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Hardware Graduation Project

CompuShade

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Abstract

In restorative dentistry, accurate shade selection of composite materials is critical for achieving aesthetic and natural-looking results. Traditionally, this process relies on manual comparison with visual shade guides, making it time-consuming and prone to inconsistency due to lighting conditions and human error. This project presents the design and implementation of an automated dental composite shade selection and dispensing device aimed at improving efficiency and precision in clinical settings.

The system captures an image of the patient's tooth using a Raspberry Pi camera, processes it using Python-based image analysis, and compares it against stored images of VITA shade samples taken under identical conditions. Once the closest matching shade is identified, the result is sent to an Arduino-controlled dispenser. The dispenser selects the appropriate composite tube, precisely dispenses the material into a hygienic disposable cup, and notifies the dentist via an LCD and buzzer. With implemented notification system to notify the doctor when the device is out of cups or if one of the fillings is empty. The system also features a mobile application for remote interaction, such as requesting additional material or resetting tube counters.

Testing demonstrated consistent performance in color matching, accurate material dispensing, and successful integration of all hardware modules. The prototype offers a cost-effective and clinically practical solution, reducing manual effort and material waste while enhancing the overall workflow for dentists. The project paves the way for smarter, more efficient dental tools through embedded automation and image-based decision-making.

Introduction

Statement of the problem

The problem addressed by this project is the time-consuming and often inaccurate process of selecting and preparing dental composite materials for tooth restorations. Existing shade selection methods rely heavily on a dentist's visual judgment and manual comparison with shade guides, which can lead to inconsistencies in matching the natural tooth color. Additionally, preparing the correct amount of composite material manually can be inefficient and prone to material waste.

Furthermore, current solutions that aim to automate shade selection and dispensing are either costly, lack essential features for real-time monitoring, or do not provide user-friendly integration with other dental tools and workflows. Many clinics still face challenges with managing composite inventory, preventing overuse or shortages, and ensuring that the right shade is consistently available for every patient.

This project aims to overcome these challenges by developing an intelligent, affordable, and user-friendly composite shade selection and dispensing device specifically designed for dental clinics. The device uses a camera and image processing system (Raspberry Pi with camera module) to analyze the tooth's color accurately and match it with pre-stored shade samples from the VITA guide. Once the matching shade is determined, the system communicates with an Arduino-controlled motorized dispenser that selects the appropriate composite tube, dispenses the calculated amount into a cup, and delivers it ready for use.

Key features include:

- **Time-efficient shade matching and dispensing:** Automating the process reduces chair time and minimizes manual errors.
- **Cost-effective solution:** Compared to existing high-end systems, this device is designed to be more affordable without compromising accuracy.
- **Smart notification system:** An LCD and buzzer alert the dentist when the cup is ready, and the system notifies when cups or composite tubes are empty.
- **Remote control and monitoring:** Integration with a mobile application allows dentists to dispense additional material or reset the filling process as needed, even without retaking a tooth image.

Overall, this project provides a more accurate, efficient, and practical solution for dentists, improving patient satisfaction and streamlining clinical workflows.

Objectives

This project aims to develop an intelligent composite shade selection and dispensing device that specifically addresses the needs of dental practitioners and clinics. It aims to achieve the following objectives:

1. **Time-saving shade matching and preparation:**

The device significantly reduces the time required to select the appropriate composite shade and prepare it for a dental restoration. By automating the processes of image capture, color analysis, shade matching, and dispensing, the device increases the efficiency and throughput of dental procedures compared to traditional manual methods.

2. **Cost-effective solution:**

This project provides an affordable alternative to expensive shade matching and dispensing systems currently available on the market. By utilizing accessible hardware components such as Raspberry Pi, Arduino, stepper motors, and standard dispensers, the system delivers advanced functionality at a lower cost, making it practical for small clinics and educational institutions.

