Compact Hospital Intelligent Robotic Operation Navigator (CHIRON)

Final Report

ESSE 3380 - Introduction to Mechatronics

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Team 2

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Executive Summary

This report presents the final design, implementation and validation of our autonomous hospital pill delivery robot developed for ESSE 3380, CHIRON. The goal of this project was to design a compact and fully autonomous system capable of navigating a simulated hospital environment. CHIRON is expected to interpret medication requirements and reliably deliver the correct pillboxes to designated patient rooms without any human intervention.

CHIRON navigates using a line following strategy along a predefined corridor while detecting room branches and identifying medication indicators through onboard sensors. Once a delivery decision is made by the On-Board Computer (OBC), the system activates a mechanically indexed dispensing mechanism based on a lug conveyor design. This conveyor system enables controlled and sequential movement of pillboxes ensuring that only one pillbox is released at a time. This approach provides a simple but effective solution to one of the most critical challenges of the project; consistency and accuracy.

The overall system is composed of three tightly integrated subsystems. The electromechanical subsystem includes drivetrain, structural chassis and final design and integration of a lug conveyer based dispensing mechanism. The circuit subsystem handles sensor interfacing and power distribution ensuring stable and protected operation of all components. The microcontroller subsystem manages navigation logic, decision making process and real time control of actuators using sensor inputs. Integration of these subsystems was a major focus of the project and required several design iterations to achieve reliable performance.

Testing demonstrated that CHIRON was able to follow the path and detect delivery zones under controlled conditions. However, consistent and accurate pill deployment was not reliably achieved due to issues such as sensitivity to lighting conditions and positioning errors during dispensing which affected overall system performance.

Despite these challenges, the project successfully demonstrated the integration of mechanical design, electronics and control systems into one single autonomous platform. The results highlight key areas for improvement particularly in the reliability and robustness of sensor feedback and power allocation.

Overall, CHIRON represents a meaningful step towards autonomous medication delivery systems. The final design reflects the complexity of real world systems integration and emphasizes the importance of iterative testing, debugging and refinement in engineering design. A photograph of the final prototype is shown below.

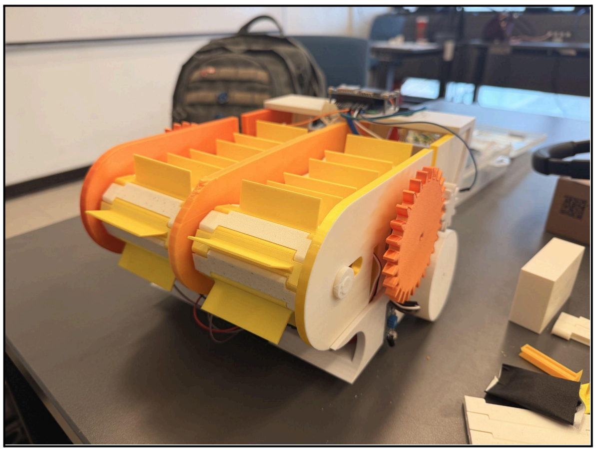

Figure 1: Final Robot Prototype

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Table of Acronyms:

Symbol / Abbreviation	Meaning
(T)	Torque (Nm)
(r)	Radius (m)
(m)	Mass (kg)
PWM	Pulse Width Modulation
FSM	Finite State Machine
ESP32	Microcontroller used for system control
GPIO	General Purpose Input/Output
I2C	Inter-Integrated Circuit communication protocol
DC Motor	Direct Current Motor
COM	Center of Mass
LiPo	Lithium Polymer Battery
SDA	Serial Data Line (I2C communication)
SCL	Serial Clock Line (I2C communication)
H-Bridge	Circuit used to control motor direction
TRIG	Trigger signal for ultrasonic sensor
ECHO	Echo signal for ultrasonic sensor
PWM Duty Cycle	Percentage of time a signal is active (used for control)

Summary of Contributions

Table 1: Table of Contributions

Name	Role	Contribution
Sarthak Sahai	Electro Mechanical	- Designed chassis, drivetrain and lug conveyor dispensing mechanism - Evaluated multiple concepts (carousel, pusher, gravity-fed) and selected final design - Developed CAD models ensuring compactness and structural integrity - Designed conveyor links and sprocket interface from scratch - Performed torque, load distribution and stability calculations - Led fabrication and mechanical assembly of all components - Integrated DC motors (drivetrain) and servo-driven conveyor system - Identified and resolved alignment, tolerance and mechanical issues - Redesigned chassis and components during integration phase - Conducted mechanical testing and implemented design improvements
Riyaz Alli	Micro Controller	- Developed navigation logic for autonomous line-following - Implemented color detection and decision-making algorithms - Designed control architecture and system state logic - Programmed actuator control for DC motors and servo system - Integrated sensor inputs for real-time navigation decisions - Refined timing and synchronization between subsystems - Debugged control logic during subsystem and system testing - Supported system integration and coordinated with mechanical and circuit subsystems - Optimized code for improved consistency and performance - Contributed to system testing and iterative refinement - Integrated sensors and actuators with the microcontroller system - Tested and debugged sensor and actuator performance - Contributed to iterative improvements during integration and refinement phases
Ashkan Abbasinia	Circuits	- Designed the H-bridge and calculated the resistor values for controlling the DC brushed motor. - At the start Design out what sensors, power needs and electrical parts we required. - During the concept phase I checked if the sensors were compatible and what their signal needs were. - Planned out the wiring. How we would distribute power. - Built the H-bridge on a breadboard. Tested it to see if it worked. - Built and designed the H-bridge circuits wired the system and connected the sensors. - Set up the power distribution. Made sure the voltage was regulated. - I finished designing the H-bridge circuits. Tested them with a Teensy to control direction. - Checked the sensor outputs. Made sure the wiring connections were correct. - Fixed issues with the subsystems. - Solved wiring problems. Made sure the signals were transmitted clearly during integration. I made the power stable and reduced electrical noise during system testing. - I made the wiring more reliable and the connections stable, during final optimization. - Helped integrate the system and contributed to the final validation.

Acknowledgements

The team would like to extend our sincere and heartfelt gratitude to Professor Michael Bazzocchi for providing us with the opportunity to take on this project and for his continued guidance throughout the course. His teaching, feedback and encouragement played a significant role in shaping our approach to engineering design and problem-solving. This project challenged us in ways that went beyond the classroom, and we are truly appreciative of the opportunity to apply theoretical concepts to a hands-on, real-world inspired system.

We would also like to express our appreciation to Ian Tomaszewski for his support and assistance during the development of the CHIRON system. His willingness to help troubleshoot issues, provide technical guidance and facilitate access to tools and resources was invaluable, particularly during critical stages of fabrication and integration. His support allowed us to move forward when facing challenges that would have otherwise slowed our progress.

In addition, we would like to thank the Lassonde School of Engineering for providing access to the facilities, equipment and collaborative workspace required to complete this project. Having a dedicated space to design, build and test our system made a significant difference in our ability to iterate on our design and work effectively as a team.

We would also like to acknowledge campus security for their support in allowing us access to lab spaces during extended hours, including weekends. While this may seem like a small detail, it played an important role in helping us stay on track with our timeline and continue working through tight deadlines. Their cooperation did not go unnoticed and is genuinely appreciated.

Finally, we would like to thank each member of our team for their persistence, effort and commitment throughout the duration of the project. This process involved numerous challenges, particularly during integration and testing, but the team continued to adapt, problem-solve and push forward. The ability to work through setbacks and continue improving the system reflects the collective dedication of the team, and we are proud of what we were able to accomplish together.

Figure 2: Final Robot Prototype with team

1.0 Introduction

1.1 Purpose of the Report

The full design, implementation, and validation of CHIRON (Compact Hospital Intelligent Robotic Operation Navigator), an autonomous robotic system created for ESSE3380, are presented in this report. Through thorough engineering study, subsystem integration, and experimental validation, this research aims to show how the suggested conceptual design has been successfully transformed into a fully functional robotic system. The whole development process, including system architecture, design choices, fabrication and performance assessment is documented in the paper.

1.2 Problem Context

Automation is being used more and more in modern healthcare settings to lower staff workloads, increase efficiency and decrease human error. Delivery of medication to patient rooms is a time-sensitive and recurring task. The necessity for a dependable and inexpensive autonomous system that can deliver pillboxes in a controlled indoor setting is addressed by this project.

The robot must follow a predetermined route that depicts a hospital hallway, recognize room branches, use sensors to recognize medicine signs, and precisely distribute the appropriate pillbox when needed. Sensing, control, and actuation systems must be integrated to solve this issue in order to provide accurate operation under limited circumstances and real-time decision-making.

1.3 Scope of Work

The design, development and testing of an autonomous mobile robot that can deliver pillboxes are all included in the project's scope. The final design incorporates several subsystems such as:

- Sensor systems for line tracking and colour detection (Circuits)
- Actuation systems for mobility and dispensing (Electro-Mechanical)
- And, Embedded control logic for navigation and decision-making (Microcontroller)

This report covers system-level design, detailed subsystem specifications, integration procedures and performance validation. Design limitations, trade-offs and potential improvements are also discussed.

1.4 Report Organization

This report is organized to clearly present the development and evaluation of the CHIRON system. Section 2 defines the problem formulation including key design specifications and constraints. Section 4 provides a detailed description of the system design covering both the overall architecture and individual subsystem specifications. Section 4 outlines the project management approach including task distribution and scheduling. Section 5 presents the project budget and section 6 summarizes the main conclusions, lessons learned and potential areas for future development.

2.0 Problem Formulation

2.1 Problem Definition

This project's goal is to develop and deploy an autonomous robotic system that can dispense pillboxes in a hospital simulation. The robot must precisely enter each delivery zone, recognize room branches, and navigate across a predetermined route using line-following algorithms.

The robot must recognize a colour-coded indicator (red, blue, or none) at each room in order to decide whether to deliver a pillbox. The system must use this input to dispense precisely one pillbox of the appropriate type or, in the absence of an indicator, do nothing. All deliveries must be made by the robot on its own, and it must stop working at the specified finish station.

This problem requires the integration of sensing, control, and actuation systems to ensure reliable navigation, accurate detection and consistent dispensing performance.

2.2 Design Constraints

The design of the CHIRON system is constrained by several physical, operational and safety requirements that define the feasible design space and influence key engineering decisions. The robot must operate within a 50 cm × 50 cm × 50 cm volume and a total cost of CAD $300, limiting overall size, component selection, and mechanical complexity.

The system must function fully autonomously, with all sensing, processing and actuation performed using onboard hardware and power. This places constraints on power management, computational capability and system reliability.

