct these issues.
4. **Commercialization**: With further refinement, this project could be transformed into a market-ready product, offering a unique automated solution for salons and at-home use.

By addressing these recommendations, the nail-painting robot can become even more efficient and user-friendly, ultimately transforming the way nail polish is applied in both personal and professional settings.

Future work

1. **Gesture Control and Voice Commands**: Integrating gesture recognition or voice control could make the system more accessible and interactive. This would allow users to select colors, initiate painting, or adjust settings without needing to physically interact with the keypad.
2. **Enhanced Nail Detection**: Implementing more advanced image processing algorithms using AI models could allow for more precise detection of nail shapes and sizes, accommodating a wider range of hand sizes and nail contours.
3. **Brush Replacement Mechanism**
4. **Artificial Nail Application**

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