3. **Accurate shade calculation:**

The system performs objective and precise analysis of the patient's tooth color using a high-resolution camera and image processing algorithms. It then compares the analyzed color with stored VITA shade guide samples to determine the most suitable composite shade. This reduces human error and ensures higher consistency in restorations.

4. **Automated and controlled dispensing:**

The device dispenses the exact amount of composite material required for the procedure by selecting the correct composite tube, cutting the dispensed material, and delivering it in a cup ready for use. This minimizes material waste and ensures optimal usage of dental supplies.

5. **Improved user experience and remote control:**

The system offers a user-friendly experience through a local LCD display and a buzzer notification system that alerts the dentist when the material is ready. Additionally, the integrated mobile application enables dentists to request more material, monitor inventory, and reset filling tubes remotely without needing to retake an image, further enhancing convenience and workflow flexibility.

By achieving these objectives, the project aims to deliver a practical, reliable, and efficient tool that streamlines the composite shade selection and dispensing process, ultimately improving treatment quality and patient satisfaction.

Scope of the Work

The dental composite shade selection and dispensing device project includes the following scope:

- 1. Design and development of the composite shade selection and dispensing device:**
The project involves designing and developing a functional hardware system capable of capturing a high-quality image of the patient's tooth using a camera module attached to a Raspberry Pi, analyzing the image to determine the closest matching shade from the pre-stored VITA shade guide samples, and dispensing the calculated amount of composite material into a cup for immediate clinical use.
- 2. Integration with Raspberry Pi and Arduino microcontrollers:**
The system utilizes a Raspberry Pi for image capture and processing, and an Arduino microcontroller to receive the shade information, control the motorized mechanism for cup handling, select the appropriate composite tube, dispense the correct amount of material, and operate the cutting mechanism to prepare the composite for the dentist.
- 3. Mobile application development:**
The project includes the development of a mobile application that enables the dentist to interact with the device remotely. The app allows the dentist to request additional material, reset the filling process, and receive notifications regarding the status of cups and composite tubes, all without needing to manually operate the device or take a new image.

The project **does not cover** the following aspects:

- 1. Detailed mechanical design of hardware components:**
While the project makes use of stepper motors, DC motors, dispensers, and mechanical moving parts for cup handling and dispensing operations, it does not include an in-depth mechanical engineering analysis or detailed custom design of these components. The focus is on functional integration and automation rather than the fine mechanical design details.
- 2. Extensive economic analysis:**
Although the project aims to deliver a cost-effective solution suitable for small clinics and educational use, it does not undertake a comprehensive economic feasibility study or detailed market cost analysis. The primary goal is to demonstrate technical feasibility and usability within reasonable budget constraints.

Significance or Importance of the Work

1. Accurate and Consistent Shade Matching:

The device enables dentists to objectively determine the most suitable composite shade for each patient's tooth, reducing human error and ensuring consistent, high-quality restorations. This level of precision improves patient satisfaction and increases the success rate of restorative treatments.

2. Time and Material Savings:

By automating the processes of shade selection and material dispensing, the system minimizes the time dentists spend manually choosing shades and preparing composite fillings. It also reduces material waste by dispensing only the required amount, leading to cost savings for clinics.

3. Accessibility and Enhanced Workflow:

The integration of a user-friendly mobile application allows dentists to conveniently manage the device, request more material, or reset the filling system remotely. This increases the device's usability and makes it practical for everyday dental practice without disrupting existing clinical workflows.

Constraints and earlier work

Constraints

During the design and development of the composite shade selection and dispensing device, several constraints were encountered which influenced the decision-making process and final implementation. The main constraints identified are as follows:

1. **Cost:**

To achieve our project this, careful consideration was given to selecting cost-effective hardware components. And high-performance industrial dispensers were found to be too expensive. As a result, more economical solutions, such as using stepper motors with simple tube clamps and cutters, were chosen to maintain functionality without exceeding budget limits.

2. **Time:**

The project had to be developed within a fixed academic timeline, which imposed constraints on the learning of a new field (dentistry), design iterations, testing phases, and integration of hardware and software.