Operational and safety requirements must also be satisfied. The robot must be capable of rapid setup and include an accessible emergency stop mechanism to immediately halt all motion, ensuring safe and reliable operation.

These constraints directly influenced the design approach, leading to the use of compact components and controlled mechanical systems, such as the lug conveyor, to balance performance with simplicity and reliability.0

2.3 Design Requirements

The robotic system must satisfy a set of functional and performance requirements to achieve the project objectives. Functionally, the robot must autonomously navigate the corridor, detect and enter room branches, identify delivery zones, and interpret colour-coded medication indicators. Based on this input, the system must determine whether a delivery is required and dispense exactly one pillbox of the appropriate type. The robot must initiate operation upon user input and terminate in a final standby state after completing all tasks.

From a performance perspective, the system must operate reliably under varying environmental conditions, including changes in lighting that may affect sensor accuracy. The robot must maintain sufficient positional accuracy to ensure correct pill placement within delivery zones and complete all required tasks within the specified time constraints. Consistent performance across multiple runs is essential for validating system reliability.

These requirements define the expected behaviour and performance of the CHIRON system and serve as the basis for subsystem design and integration.

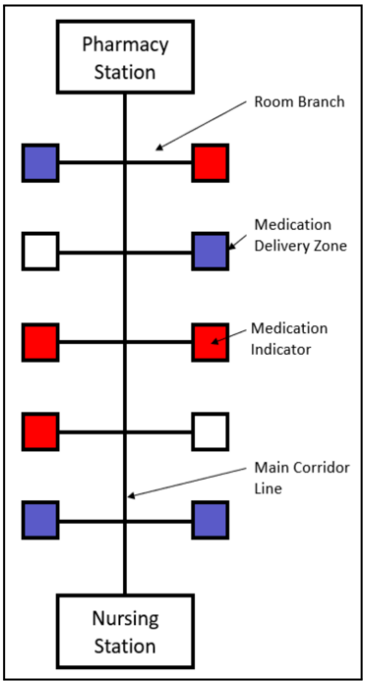

Figure 3: Simulated Hospital Corridor Layout

2.4 Additional Design Features

In addition to the core system requirements, several additional design features were implemented to align with the bonus performance criteria outlined in the design brief. These features focus on improving system feedback, usability and overall performance.

Display-based functionality was incorporated to provide real-time feedback on system operation. The robot was designed to indicate medication dispensing status, track the total number of pillboxes correctly delivered and display which rooms received a delivery. In addition, the system records and reports total operation time, providing useful insight during testing and performance evaluation.

Design considerations were also made to improve compactness and portability. The system was developed within a constrained footprint and was designed to fit within a 25 × 25 × 25 cm^3 envelope, with careful component placement to minimize overall size while maintaining functionality. This contributes to easier handling, improved portability and more efficient use of space.

Finally, emphasis was placed on system elegance and integration. The robot was designed to operate smoothly with minimal unnecessary complexity, resulting in a cleaner mechanical layout and more stable overall behaviour.

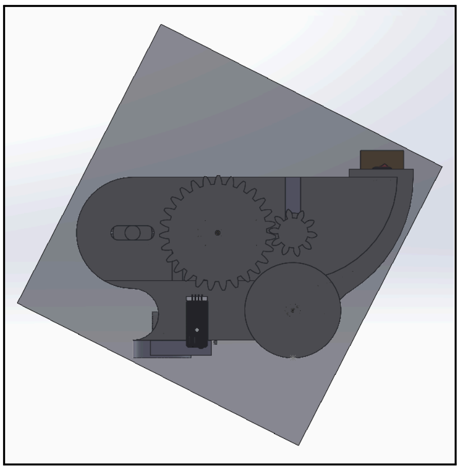

Figure 4: CHIRON in the $25cm^3$ Envelope

These additional features extend the CHIRON system beyond basic functionality, demonstrating improved feedback capability, usability and design efficiency within the given project constraints.

3.0 Background

Autonomous mobile robots are widely used in structured indoor environments to perform repetitive tasks with high precision and consistency. In healthcare settings, automation is increasingly adopted to reduce staff workload, improve reliability and minimize human error. Tasks such as medication delivery are well suited for automation due to their repetitive nature and the need for dependable operation.

Line-following is a commonly used navigation method in such environments due to its simplicity and reliability. Infrared (IR) reflectance sensors allow robots to detect contrast between a predefined path such as black tape and the surrounding surface. This approach provides a low-cost and effective solution for corridor-based navigation.

Color detection is another key capability for decision-making. RGB sensors enable the system to distinguish between basic colors such as red and blue, allowing the robot to interpret environmental cues without complex image processing. This simplifies system design while maintaining sufficient accuracy for determining delivery requirements.

Differential-drive systems are widely used for mobility due to their mechanical simplicity and ease of control. Independent control of the left and right wheels allows the robot to move forward, turn and accurately align itself, which is essential for navigating corridors and entering room branches.

For dispensing mechanisms, simple mechanical systems are often preferred in low-cost robotic designs to reduce complexity and improve reliability. These systems must ensure controlled single-item release while minimizing the risk of jamming or misalignment. Achieving consistent and accurate dispensing remains a key challenge, particularly when precise positioning and timing are required. The CHIRON robot addresses this by implementing a lug conveyor-based dispensing mechanism, designed to provide indexed and sequential movement of pillboxes for controlled release.

Overall, the combination of line-following navigation, color-based decision-making, differential-drive locomotion and simple dispensing mechanisms represents a proven approach for autonomous delivery systems in structured environments. The CHIRON system builds upon these established methods with a focus on controlled dispensing through a lug conveyor mechanism.

4.0 System Design Specifications

4.1 System-Level Description

4.1.1 System Overview

The CHIRON system is a compact autonomous mobile robot designed to deliver pillboxes within a structured indoor environment. The system integrates sensing, control and electromechanical subsystems to enable fully autonomous operation without external input.

At a system level, the robot navigates a predefined path using line-following sensors while detecting room branches and delivery zones. A color detection sensor is used to interpret medication indicators and determine whether a delivery is required. Based on this input, the system either dispenses a pillbox or continues navigation.

The circuit subsystem is responsible for interfacing sensors and providing real-time environmental data, including line position and color detection. The electromechanical subsystem enables physical motion and controlled pillbox dispensing through the drivetrain and lug conveyor mechanism. The microcontroller coordinates these subsystems by processing sensor inputs and executing the required control actions.

Through integration of these subsystems, the robot continuously senses, processes and responds to its environment in real time. The design emphasizes simplicity, reliability and effective coordination between mechanical and control systems within the given constraints.

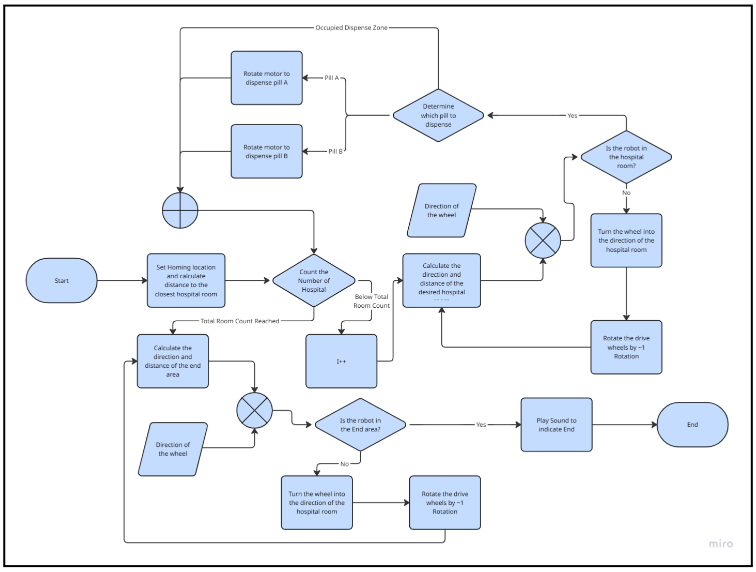

Figure 5: High Level System Architecture Design

4.1.2 Functional Description

The CHIRON system operates through a sequence of autonomous actions to complete pillbox delivery within the simulated hospital environment. The robot begins in a standby state and initiates operation upon user input.

Once activated, the robot follows the main corridor using line-following sensors to track a predefined path. As it navigates the environment, it continuously monitors for room branches and delivery zones. When a branch is detected, the robot adjusts its motion to enter the room and position itself within the designated delivery zone.

At each delivery zone, the system reads the color-coded medication indicator to determine whether a delivery is required. If a valid indicator is detected, the robot activates the dispensing mechanism to release exactly one pillbox of the appropriate type. If no indicator is present, the robot performs no action and resumes navigation.

After completing the required action, the robot exits the delivery zone and continues along the main corridor to service the next room. This process repeats until all required deliveries are completed or the operation time limit is reached.

Upon completion, the robot returns to the designated end position and enters a final standby state, indicating that all tasks have been completed.

4.1.3 Operational Procedure

The operation of the CHIRON system follows a defined procedure to ensure safe and consistent performance during testing. Prior to operation, the robot is placed at the designated start position behind the pharmacy or nursing station line. The system is powered on and checked to ensure all components are functioning correctly. Any required setup, including alignment with the line and loading of pillboxes, is completed within the allowed setup time.

Once the system is ready, the operator initiates the run using the designated start input. After activation, the robot operates fully autonomously. Two DC motors drive the robot’s movement along the corridor, while servo motors control the rotation of the track mechanism used to move the lug conveyor for pill dispensing.

During operation, the robot continuously navigates the corridor, detects delivery zones and performs pillbox delivery without user intervention. At each delivery zone, the system determines whether a delivery is required and activates the dispensing mechanism accordingly.

At the end of the run, the robot returns to the designated end position and enters a stationary standby state to indicate completion. The emergency stop can be activated at any time to immediately halt system operation. The system is then powered off and prepared for the next run if required.

4.2 Subsystem Specifications

4.2.1 Microcontroller Subsystem

As the CHIRON robotic system's central control unit, the microcontroller subsystem is in charge of processing sensor inputs, carrying out decision-making logic, and producing control signals for each actuator. The ESP32-WROOM-based microcontroller used in the system was chosen due to its high processing power, several GPIO interfaces, and interoperability with a variety of sensors and actuators.