3. **Technical Limitations:**

The hardware used—Raspberry Pi, Arduino, stepper motors, and standard dispensers—comes with inherent technical limitations that needed to be addressed during design and testing. For example, the torque of small stepper motors restricts the type and viscosity of composite materials that can be handled reliably. Ensuring precise control over small quantities of highly viscous dental composite required tuning motor speeds and testing different tube and valve configurations to prevent leakage and ensure repeatable performance.

4. **The composite material itself**

The composite material's nature was a challenge to deal with as it dries fast and is sensitive to light and heat, so we had to make sure it was closed when not used. And also it was hard to master the cutting process as it can't be cut by the common methods, such as heat or air pressure so we had to test multiple techniques until we landed on the sharp wire method as it didn't affect the material and gave a clean cut.

Earlier work

The successful development and implementation of this dental composite shade selection and dispensing project were strongly supported by the knowledge and skills gained through various key courses completed by the project team. The most relevant coursework includes:

1. **Electronics and Circuit Design:**

This course provided essential knowledge about electronic components, circuit design principles, and both analog and digital systems. The understanding gained was crucial for designing the device's hardware circuitry, including power management, motor drivers, sensor interfacing, and the LCD and buzzer alert systems that inform the dentist when the dispensing process is complete.

2. **Microprocessors:**

This course equipped the team with the ability to program microprocessors and interface them with external modules and sensors. It covered fundamental topics such as I/O operations, data communication, and peripheral control. This knowledge was directly applied in programming the Raspberry Pi for image processing tasks and the Arduino for motor control, cup handling, and shade dispensing logic.

3. **Microcontrollers:**

The Microcontrollers course focused on advanced concepts in system modeling, feedback control, and real-time embedded systems. Skills gained from this course were vital in designing and implementing the precise control algorithms needed for the stepper motors and actuators responsible for moving the cup, selecting the correct composite tube, and accurately dispensing and cutting the material to the desired amount.

By leveraging the theoretical and practical knowledge acquired from these earlier courses, the team was able to effectively address real-world engineering challenges, integrate hardware and software components, and deliver a reliable and functional composite shade selection and dispensing device tailored for dental clinical use.

Literature review

In this chapter, we review relevant literature and previous works that contributed to the understanding and development of automated composite shade selecting and dispensing systems. This review demonstrates our familiarity with the topic and provides a background foundation for the design and implementation of our device.

The composite material was difficult to handle and cut properly, as it is sensitive to light exposure and dries quickly. Therefore, we developed a specific professional cutting method to overcome these challenges and maintain material integrity. To ensure accurate shade matching, we studied the VITA Classical Shade Guide and other standardized systems, recognizing the critical importance of consistent color matching in restorative dentistry.

Modern restorative dentistry heavily depends on precise shade matching between a patient's natural tooth and composite resin material. Conventional methods rely on visual inspection and manual comparison with standardized shade guides such as the VITA Classical A1–D4, which can be inconsistent due to lighting variations, subjective interpretation, and human error. While commercial devices like the VITA Easyshade provide some degree of automation, they lack integration with dispensing systems and often come at a high cost with limited customization options.

Arduino microcontrollers, especially the Arduino Mega, are extensively used as main controllers in automation projects due to their multiple input/output pins and ease of integration with sensors, motors, and communication modules. Tutorials like the “Arduino DC Motor Control Tutorial — L298N | PWM | H-Bridge” [2] provide essential guidance on driving stepper motors using L298N drivers, implementing PWM control, and managing power consumption to avoid overheating. These insights were critical in designing the motor control sequence for dispensing composite shades.

By synthesizing findings from these studies, tutorials, and practical implementations, including camera-based image processing, Arduino motor control, sensor feedback, and user notifications, we developed a reliable, accurate, and user-friendly automated composite shade selecting and dispensing system tailored for dental clinics.

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1. Raspberry Pi Foundation. *Getting Started with Raspberry Pi*. Available online: <https://www.raspberrypi.com/documentation/computers/getting-started.html>
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4. W. Parker. *How to Connect Raspberry Pi and Arduino — Step by Step Tutorial*. YouTube, 2021. Available online: <https://www.youtube.com/watch?v=xc9rUI0F6Iw>
5. VITA Zahnfabrik. *VITA Classical Shade Guide*. Available online: https://www.vita-zahnfabrik.com/pdb_GG1G10G100_pt.html
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Methodology

Overview of the system

The system we developed is a shade selecting and dispensary system, it enables doctors to get the correct shade of composite for their patients. The modules and subsystems that worked together to achieve the device's goal:

- Input and camera module

Doctors interact with the system through a camera that they use to take a picture of the tooth that needs restoration, we give them a few seconds preview to see the correct positioning of the tooth in the camera. Also, they can turn on the device and reset its setting by using a mobile application.

- Shade selection

After the picture has been taken the python code in the raspberry pi process the image and its color and then it compares it to the colors of the samples we've taken and stored of the VITA shade guide, since the raspberry cam's resolution and colors differ from high resolution camera we couldn't just put general RGB values of take images of the shade samples from the internet instead we took pictures with the camera of the shades so the environment and camera sittings are the same and thus the comparison truly works. And after the shade is selected it's sent to the Arduino via a serial connection to start the dispensing process.

- Dispensing the shade

After the signal is received in the Arduino it starts the sequence of dispensing one cup on the belt that'll move till it reaches under the tubes, the tubes are on a gear closed in a homing position -we printed new tips specifically for this functionality since we wanted the tubes to be closed and not get dry but also wanted a seamless open/close operation on them-, once the belt reaches under them the motor that moves their gear moves to the angle associated with the shade selected so its in the cutting position and open, then its filling motor works to push the composite out of the tube so the motor on the cutting pulls the string -after much trial with different techniques we reached a conclusion that a sharp wire is the perfect tool, since cutting with heat or air pressure would damage the material and using a blade will make the material stick to it- and cuts the material that falls in the cup, then the belt moves to the end for the doctor to grab, the doctor is notified of the arrival and the shade selected by the LCD and a buzzer. Then the system goes back to homing positions ready to be used again.

- Notifications

We implemented a notifications system for the cups so that the doctor gets a notification when they're empty -since we used disposable cups for hygienic standards- by printing it on the LCD and turning on the buzzer. We also notify the doctor once any tube is empty - by storing number of rotations done to it in the Arduino's EEPROM and checking it with the max number of rotations before its empty- and also allowed him to reset this counter after replacing the tube easily with the mobile app.

Hardware components and implementation

Here a list of the hardware components used to create the device:

- Raspberry cam v2

This is the most advanced version of the Ras Cam that we found, we needed a high-quality camera since we were concerned with differentiation different shades that are very close to each other, this cam was connected to the Raspberry Pi.

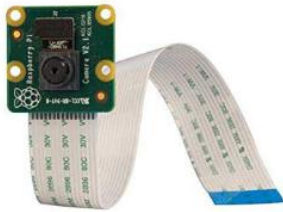


Figure 1:Raspberry cam

Due to the sensitivity of the shades we're filming we needed a controlled environment for the pictures, so we printed a cone and a holder for the camera, we surrounded the camera with pure light LEDs so when we take a picture of the tooth it always has the same lighting regarding of the environment because lightening makes teeth look whiter or darker to a degree, but with this setup we insured all the tooth (and the shade samples) were taking in the same lightening to get the most accurate results.