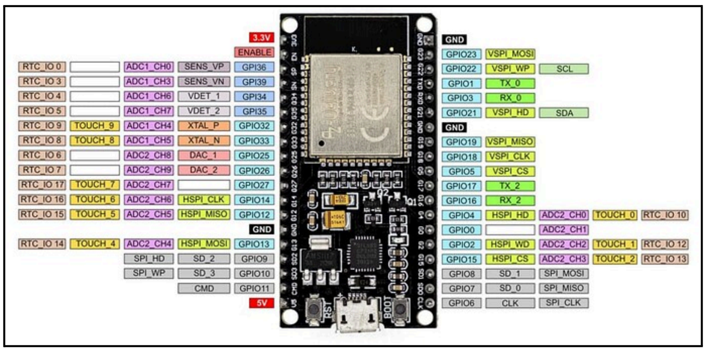

Figure 6: Pin Diagram of the ESP-WROOM-32

The ESP32 has the digital and analog input/output capacity to communicate with the infrared line sensors, color detecting sensor, motor drivers, and dispensing mechanism. The TCS34725 color sensor (GPIO 21 and 22) is communicated using the I2C protocol, while the IR line-following and intersection sensors are read via digital input pins. The dispensing system's motor speed, direction, and servo positioning are all controlled by pulse-width modulation (PWM) outputs.

Control Strategy and Software Architecture

The robot can move between specified operational modes in an organized and predictable way thanks to the control system's implementation of a finite state machine (FSM) architecture. Line following, branch detection, dispensing, and going back to the main hallway are some of these states. This method makes troubleshooting and testing during integration easier while guaranteeing consistent system behavior.

Navigation, sensing, actuation, and state management are divided into discrete functional blocks inside the software's modular design. Prior to complete system integration, different subsystems can be built and tested separately thanks to this structure, which also enhances code clarity. Future scalability and simpler troubleshooting are also supported by the modular design.

Sensor Processing and Decision Logic

To choose the proper system reaction, the microcontroller continually analyzes and interprets sensor inputs in real time. While the colour sensor offers input for deciding whether to dispense a pillbox, infrared sensors are employed to detect the robot's position in relation to the path and identify intersections. Positioning and environmental awareness are supported by ultrasonic sensors.

The system may determine whether to proceed with navigation, enter a room, or turn on the dispensing mechanism by interpreting sensor data using predetermined logic conditions. The ESP32 uses these choices to produce control signals that modify motor speeds and start dispensing operations when necessary.

User Interface

Basic UI elements are included in the microcontroller subsystem to facilitate system monitoring and operation. A digital input with an internal pull-up resistor is used to implement a start/stop button, guaranteeing dependable activation and avoiding accidental triggering. In order to give real-time feedback on operational status, including system activity and performance during testing, the system additionally makes use of an integrated OLED display.

Task Scheduling

The system uses a continuous loop-based scheduling technique in which tasks are carried out one after the other in a cycle that repeats. After gathering sensor data, control actions are carried out and the state is assessed. This method keeps navigation, sensing, and dispensing activities synchronized while guaranteeing real-time responsiveness.

I/O Constraints and Resource Utilization

All of the sensors and actuators in the CHIRON system are supported by the ESP32's many GPIO pins. However, during implementation, several hardware limitations were taken into account. Since pins 34 through 39 are input-only, they were set aside for sensor inputs. While I2C communication for the color sensor was restricted to specific pins, PWM-capable pins were needed for motor and servo control. The ESP32 was able to support all necessary functions without going over its allotted resources in spite of these limitations.

Failure Modes and Limitations

A number of microcontroller subsystem limitations and failure scenarios were discovered during testing. Line-following performance became variable due to sensor noise, especially when the surface conditions changed. Medication indicators were often misinterpreted because of the color detection system's sensitivity to ambient lighting. Additionally, synchronization was impacted by timing discrepancies between sensor processing and actuator response, which resulted in slight variations in system behavior. These drawbacks show that future iterations must include better filtering, calibration, and timing optimization.

Validation and Testing

Both full-system and subsystem-level testing were used to validate the microcontroller subsystem. To ensure proper operation, individual parts, such as motors, actuators, and sensors, were first tested separately. During full-system testing after integration, the ESP32 successfully coordinated duties related to navigation, sensing, and dispensing. Although the system's general performance was dependable, certain irregularities were noted as a result of sensor and mechanical constraints.

Table 2: ESP32 Pin Mapping for CHIRON System

Subsystem	Component	Signal / Function	ESP32 Pin	Notes
Motor Driver	Left Motor	ENA (PWM)	GPIO 25	Speed control
Motor Driver	Right Motor	ENB (PWM)	GPIO 26	Speed control
Motor Driver	Left Motor	IN1	GPIO 27	Direction
Motor Driver	Left Motor	IN2	GPIO 14	Direction
Motor Driver	Right Motor	IN3	GPIO 13	Direction
Motor Driver	Right Motor	IN4	GPIO 23	Direction
Dispensing System	Main Servo	PWM	GPIO 18	Pill dispensing
Dispensing System	Gate Servo	PWM	GPIO 19	Secondary mechanism
User Interface	Start/Stop Button	Digital Input	GPIO 4	INPUT_PULLUP (toggle control)
Line Sensors	Front Left IR	Digital Input	GPIO 34	Line tracking
Line Sensors	Front Right IR	Digital Input	GPIO 35	Line tracking
Intersection Detection	Side Left IR	Digital Input	GPIO 36	Branch detection
Intersection Detection	Side Right IR	Digital Input	GPIO 39	Branch detection
Ultrasonic Sensor	Front Sensor	TRIG	GPIO 17	Distance
Ultrasonic Sensor	Front Sensor	ECHO	GPIO 5	Distance
Ultrasonic Sensor	Secondary Sensor	TRIG	GPIO 32	Distance
Ultrasonic Sensor	Secondary Sensor	ECHO	GPIO 33	Distance
I2C Bus	Color Sensor (TCS34725)	SDA	GPIO 21	I2C
I2C Bus	Color Sensor (TCS34725)	SCL	GPIO 22	I2C

Microcontroller	Built-in OLED	Internal	N/A	Integrated on ESP32

4.2.2 Circuits Subsystem

The circuits subsystem of CHIRON is responsible for all electrical interfacing between sensors, actuators, and the microcontroller, as well as power distribution and signal conditioning. This subsystem was designed and implemented to ensure reliable communication between components and stable operation under real-world conditions.

4.2.2.1 Open-Circuit Motor Driver (H-Bridge)

A key requirement of the project was the design and construction of at least one open circuit motor driver using discrete components. To satisfy this requirement, a dual H-bridge circuit was designed using TIP120 and TIP125 Darlington transistors to independently control the direction of the two DC drive motors.

The H-bridge configuration uses four Darlington transistors per motor (two TIP120 NPN and two TIP125 PNP) arranged in a standard H topology, as shown in Figure below. The TIP120 and TIP125 were selected for their high current capability (5A continuous, 60V rating) and high DC current gain (β = 1000), which allows direct control from ESP32 GPIO pins (3.3V logic) without additional driver ICs. Each PNP transistor base is driven through a two 1kΩ current-limiting resistor to protect the GPIO pins while providing sufficient base current to saturate the transistor.

Figure 7 & 8: H-Bridge schematic design.

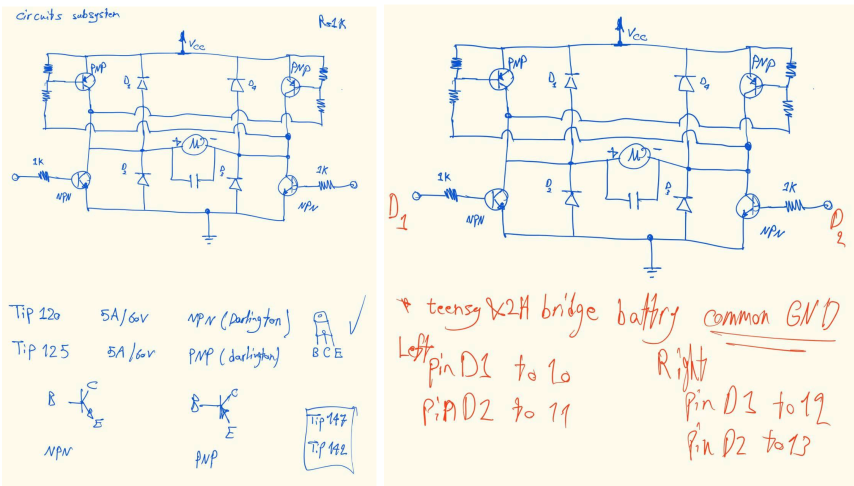

Figure 9 & 10: H-Bridge open circuit Grounding and connection Configuration.

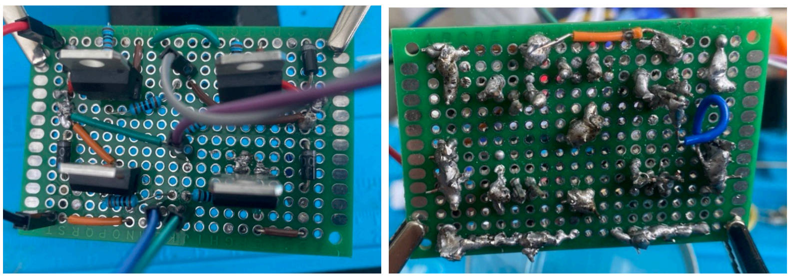

Table 3: H-Bridge Control Truth Table

IN1	IN2	Motor State
HIGH	LOW	Forward
LOW	HIGH	Reverse
LOW	LOW	Coast (Free Run)
HIGH	HIGH	Dynamic Braking

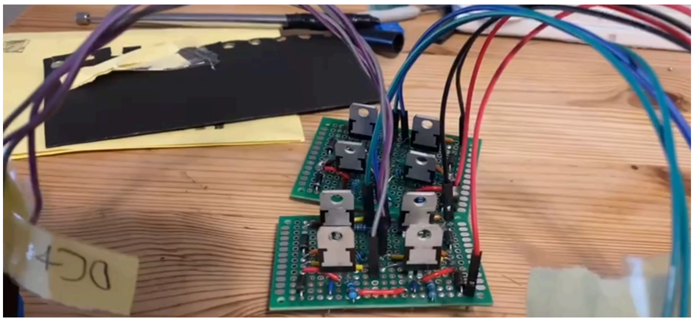

Figure 11: Right and Left H-bridge configuration.

Circuit Topology:

• Left Motor: Controlled by GPIO 27 (IN1) and GPIO 14 (IN2)

• Right Motor: Controlled by GPIO 13 (IN3) and GPIO 23 (IN4)

Flyback Protection: Each motor terminal is protected with Schottky diodes (SS34) connected to VCC and GND to suppress back-EMF spikes generated during PWM switching, preventing damage to the transistors.

PWM Speed Control: Motor speed is controlled using PWM signals from GPIO25 (ENA-left motor) and GPIO26 (ENB-right motor) connected to the enable lines of the H-bridge.

ESP32 generates 20kHz PWM signals with 8-bit resolution (0-255) for smooth velocity control during line following and turning maneuvers.