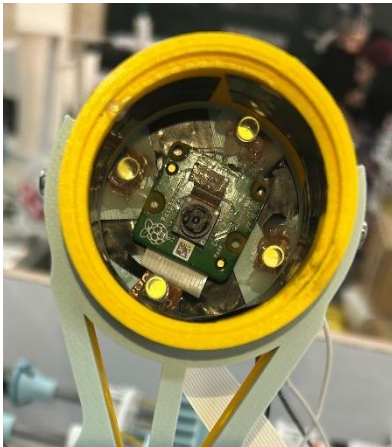


Figure 3: LEDs setup



Figure 2: printed cone

The vita shade guide we used to get the color samples:



Figure 4: VITA shade guide

- Raspberry Pi 4

We used the Ras Pi 4 controller to control the camera and the image processing code that was writing with python, then after running the code and take the picture it was responsible for sending a serial signal to the Arduino with the selected shade's symbol to start the dispensing process.



Figure 5:Raspberry Pi 4

- Arduino Mega

We used the Arduino as the main controller of the system, it was connected to all the motors' drivers and to all the sensors and the LCD besides the Bluetooth module for the app and the raspberry through serial connections. It had the sequence code that received the signal of the shade to start and checked for cups and tube emptiness before starting the dispensing process. We couldn't have achieved all this with a controller with less pins because the project used almost of the Mega's pins.

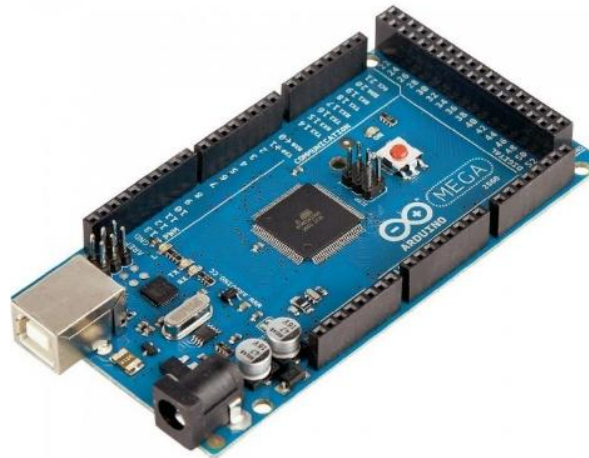


Figure 6:Arduino Mega

- Stepper motors and L298N Drivers

We used Nema 17 stepper motors to control the movements of the gears for all the parts of the systems, we had 7 motors: 1 for the cup dispensary, 1 for the belt, 1 for the selection gear, 13 for the composite tubes fillings, and 1 for the cutting wire. Each one was connected with an L298N driver that connected to the Arduino for control. Due to the need of many drivers we opted for a simple one which made us cautious in use so we implemented a sleep order for each driver after its movement so it wouldn't heat up (as these drivers tend to do, and larger drivers are usually used with the stepper motor we have).



Figure 7: Stepper motor



Figure 8: L298N Driver

- Tubes of composite shades

We collaborated with the faculty of dental medicine in our university and they gave us the tubes (besides the VITA shade guides and the teeth model) and we placed those on a gear each in a place with its own degree of movement, we insured the gear's home position with a sensor, and we printed costume lids for them to keep them closed yet allow them to open when selected seamlessly.

Figure 9: Tubes lids

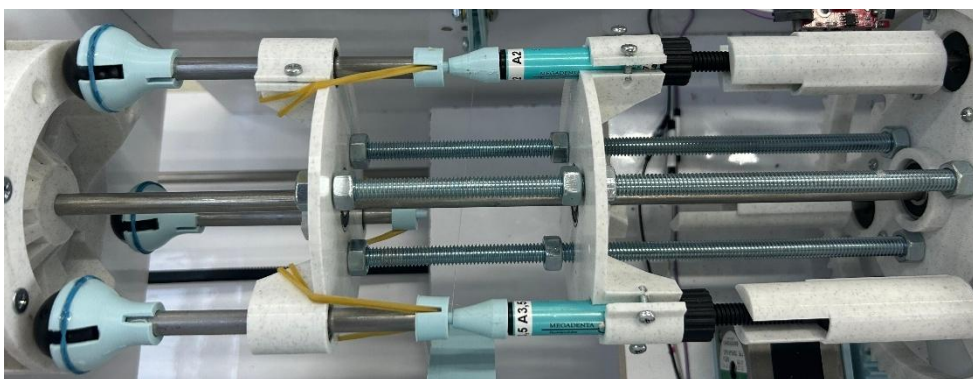


Figure 10: Shade tubes

- Hall-effect sensors

We used hall effect sensors to get the homing position of the cup dispensary, the belt, and the selection gear. The sensor senses magnets so we glued magnets on the positions we want to consider “home positions” and read its value to base our logic and functionality off of it, it was connected to the Arduino.