This open-circuit design provides a complete, transparent implementation of motor control that was fully tested and validated before integration into the final robot.

4.2.2.2 Sensor Interfacing and Signal Conditioning

Bottom IR Sensors (2 units): Mounted on the underside of the chassis facing downward. These sensors detect the black tape line on the white corridor surface. Both sensors are used simultaneously for line tracking: when the robot drifts offcenter, the difference in reflected IR signal between the left and right bottom sensors is used by the microcontroller to adjust motor PWM outputs and steer back onto the path. This differential line-following approach proved more robust than single-sensor or array-based methods under varying lighting conditions.

Side IR Sensors (2 units): Mounted on the left and right sides of the chassis at approximately 45-degree angles. These sensors detect room branches by sensing the reflective tape or markers placed at corridor intersections. When a side sensor detects a branch, the robot initiates a turn sequence to enter the room.

Each IR sensor operates at 5V and provides a digital output (HIGH/LOW) based on reflected IR light. Sensor outputs are connected to ESP32 digital input pins with 1kΩ series resistors and 0.1μF capacitors to ground forming a low-pass filter (cutoff frequency = 1.6kHz) to attenuate high-frequency noise from motor drivers.

Color Sensing (TCS34725): The color sensor communicates with the ESP32 via the I2C protocol (SDA => GPIO 21, SCL => GPIO 22) at 100kHz. The sensor is powered from a clean 3.3V rail via a dedicated linear regulator with 22nF and 0.1μF ceramic filtering capacitors. To minimize ambient light interference, the sensor was mounted within a 3D-printed ABS light shield with internal baffles. A white LED integrated into the sensor module provides consistent illumination during color readings. The ESP32 reads normalized RGB ratios and applies threshold values to distinguish red, blue, or no indicator.

4.2.2.3 Power Distribution and Regulation

The power distribution system was designed to isolate noisy motor power from sensitive logic and sensor supplies, using a 2S LiPo battery (7.4V nominal, 3000mAh).

Table 4: Power Distribution table

Power Rail	Voltage	Components	Regulator
Motor Power	5-6 V	H-bridge, DC motors	LM2596 buck converter
Servo Power	5 V	Dispensing servos	LM2596 buck converter
Logic Power	5 V	IR sensors	LM2596 buck converter
MCU Power	3.3V	ESP32, TCS34725	ESP32 built-in (from 5V to 3.3V)

Power Rails:

• Motor Power (5V direct): Supplied directly from the 2S LiPo battery through a Buck converter fuse and emergency stop switch to the H-bridge motor driver. Filtered with 470uF polymer capacitor and 0.1uF ceramic bypass capacitor.

• Servo Power (5V): Regulated using an LM2596 buck converter (7.4V to 5V, 2A).

• Sensor & Logic Power (5V): LM2596 buck converter steps down 7.4V to 5V to power all four IR sensors (2 bottom + 2 side) and the TCS34725 color sensor.

• Microcontroller Power (3.3V): The Waveshare ESP32 board includes an onboard 3.3V voltage regulator. The board accepts 5V input from the LM2596 buck converter and regulates it down to 3.3V for the ESP32 chip.

Grounding Strategy: A multi point grounding scheme was implemented with separate analog, digital, and power ground planes connected through 0Ω resistors to minimize ground loops and reduce electrical noise coupling between subsystems.

Emergency Stop and Safety: An emergency stop switch (SPDT toggle) is wired in series with the main battery power to the motor driver and servos, providing a hardware-level cutoff of all actuators. The ESP32 remains powered to maintain state, but motion is immediately halted when the E-stop is engaged.

4.2.3 Electromechanical Subsystem

The electromechanical subsystem of the CHIRON system is responsible for enabling physical interaction with the environment through mobility, structural support and controlled pillbox dispensing. This subsystem integrates the drivetrain, chassis structure and a lug conveyor based dispensing mechanism to achieve both navigation and delivery functionality within a compact design.

Several dispensing concepts were explored during the design process before finalizing the lug conveyor mechanism. A carousel-based approach was initially considered due to its ability to store multiple pillboxes in a compact circular arrangement. However, this design was not pursued due to the concentration of load at a single rotational axis, which introduced structural stress concerns and required a more robust support system than permitted within the size and weight constraints.

A linear pusher mechanism was also evaluated as a simple method for dispensing pillboxes. While this approach offered straightforward actuation, it required stacking pillboxes vertically, which resulted in a higher center of mass and reduced system stability. This increased the risk of tipping during motion, particularly when entering room branches, making it unsuitable for the application.

Additionally, a gravity-fed dispensing system was considered due to its simplicity and minimal actuation requirements. However, this approach lacked precise control over individual pillbox release and was prone to multiple items being dispensed unintentionally, reducing overall reliability.

Based on these evaluations, the lug conveyor mechanism was selected as it provides controlled, sequential movement of pillboxes while maintaining a lower center of mass and more uniform load distribution. Although this design introduces greater mechanical complexity and sensitivity to alignment, it offers improved dispensing control compared to the alternatives.

The overall mechanical layout of the robot is shown in Figure 9. The system adopts a differential-drive configuration powered by two DC motors, allowing independent control of the left and right sides of the robot. This configuration was selected due to its simplicity, ease of control and suitability for navigating structured environments such as corridors and room branches. The drivetrain directly drives the robot's wheels, enabling forward motion, turning and positioning within delivery zones.

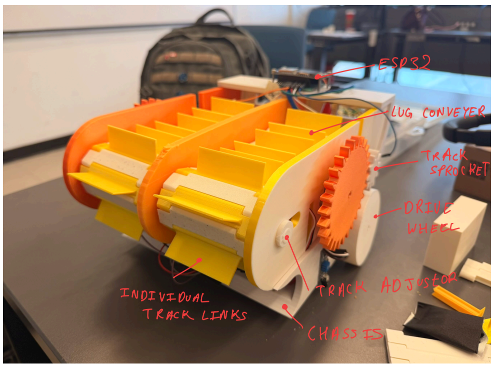

Figure 9: CHIRON Electro-mechanical Parts Labelled

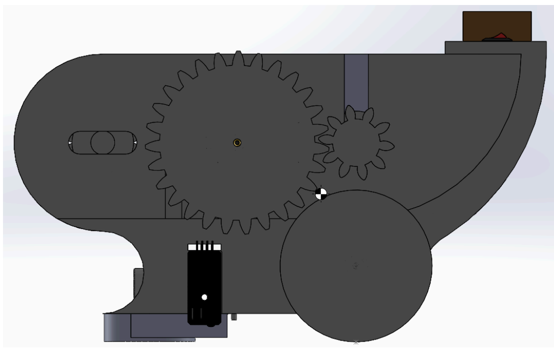
Figure 10: Center of Mass for CHIRON

The pillbox dispensing mechanism is independent of the drivetrain and is based on a lug conveyor system, as shown in Figure 9. This mechanism uses a servo-driven rotating track to move pillboxes in discrete steps toward a release point. The track in this context functions solely as part of the dispensing system and is not involved in robot locomotion. This separation of mobility and dispensing simplifies system design and allows independent control of movement and pill deployment.

The structural design of the chassis was developed to support all subsystems while maintaining compactness and manufacturability. Components were arranged to achieve a low and centrally located center of mass, as illustrated in Figure 10. As shown, the center of mass lies between the castor wheels and the drive wheels preventing rearward tipping during acceleration. The battery and motors were positioned near the base of the robot to reduce tipping moments during acceleration and turning. Mass distribution was approximated based on component weights, ensuring stable dynamic behaviour during operation.

The pillbox storage and deployment mechanism is based on a lug conveyor system, shown in Figure 9. This mechanism uses a servo-driven rotating track to move pillboxes in discrete steps toward a release point. The spacing and geometry of the lugs were designed to match the dimensions of the pillboxes, ensuring controlled movement while minimizing friction and interference. This approach allows for sequential single-item dispensing and reduces the likelihood of multiple releases compared to passive systems.

The lug conveyor system was designed from the ground up, including the individual links and the sprocket/spindle interface responsible for driving the mechanism. The link geometry was developed to securely carry pillboxes while maintaining consistent spacing for indexed movement. As shown in Figure 11, key dimensions such as link pitch, thickness and overall geometry were selected to match the size of the pillboxes, ensuring stable transport while minimizing interference and friction.

The sprocket and spindle were designed to engage directly with the conveyor links, with tooth spacing aligned to the defined pitch to ensure smooth motion and consistent indexing. The overall geometry of the link and its integration within the conveyor system are further illustrated in Figure 12.

From a manufacturing perspective, the links were fabricated using 3D printing, enabling rapid iteration and refinement of geometry. However, limitations in dimensional accuracy introduced small variations in pitch and alignment, which contributed to inconsistencies in conveyor motion observed during testing.

These results highlight the importance of precise geometry and tight tolerances in achieving reliable indexing and consistent pillbox dispensing.

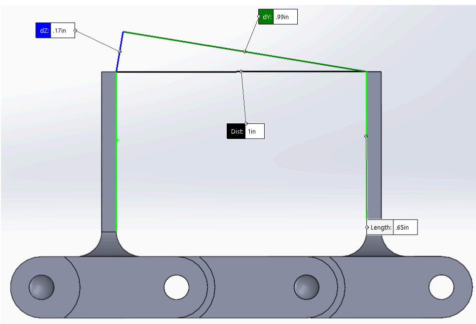

Figure 11: Spacing between Track Links

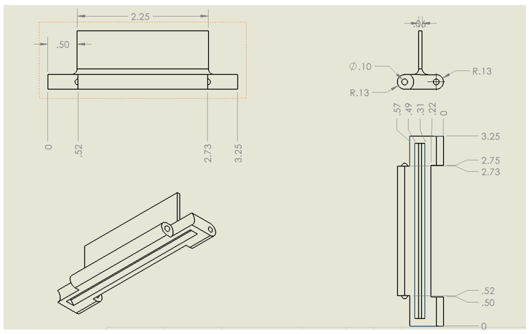

Figure 12: Engineering drawing for track link

The sprocket driving the lug conveyor was designed using standard gear relationships to ensure proper engagement with the conveyor links. A configuration of 10 teeth with a diametral pitch of 7 was selected, resulting in a pitch diameter of approximately 1.43 inches and a circular pitch of 0.449 inches. The circular pitch represents the arc distance between adjacent teeth along the pitch circle and was used to define the linear spacing between conveyor links. By matching the link pitch to the sprocket circular pitch, the system achieved consistent indexing and controlled sequential advancement of pillboxes. The larger pitch spacing also improved tolerance to manufacturing variation in the 3D printed components, reducing sensitivity to minor dimensional errors and helping maintain more reliable engagement during operation. This design choice was particularly beneficial given the fabrication constraints and observed alignment challenges during testing.