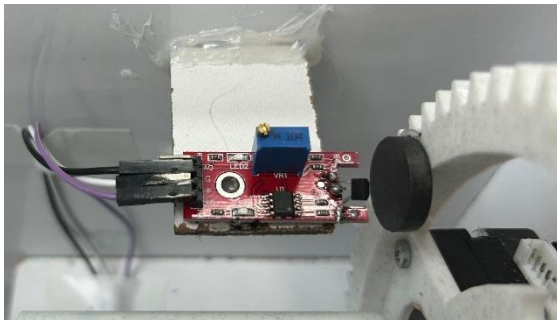


Figure 12:sensor with magnet

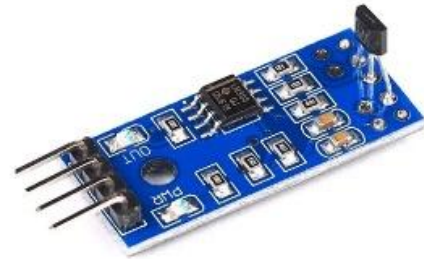


Figure 11:hall effect sensor

- LCD and buzzer

We used a 16x2 LCD to display notifications to the doctor, as it was connected to the Arduino and displayed text in many cases such as : when there are no cups left, when a tube is empty (with instructions on how to reset the device after replacing it), and when the cup of material has reached the end and is ready for pick up (while displaying the shade selected for confirmation).

We also used a buzzer to for sound notification and to grab the attention of the doctor.

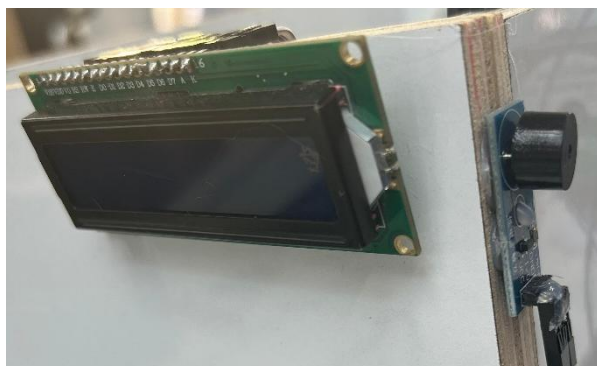


Figure 13: Notification system

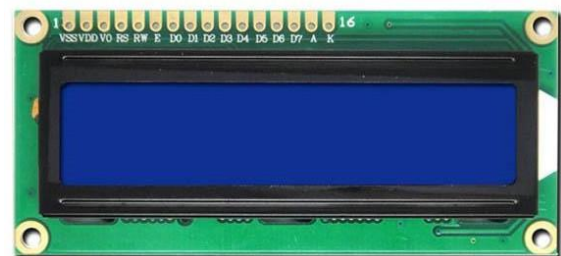


Figure 14:LCD



Figure 15:buzzer

- HC-05 Bluetooth module

We connected the Bluetooth module to the Arduino so the doctor can connect to it and run the app on his phone and send signals to the device to control it remotely.

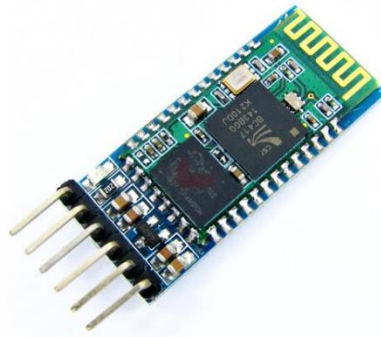


Figure 16:Bluetooth module

Software Application

We created an app using App Inventor that allows the doctor to pick a shade and the device will start and give it this shade, if he wants more material or if he was in a hurry and knew the shade and just wanted a certain material. We also allowed him to reset the tubes counter after replacing them by entering 'X' on the app and then selecting the shade he replaced its empty tube.



Figure 19:App1



Figure 18:App2



Figure 17:App3

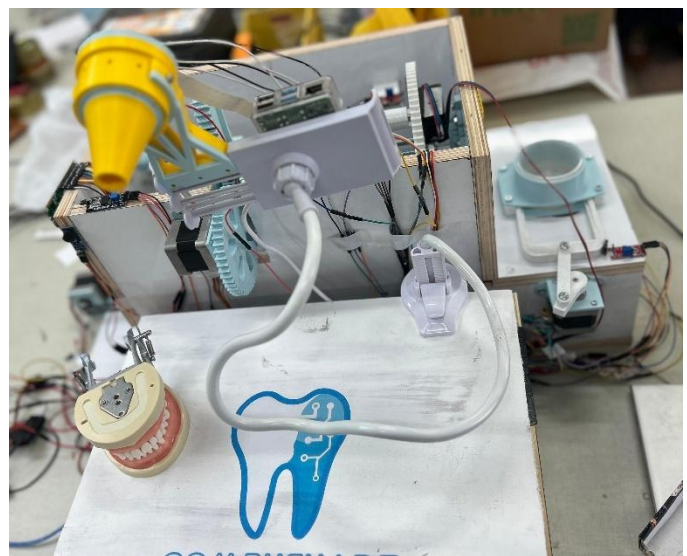
Results and conclusions

The developed dental composite shade selection and dispensing system successfully achieved its core objectives, demonstrating both technical feasibility and clinical usefulness.

Through the integration of a Raspberry Pi-based image processing module and an Arduino-controlled mechanical dispensing mechanism, the device was able to:

- Capture high-quality images of a patient's tooth using a Raspberry Pi camera.
- Accurately analyze tooth color and match it with VITA shade samples taken under identical lighting and camera conditions.
- Reliably control a stepper motor-driven mechanism to dispense the correct shade of composite material into a hygienic cup.
- Notify the dentist via an LCD screen and buzzer when the material is ready or when supplies (cups or tubes) run low.
- Allow remote interaction through a mobile application, enabling shade re-dispensing or tube resets without the need to retake images.

This project delivers a practical and innovative solution to a long-standing problem in restorative dentistry. By combining computer vision, embedded systems, and mechanical automation, the device enhances the speed, accuracy, and convenience of dental composite selection and preparation — ultimately improving both clinician workflow and patient outcomes.



Future work

While the project met its primary goals, several improvements and extensions can be made to enhance its functionality, usability, and scalability.

1. Improved Color Calibration and Lighting Control

Adding a dedicated ring light or color calibration reference card during image capture can improve accuracy further and reduce dependency on ambient lighting. Future versions can include automatic white balance adjustment or real-time lighting correction using software.

2. Expanded Shade Database and AI-Based Matching

The current system uses direct RGB distance matching. Integrating more advanced machine learning models (e.g., k-NN, SVM, or CNNs) trained on labeled tooth images could improve robustness across lighting conditions and tooth surface variations. Additionally, supporting custom shade libraries used by specific clinics can increase adoption.

3. Real-Time Feedback and Adjustment

Introducing a feedback loop that allows the dentist to confirm or override the selected shade before dispensing could make the system more interactive and flexible.

4. Improved Mechanical Design

While functional, the dispensing mechanism can be optimized for reliability and hygiene — for instance, switching to modular, disposable nozzles or implementing automatic self-cleaning. A more compact and enclosed design would also be more suitable for clinical environments.