From an actuation perspective, DC motors were selected for mobility due to their continuous rotation capability and sufficient torque output for driving the robot. To ensure reliable motion, the required wheel radius and corresponding torque were determined based on the total system weight, including the chassis, conveyor system and pillboxes, as well as estimated frictional losses at the wheel surface interface. As shown in Figure 13, Using T=F*r the required torque was estimated based on system weight and wheel radius to ensure sufficient traction.

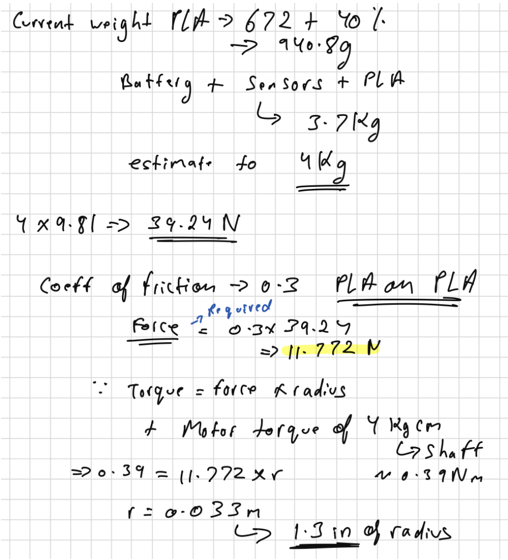

Figure 13: Torque Calculations

The selected wheel dimensions were chosen to balance torque requirements and mobility, allowing the motors to overcome rolling resistance while maintaining controllable speed. However, variations in load distribution and surface conditions occasionally affected performance, highlighting the sensitivity of the system to torque estimation and the importance of efficient power transmission in mobile robotic systems.

Mechanical performance is influenced by frictional losses within the navigation system and conveyor mechanism. While the conveyor track enables controlled dispensing, they also introduce additional resistance, which affects efficiency. Alignment and tolerance also play a critical role in system performance. Small misalignments in the conveyor and dispensing interface resulted in inconsistent pill release during testing, highlighting the importance of tight tolerances and precise assembly.

From a fabrication perspective, the system was designed for ease of manufacturing using 3D-printed components and off-the-shelf hardware. This approach supports rapid prototyping and iterative design but introduces limitations in dimensional accuracy and structural rigidity. These factors contributed to variability in mechanical performance.

During testing, key challenges were observed in the dispensing mechanism. Inconsistent conveyor indexing, combined with alignment errors and servo variability, resulted in unreliable pill release. These issues represent the primary risk to system performance and highlight the sensitivity of the design to mechanical tolerances and actuation accuracy.

To mitigate these issues, future improvements would focus on improving alignment through tighter tolerances, refining the conveyor geometry and incorporating more precise actuation or feedback mechanisms. These modifications would significantly enhance dispensing reliability and overall system performance.

Table 5: Risk Mitigation Strategies for Electro-Mechanical

Risk / Challenge	Cause	Impact on System	Mitigation Strategy	Future Improvement
Conveyor misalignment	3D printing tolerances and assembly error	Inconsistent or failed pill dispensing	Improve assembly precision and alignment during fabrication	Use higher precision manufacturing or guiding rails

Inconsistent indexing of lug conveyor	Servo positioning variability and link geometry errors	Multiple or missed pill releases	Refine link geometry and calibrate servo actuation	Implement feedback control (encoder or limit detection)
Friction in conveyor system	Contact between links and structural components	Increased load and reduced efficiency	Reduce contact surfaces and optimize spacing between links	Use low-friction materials or bearings
High sensitivity to tolerances	Small dimensional variations in printed parts	Reduced repeatability across runs	Tighten tolerances and improve CAD accuracy	Transition to machined or higher-quality printed parts
Load distribution variability	Uneven mass placement during operation	Affects drivetrain performance and stability	Centralize mass and maintain low center of mass	Further optimize component placement
Structural flex in 3D printed parts	Material limitations of PLA components	Misalignment and reduced mechanical reliability	Reinforce critical load-bearing components	Use stronger materials or hybrid construction

Overall, the electromechanical subsystem demonstrates a functional and integrated design that satisfies mobility and dispensing requirements within the given constraints. While limitations were observed, the design provides a strong foundation for further refinement and optimization.

4.3 Integration and Testing

4.3.1 Integration Process

The integration of the CHIRON system involved combining the electromechanical, circuit and microcontroller subsystems into a single functional platform. Integration was performed in stages to ensure that individual subsystems were operating correctly before full system assembly.

Initial integration focused on the drivetrain, where DC motors and motor drivers were connected to the microcontroller and tested for basic motion control. Following this, the line-following sensors were integrated and calibrated to ensure reliable detection of the predefined path.

The dispensing subsystem was integrated separately, with servo motors connected to the microcontroller and tested for controlled actuation of the lug conveyor mechanism. Once individual subsystems were verified, full system integration was performed, combining navigation, sensing and dispensing into a unified control sequence.

During integration, individual modules such as motor control, sensor reading and servo actuation were first tested independently to verify correct functionality. These modules were then combined into a unified control system, where timing and sequencing became critical. Particular attention was given to ensuring that navigation, decision-making and dispensing actions were properly synchronized, as delays or misalignment in control signals could result in incorrect behaviour.

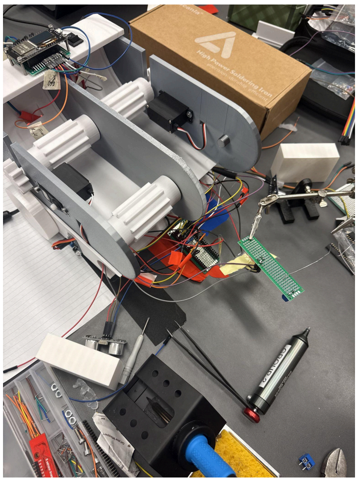

Figure 14: CHIRON during Final integration

Several iterations of code refinement were required to address issues such as inconsistent sensor readings, timing delays and actuator response. This process highlighted the importance of robust control logic and effective communication between software and hardware components in achieving reliable system performance.

Throughout the integration process, several iterations were required to resolve issues related to signal timing, sensor noise and mechanical alignment. Integration challenges primarily arose from the interaction between subsystems, particularly the synchronization of navigation and dispensing actions.

4.3.2 Testing Procedures

Testing of the CHIRON system was conducted in a controlled environment designed to replicate the simulated hospital corridor. A predefined track with clearly marked delivery zones and color-coded indicators was used to ensure consistency across test runs. The robot was placed at a fixed starting position for each trial to maintain repeatability and allow for direct comparison between runs.

Testing was divided into subsystem-level and full-system evaluations. Subsystem testing was first carried out to validate individual components before integration. This included verifying DC motor functionality and drivetrain response, calibrating line-following sensors for accurate path detection and evaluating servo actuation for the lug conveyor mechanism. These tests ensured that each subsystem operated as intended under isolated conditions.

Following subsystem validation, full-system testing was performed to evaluate overall system performance. During these tests, the robot executed its complete operational sequence, including line following, branch detection, color recognition, decision-making and pillbox dispensing. Multiple runs were conducted to assess repeatability and identify inconsistencies in behaviour.

To further evaluate system robustness, testing conditions were varied by introducing changes in environmental lighting and minor variations in track alignment. These variations were used to assess the sensitivity of the sensors and control logic to real-world disturbances. Key performance metrics recorded during testing included successful path tracking, accuracy of delivery zone detection, correctness of dispensing decisions and consistency of pillbox release.

Observations were documented for each test run, with particular attention given to failure modes such as missed detections, incorrect dispensing and mechanical misalignment. This structured testing approach allowed for identification of both subsystem-specific and system-level issues, providing valuable insight into overall system performance and reliability.

4.3.3 Performance Results

The performance of the CHIRON system was evaluated based on its ability to successfully complete navigation and dispensing tasks during full-system testing. Results indicate that the system was able to achieve consistent line-following behaviour and detect room branches with reasonable reliability under controlled conditions.

The robot demonstrated stable navigation along the predefined path, with the differential-drive system providing sufficient control for forward motion and turning. In most test runs, the robot was able to correctly identify delivery zones and position itself within the required area. This indicates that the integration of line-following sensors and control logic was effective for basic navigation tasks.

However, the performance of the dispensing mechanism was less consistent. While the lug conveyor system was capable of advancing pillboxes toward the release point, reliable single-item dispensing was not consistently achieved. Issues such as misalignment between the conveyor and release point, variability in servo positioning and inconsistencies in indexing resulted in occasional failed or incorrect deliveries.

Sensor performance also exhibited limitations under varying environmental conditions. Changes in lighting affected the accuracy of the color detection system, leading to occasional misinterpretation of medication indicators. These errors impacted the decision-making process and contributed to incorrect dispensing behaviour in some test runs.

Overall, the system demonstrated partial success, with strong navigation performance but limited reliability in dispensing and sensor-based decision-making. These results highlight the importance of precise mechanical alignment, robust sensor calibration and accurate actuation control in achieving consistent system performance.

4.3.4 Design Changes and Improvements

Based on testing results, several design changes and improvements were identified to enhance the performance and reliability of the CHIRON system. These changes focus on improving consistency and stability, particularly within the circuit subsystem, which was found to be a major limiting factor in overall system performance.

A primary area for improvement is the quality of electrical connections and wiring throughout the system. Inconsistent or unstable connections introduced variability in signal transmission between sensors, the microcontroller and actuators. This resulted in unreliable sensor readings and inconsistent actuation behaviour. Improving wiring practices, including secure connections, proper routing and strain relief, would significantly enhance system stability.

Power distribution was also identified as a key limitation. Fluctuations in voltage supply and uneven power delivery affected both sensor accuracy and actuator performance. To address this, improved power regulation and distribution methods are required, including the use of dedicated voltage regulators, proper grounding and decoupling components to reduce electrical noise.

Signal integrity within the circuit subsystem can be further improved through basic signal conditioning techniques. Implementing filtering methods and ensuring stable communication between components would reduce the impact of noise and improve reliability of sensor data.

In addition to circuit-level improvements, refinements to system synchronization were identified. Variability in signal timing affected coordination between sensing, decision-making and actuation. Adjusting control logic to better account for these delays would improve consistency during operation.

Overall, these improvements highlight the importance of robust electrical design and reliable signal transmission in mechatronic systems. Addressing these issues would significantly improve system performance without requiring major changes to the mechanical design.

5.0 Project Management

5.1 Design Process

The design process for the CHIRON system followed a structured and iterative approach, progressing through concept development, subsystem design, prototyping, integration and testing. This approach allowed for continuous refinement of the system based on observed performance and identified limitations.

The initial phase focused on problem definition and requirement analysis, where key functional and performance constraints were identified. Based on these requirements, multiple design concepts were generated for both the mobility and dispensing subsystems. Several dispensing mechanisms, including carousel-based, linear pusher and gravity-fed designs, were evaluated before selecting the lug conveyor mechanism due to its ability to provide controlled and sequential pillbox delivery.

Following concept selection, subsystem design was carried out in parallel. The electromechanical subsystem involved chassis modeling, drivetrain configuration and development of the conveyor mechanism. The circuit subsystem focused on sensor interfacing, power distribution and wiring design, while the microcontroller subsystem involved implementation of navigation logic and actuator control.

Prototyping and initial testing were conducted to validate subsystem functionality before full integration. During this phase, issues related to mechanical alignment, sensor accuracy and signal stability were identified. These findings informed subsequent design refinements.

During the integration phase, several challenges arose that required significant modifications to the original design. These included changes to the chassis layout, redesign of individual mechanical components and adjustments to subsystem placement to improve stability and integration. These changes were necessary to address issues such as poor alignment, unstable electrical connections and interference between components. As a result, the design evolved beyond the initial concept to better meet system requirements and improve overall performance.

Final stages of the design process focused on system-level testing and refinement. Observed performance issues led to targeted adjustments in control logic, mechanical alignment and circuit stability. This iterative process highlights the importance of testing and adaptability in the development of complex mechatronic systems.

Overall, the design process reflects a practical engineering workflow, where design decisions were continuously evaluated, revised and improved to achieve the best possible system performance within the given constraints.

5.2 Task Breakdown

The development of the CHIRON system was organized through a structured division of tasks across the three primary subsystems: electromechanical, circuit and microcontroller. Each team member was assigned responsibility for a subsystem, with clearly defined tasks to ensure accountability and steady progress throughout the project.

Tasks were planned to align with key project phases, including design, prototyping, integration and testing. While subsystem development was carried out independently during early stages, later phases required significant collaboration between team members, particularly during integration and debugging. This ensured that interactions between hardware and software components were properly addressed.

The task breakdown also evolved over time as challenges arose during development. Adjustments were made to task allocation and priorities, especially during integration, where additional effort was required to resolve issues related to wiring, power distribution and synchronization between subsystems.

Table 6: Original Distribution of Tasks

Phase	Timeline	Subsystem	Task Description	Team Member
Project Initiation	Week 1	All	Project kickoff and requirement analysis	All
Project Initiation	Week 1	Microcontroller	Define control system architecture and logic flow	Riyaz
Project Initiation	Week 1	Circuits	Design H-bridge schematic calculation of resistors, Identify sensors, power requirements and electrical components	Ashkan
Project Initiation	Week 1	Electromechanical	Define mechanical constraints and overall robot layout	Sarthak
Concept	Week 1–2	Electromechanic	Evaluate dispensing concepts (carousel, pusher,	Sarthak

Development		al	gravity-fed, conveyor)	
Concept Development	Week 1–2	Microcontroller	Develop preliminary navigation and decision-making logic	Riyaz
Concept Development	Week 1–2	Circuits	Assess sensor compatibility and signal requirements	Ashkan
Concept Development	Week 1–2	All	Select final system architecture and design approach	All
Planning	Week 2	Electromechanical	Create initial CAD models of chassis and drivetrain	Sarthak
Planning	Week 2	Circuits	Plan wiring layout and power distribution scheme, Implement H-bridge in Bread board and test operation	Ashkan
Planning	Week 2	Microcontroller	Define software structure and state machine logic	Riyaz
Planning	Week 2	All	Finalize design proposal and procurement plan	All
Procurement	Week 2–3	Circuits	Order sensors, wires, connectors and power components	Ashkan
Procurement	Week 2–3	Electromechanical	Order motors, structural components and hardware	Sarthak
Procurement	Week 2–3	All	Verify component compatibility and availability	All
Subsystem Development	Week 3–5	Electromechanical	Fabricate chassis using 3D printing	Sarthak
Subsystem Development	Week 3–5	Electromechanical	Design and assemble lug conveyor and link system	Sarthak
Subsystem Development	Week 3–5	Circuits	Start building Both H-bridge open circuits, build wiring system and integrate sensor connections	Ashkan
Subsystem Development	Week 3–5	Circuits	Implement power distribution and voltage regulation	Ashkan
Subsystem Development	Week 3–5	Microcontroller	Implement line-following algorithm	Riyaz
Subsystem Development	Week 3–5	Microcontroller	Implement color detection and control logic	Riyaz
Subsystem Testing	Week 5–6	Electromechanical	Test drivetrain motion and mechanical stability	Sarthak
Subsystem Testing	Week 5–6	Circuits	Completing both H-Bridge circuit design & Test direction control with teensy. Test sensor outputs and verify wiring connections	Ashkan
Subsystem Testing	Week 5–6	Microcontroller	Test sensor input processing and actuator control	Riyaz
Subsystem Testing	Week 5–6	All	Debug subsystem-level issues	All
Subsystem Evaluation	Week 6	All	Evaluate subsystem performance and identify limitations	All
Integration	Week 6–7	All	Integrate mechanical, electrical and software subsystems	All
Integration	Week 6–7	Circuits	Resolve wiring issues and stabilize signal transmission	Ashkan
Integration	Week 6–7	Microcontroller	Refine control logic for synchronization	Riyaz
Integration	Week 6–7	Electromechanical	Adjust mechanical alignment and subsystem placement	Sarthak
System Testing	Week 7	All	Perform full system testing and evaluate	All

			performance	
System Testing	Week 7	Microcontroller	Adjust timing and improve decision-making logic	Riyaz
System Testing	Week 7	Circuits	Improve power stability and reduce electrical noise	Ashkan
System Testing	Week 7	Electromechanical	Refine conveyor alignment and mechanical reliability	Sarthak
Final Optimization	Week 7–8	All	System optimization and robustness testing	All
Final Optimization	Week 7–8	Circuits	Improve wiring reliability and connection stability	Ashkan
Final Optimization	Week 7–8	Microcontroller	Optimize code for consistent system behaviour	Riyaz
Final Optimization	Week 7–8	Electromechanical	Final adjustments to structure and component mounting	Sarthak
Finalization	Week 8	All	Design review and final system validation	All
Finalization	Week 8	All	Final report writing and submission	All

The project was completed over an approximately 8-week period, with parallel subsystem development and a compressed integration phase that required rapid iteration to address system-level challenges.

5.3 Project Schedule

The project schedule for the CHIRON system was structured over an approximately 8-week period and is illustrated in the Gantt chart in Figure 15. The schedule was divided into key phases, including project initiation, concept development, design and planning, subsystem development, integration and final system testing. This phased approach ensured that progress was organized and aligned with major project milestones.

As shown in Figure 15, the early stages of the project focused on requirement analysis and concept evaluation, where multiple design alternatives were explored before finalizing the system architecture. This was followed by a planning phase that included design finalization and component procurement, ensuring that all necessary resources were available before development began.

Subsystem development was carried out in parallel across the electromechanical, circuit and microcontroller subsystems to maximize efficiency within the limited timeline. This phase included fabrication, wiring and software implementation, and represents the longest portion of the schedule. Following this, a dedicated subsystem testing phase was included to verify individual component performance before full system integration.

The integration phase marked a critical milestone in the project, where all subsystems were combined and tested as a unified system. As indicated in the Gantt chart, this phase required additional time for debugging and redesign due to challenges related to wiring reliability, power distribution and synchronization between subsystems. These challenges necessitated iterative adjustments to both hardware and software components.

The final stages of the schedule focused on integrated system testing, optimization and final validation. This included refining system performance, improving robustness and preparing for final demonstration and report submission. Overall, the schedule reflects a structured yet adaptable approach, where planned milestones were maintained while allowing flexibility to address unforeseen challenges during integration and testing.

Figure 15: Gantt Chart for Project Milestone Tracking

5.4 Challenges and Mitigation

Throughout the development of the CHIRON system, several challenges were encountered that impacted system performance and required iterative problem-solving. These challenges were primarily associated with circuit reliability, system integration and mechanical precision, highlighting the complexity of coordinating multiple subsystems within a constrained timeline.

A major challenge identified during integration and testing was related to the circuit subsystem, particularly wiring quality and electrical connections. Inconsistent or unstable connections resulted in unreliable signal transmission between sensors, the microcontroller and actuators. This led to variability in sensor readings and inconsistent actuation behaviour, which directly affected system performance. To mitigate this issue, improved wiring practices such as secure connections, better cable management and proper routing are recommended to ensure stable and reliable signal transmission.

Power distribution was also a significant challenge. Variations in voltage supply and electrical noise affected both sensor accuracy and actuator response, particularly during simultaneous operation of multiple components. These issues can be mitigated through improved power regulation, proper grounding techniques and the use of filtering components to reduce electrical noise and stabilize the system.

System integration presented additional challenges, particularly in synchronizing sensing, decision-making and actuation. As shown in the Gantt chart in Figure 19, the integration phase required additional time due to debugging and redesign efforts. Delays in signal processing and inconsistencies in actuator response led to misalignment between the robot's position and the intended dispensing action. Refining control logic and improving communication between subsystems would help improve synchronization and overall system performance.

Mechanical challenges were primarily related to alignment and tolerance within the dispensing mechanism. While the lug conveyor system provided controlled pill movement under ideal conditions, small variations in assembly and component fit affected repeatability. These issues can be mitigated through tighter tolerances, improved assembly practices and refinement of component geometry.

Overall, the challenges encountered emphasize the importance of robust electrical design, precise mechanical integration and effective system coordination in mechatronic systems. The mitigation strategies identified provide a clear pathway for improving system reliability, consistency and overall performance in future iterations of the CHIRON robot.

6.0 Budget

The final cost of the CHIRON system was evaluated based on the components used in the final competition prototype. The design was developed under a budget constraint of CAD $300, requiring careful selection of cost-effective components while maintaining system performance and reliability. Table 7 presents the detailed bill of materials for the system.

Table 7: Final System Budget for CHIRON

Component	Quantity	Unit Cost (CAD)	Total Cost (CAD)	Supplier / Source	Subsystem
PLA Filament	1	17.99	20.33	https://a.co/d/09XwhqTv	Mechanical / Fabrication
DC Motors (x2)	1	15.39	17.39	https://a.co/d/05dLdQpk	Navigation
Servo Motors (×2)	1	31.34	35.41	https://a.co/d/00aKPg60	Dispensing System
E-Stop Toggle Switch (SPDT)	1	1.29	1.46	CanadaRobotix	Safety
ESP32 Waveshare (ESP32-WROOM)	1	18.99	21.46	Amazon	Control System
2S LiPo Battery (3000mAh)	1	21.34	24.11	Crazepony	Power System
JST-XH Connectors	1	8.99	10.16	Amazon	Power Distribution
MP1584 Buck Converter	1	6.99	7.90	Amazon	Power Regulation
Bottom IR Sensors	2	3.00	6.78	AliExpress / Amazon	Line Tracking
Side IR Sensors	2	3.00	6.78	AliExpress / Amazon	Intersection Detection
RGB Color Sensor (TCS34725)	1	14.99	16.94	Adafruit / Amazon	Sensing

Ultrasonic Sensors	2	4.00	9.04	Amazon	Obstacle Detection
IRLZ44N MOSFET	8	1.20	10.85	Electronics Supplier	Power Switching
PNP Transistor	2	0.80	1.81	Electronics Supplier	H-Bridge Stage
Bulk Capacitor	1	2.50	2.83	Electronics Supplier	Power Stability
Schottky Diodes	8	0.30	2.71	Electronics Supplier	Flyback Protection
Mini Caster Wheel	1	3.50	3.96	Mechanical Supplier	Mobility Support
Total			**200.92 CAD**		

7.0 Conclusion

This project presented the design, development and evaluation of CHIRON, an autonomous robotic system intended for pillbox delivery in a structured hospital environment. The system demonstrated the successful integration of electromechanical, circuit and microcontroller subsystems to achieve autonomous navigation and controlled dispensing.

While the robot was able to perform key functions such as line-following and full system integration, its overall performance was limited by challenges related to circuit reliability, signal stability and mechanical precision. Issues such as inconsistent wiring connections, power distribution instability and sensitivity to mechanical tolerances affected the consistency of system behaviour. Despite these limitations, the lug conveyor mechanism demonstrated strong potential as a controlled dispensing solution, reinforcing the effectiveness of the chosen design approach.

A major outcome of this project was the development of a deeper understanding of subsystem interaction and the challenges associated with real-world integration. The iterative design process, including significant redesign efforts during the integration phase, emphasized the importance of adaptability, testing and refinement in engineering design.

Future improvements to the CHIRON system would focus on enhancing electrical reliability through improved wiring practices and power regulation, refining mechanical tolerances to improve repeatability and optimizing control logic to ensure consistent system performance. Incorporating feedback mechanisms and more precise manufacturing methods would further improve system robustness.

Overall, this project represents a meaningful application of mechatronic design principles and provides a strong foundation for further development of autonomous delivery systems. The insights gained from this project reinforce the importance of system-level thinking in mechatronics, where electrical, mechanical and control subsystems must function seamlessly to achieve reliable autonomous performance.

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9.0 Appendices

9.1 Assigned Roles

Name	Role
Sarthak Sahai	ElectroMechanical
Riyaz Alli	Microcontroller
Ash	Circuits

9.2 Description of Roles

9.2.1 Microcontroller (Processing and Control)

One student shall be primarily in charge of developing all the software for the system. In addition to combinational and sequential logic required for the algorithms, interactions with the microcontroller (e.g., buttons, keypads, displays) is also part of this assignment. Some extra coding may also be needed for system debugging. Further utilization of the microcontroller may be needed if the team plans to accomplish some of the Extra Design Features. Generally, the microcontroller employed is expected to be an Arduino Mega; however, other microcontroller options may be considered at the instructor's discretion. It is required that the microcontroller be functional for basic design features and programmable by the subsystem evaluation, so that system integration and testing may begin right afterwards. Often integration requires additional adjustments to the microcontroller hardware and/or software.

9.2.2 Circuits (Instrumentation and Sensing)

One student shall construct all the digital and analog interfacing electronics to connect the sensors and actuators to the microcontroller board. This includes motor/solenoid driver circuits. All sensors and input/output signal calibration/protection are also part of this subsystem. In those situations where the primary calibration for a transducer is positional in nature, such as a stop switch, the task is still part of Circuit subsystem, but consultation with the Electromechanical member is advised. For the actuator drivers, the use of driver boards or driver IC's is permitted if the budget allows, but the Circuit member must design and build at least one "open" circuit (i.e., made of basic components, such as transistors, resistors, capacitors, diodes, timer chips, etc.) for a motor (DC, stepper or servo) in the final robot and prove its functionality. Shaft encoding and detection would be examples of major sensory tasks of this subsystem, in addition to the driver circuits and cabling. The circuit member shall also complete wiring the robot and acquire suitable power supplies for the actuators, circuits, sensors, and the microcontroller.

9.2.3 Electromechanical (Mechanisms and Actuation)

One student shall be primarily responsible for constructing the platform, structure and frames and incorporating whatever actuators and mechanisms are required in the system. Major components of the Electromechanical subsystem can include: mobile platform, structure and frames, deployment mechanisms, and mounting sensors, microcontroller, and keypad/LCD. Some off-the-shelf mechanisms or platforms can be used for the above-mentioned components, but this must be clearly addressed in the proposal and authorized by the instructor. In addition to design and analysis of these components, their fabrication and/or assemblage as well as assigning the locations of the sensors and boards are also parts of the Electromechanical subsystem. Although integration of the entire system might seem as a “mechanical” task by nature, all members of the team should equally and effectively take part in the integration process.

9.3 Additional Links

This section of the report is a collection of links and resources that are referenced throughout the document.

9.3.1 Interactive 3D model of the Rotating Carousel

https://app.shapr3d.com/v/Ni6uJwZseCvuOgpmntsGN

9.3.2 CHIRON Gantt Chart

https://script.google.com/macros/s/AKfycbyxvv5sj0MBz7zhn16C2cACsiQozvMsi_O9B0W7k5uRsvFelmia/exec?id=1yz19uHCtgHdf72_nywnuu8Klg76nHE9oPWt5jh4Sv7Q

9.4 Requirements

9.4.1 Functional Requirements

Table 9: Functional Requirements Table

Requirements ID	Requirements Description	Rational
Func.1	The robot shall autonomously navigate to the hospital rooms	Required for navigation within the simulated hospital environment
Func.2	The robot shall detect the medication delivery zone at the end of each room branch	Required to locate and identify the delivery position
Func.3	The robot shall identify the medication indicator (Red, Blue or none) within the delivery zone.	To determine the pillbox type to be delivered or a no delivery condition
Func.4	The robot shall decide whether the room already has a medicine	Prevents incorrect deployment (overdose case)
Func.5	The robot shall dispense exactly one pillbox per room	Core objective
Func.6	The robot shall enter a standby state at the end of operation	Required for run completion
Func.7	The robot shall initiate operation only after the start button is pressed	Required for the operation to start

9.4.2 Performance Requirements

Table 9: Performance Requirements

Requirements ID	Requirements Description	Rational
Req.1	The robot shall correctly detect medication indicators under all lighting conditions	Ensures performance during varying light conditions
Req.2	The robot shall deploy the pillboxes within the marked deployment zone	Required for scoring
Req.3	The robot shall finish its operations under or equal to 5 minutes	Competition constraint
Req.4	The robot shall be able to operate several times without losing accuracy	Required for qualification and scoring across multiple runs
Req.5	The robot shall navigate and stop at the end station	Required for run qualification

9.4.3 Physical and Operational Constraints

Table 10: Physical and Operational Constraints

Requirements ID	Requirements Description	Rational
PNO.1	The robot shall fit within a 50cm^3 envelope	Physical constraint
PNO.2	The robot shall fit in a 50cm^3 cubic envelope	Physical Constraint
PNO.3	The total material cost shall not exceed CAD$300	Budget Constraint
PNO.4	The robot shall use an onboard power supply	Physical Constraint
PNO.5	The robot shall be fully autonomous with no external control	Competition Rule
PNO.6	The robot shall have an easily accessible E-Stop	Safety Requirement

PNO.7	The robot shall be able to be set up within 2 minutes or less	Operational Constraint
PNO.8	The robot shall clearly indicate when it has completed operations	End of run indication

9.5 Operational Flow Chart

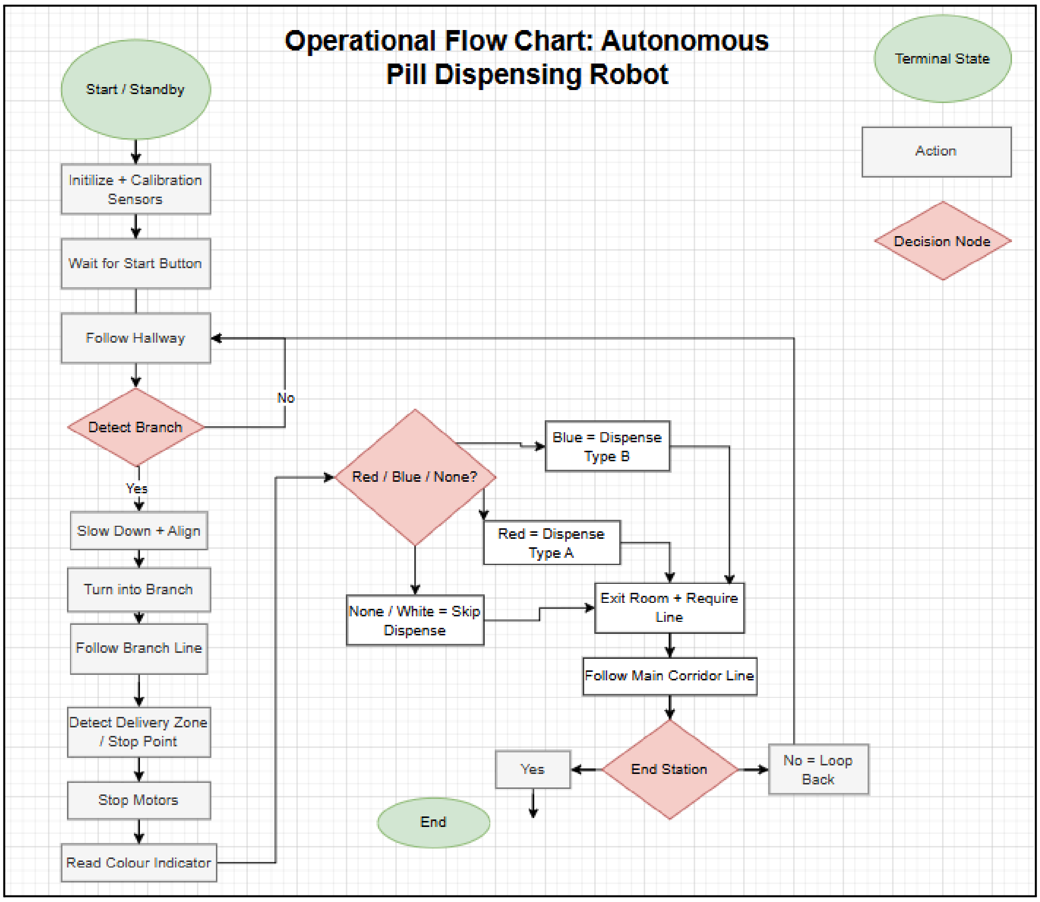


Figure 16: Operational Flow Chart

The entire process that CHIRON follows during an autonomous run is displayed in the flow chart. The ESP32 waits for the start button after calibrating the sensors. Pressing it starts the robot's main loop, which uses the QTR array to follow the corridor line while modifying the motor outputs in real time.

The robot slows down, turns into the room, and follows the branch line to the delivery zone when it detects a branch pattern. After stopping, CHIRON turns the servo to dispense the appropriate pillbox after reading the TCS34725 color sensor. Following dispensing, it heads back to the hallway and keeps going until it hits the end-station sign. After that, the robot stops and indicates that it is finished.

This flow ensures predictable behavior and clearly links each sensor reading to the correct action and state transition.

9.6 Project Timeline

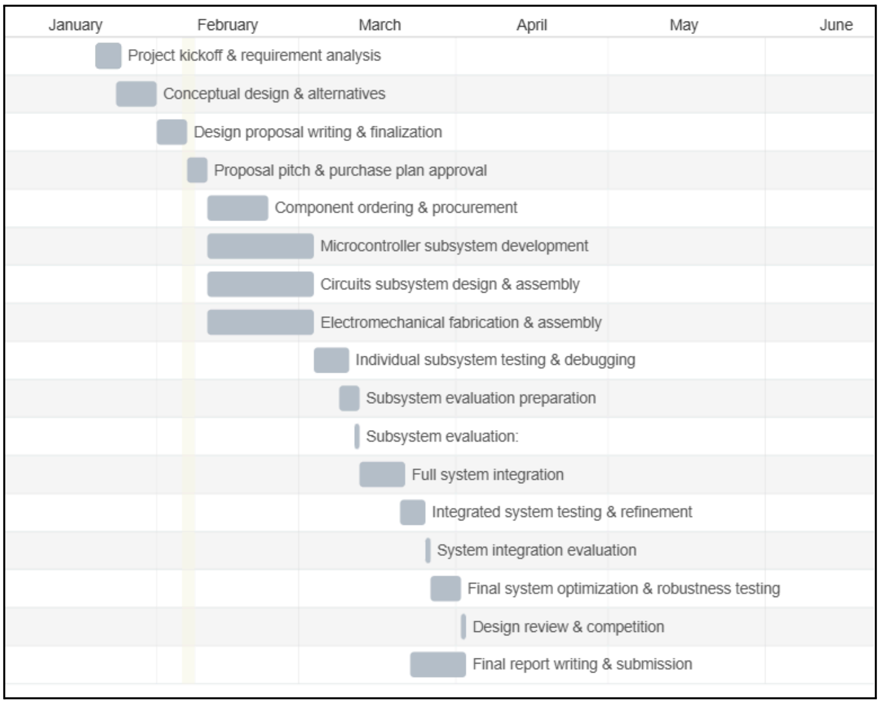


Figure 17: Gantt Chart for CHIRON

9.7 Detailed Cost Breakdown for CHIRON

Table 10: Cost Breakdown of CHIRON

Requested by	Item	Description	Quantity	Unit Price	Total Price	Link
Sarthak Sahai	PLA Filament	PLA filament needed for 3d printing functional parts such as the carousel system and related supports.	1	17.99	20.3287	https://a.co/d/09XwhqTv
Sarthak Sahai	TPU Filament	TPU filament needed for 3d printing parts like the wheels	1	21.84	24.6792	https://a.co/d/0hgFbmug
Sarthak Sahai	BLDC Motors	Required for Navigation	1	15.39	17.3907	https://a.co/d/05dLdQpk
Sarthak Sahai	Servo Motor	2x Servo motor for dispenser	1	31.34	35.4142	https://a.co/d/00aKPg60
Sarthak Sahai	Toggle SPDT switch	E-Stop	1	1.29	1.4577	https://www.canadarobotix.com/products/190
Riyaz Alli	ESP32	Main microcontroller	1	31.99	36.1487	ESP32-WRO

	Waveshare Servo Driver Board					OM
Riyaz Alli	TCS34725 Colour Sensor	Reads red/blue indicators	1	14.99	16.9387	TCS34725
Riyaz Alli	QTR-8RC Line Sensor Array	Used for line following / branch detection	1	4.84	5.4692	Line Sensor Array
Riyaz Alli	Status LEDs + Resistors	Used for status indicators	1	6.99	7.8987	LEDS + Resistor Pack
Ashkan Abbasnia	TB6612FNG Dual H-Bridge	Motor driver for DC motors	1	12.99	14.6787	TB6612FNG Motor Driver Module Dual Driver High Performance
Ashkan Abbasnia	MCP6022 Op-Amp	Current sensing amplification	4	2.79	12.6108	https://www.mouser.ca/ProductDetail/Microchip-Technology/MCP6022-I-SN?qs=cQYLKLPzRJnTeOronWtTyA%3D%3D&srsltid=AfmBOoreCkSgEThFPnmyaQR3TAZoVxyJLqasw_2j6L_eow9jTKGIQ8hP
Ashkan Abbasnia	INA219 Current Sensor	Power rail monitoring	1	21.62	24.4306	https://www.digikey.ca/en/products/detail/adafruit-industries-llc/5832/21839815?gclsrc=aw.ds&gad_source=1&gad_campaignid=17336435733&gbraid=0AAAAADrbLlhOb6JJIAHGB

						pNWfqR4_jGa3&gclid=Cj0KCQiA4pvMBhDYARIsAGfgwvyH88Yzjw3XdON_W3oJro83GaF13Mnf1FnsBK-uhJYwNHbl-mF0cHMaArLIEALw_wcB
Ashkan Abbasnia	MP1584 Buck Converter	7.4V to 5V/6V/3.3V regulation	1	6.99	7.8987	MP1584 DC-DC Step Down Power Supply Module
Ashkan Abbasnia	MT3608 Boost Converter	7.4V to12V for stepper	1	2.99	3.3787	https://www.amazon.ca/Module-Converter-3-3V-35V-Attractive-Design/dp/B09TSKDT8B/ref=asc_df_B09TSKDT8B?mcid=2150d6cd1c193ad2a93a6f9d5647291a&tag=googleshopc0c-20&linkCode=df0&hvadid=706724917107&hvpos=&hvnetw=g&hvrand=9390880420384174050&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9000945&hvtargid=pla-2488051432797&psc=1&hvocijid=9390880420384174050-B09TSKDT8B-&hvexpln=0&gad_source=

						1
Ashkan Abbasnia	2S LiPo Battery 3000mAh	Main power, 7.4V, XT30 connector	1	21.34	24.1142	Crazepony 3000mAh 2S LiPo Battery
Ashkan Abbasnia	XT30 Connectors	Battery and power connectors	1	3.62	4.0906	https://www.digikey.ca/en/products/detail/sparkfun-electronics/10474/8258064?gclsrc=aw.ds&gad_source=1&gad_campaignid=23152963569&gbraid=0AAAAADrbLlgW2Oz98OP1gk3M4hz8Z3_ZA&gclid=Cj0KCQiA4pvMBhDYARIsAGfgwvx0sBIQg0WvtQPkMuYDQVXCHAAqU3oAX3I_cY7j1RiPypINXoOlFy8aAoeREALw_wcB
Ashkan Abbasnia	JST-XH Connectors	Power distribution	1	8.99	10.1587	https://a.co/d/0a2BC9ej
Sarthak Sahai	PCB Board	For open circuits	1	11.89	13.4357	https://a.co/d/0gVPicCD
				Remaining Budget	19.4775	

9.8 Circuits Details

This section documents the open circuit H-bridge motor drivers and the fusion structure of sensors Used in the CHIRON project.

9.8.1 Open-Circuit Dual H-Bridge

The Dual H-bridge circuit contains two individual H-Bridge structures to control two separate DC brushed motors at once. Each H-bridge circuit uses four discrete Darlington transistors **(TIP120 / TIP125)** with six 1kΩ resistors and 4 flyback diodes to independently control the direction of DC Motors without jumping spikes and no over heat.

Table 11: Motor Digital pin connection to the Microcontroller.

Motor	Driver Pin	ESP32 Pin	Signal Type	Function
Left Motor	ENA	GPIO 25	PWM Output	Speed control
Right Motor	ENB	GPIO 26	PWM Output	Speed control
Left Motor	IN1	GPIO 27	Digital Output	Direction
Left Motor	IN2	GPIO 14	Digital Output	Direction
Right Motor	IN3	GPIO 13	Digital Output	Direction
Right Motor	IN4	GPIO 23	Digital Output	Direction

Table 12: Motor signal pin logic operation modes.

IN1	IN2	Motor State	Description
HIGH	LOW	Forward	Normal forward rotation
LOW	HIGH	Reverse	Reverse rotation
LOW	LOW	Coast	Motor free spins (no driving force)
HIGH	HIGH	Dynamic Braking	Motor actively resists motion

All the H-bridge electric components were soldered on the prototype PCB board (70*50mm) and Secured with fit to place next to the battery source.

9.8.2 MP1584 Buck Converter

The MP1584 steps down the 7.4V 2s Lipo to 5V for the motors, servos and sensors.

The INPUT of the Buck Converter connected to the GND of the battery and Vcc of the battery, and The emergency switch connected within the VCC of the battery and Vcc of Buck converter. And OUTPUT connected to the power rail. To power all sensors and microcontrollers.

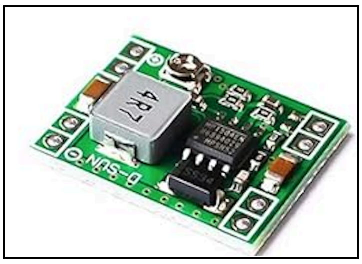


Figure 18: MP1584 Buck Converter

9.8.3 Bottom IR Sensors – 2 Units

Two individual IR reflectance sensors were mounted on the underside of the chassis to detect the black line on the white surface and allow feedback to the DC Motor direction control to correct its error offset position within the lines as follows and detect lines and intersections.

Sensors mounted approximately 11mm above the floor. Adjusted the spacing between left and right sensor to cover width of the Black Tape Line which was 40mm center to center.

Table 13: Two bottom IR Pin configuration.

Sensor Position	Sensor Type	Signal Type	GPIO Pin	Function
Front Left IR	IR Sensor	Digital Input	GPIO 34	Line tracking
Front Right IR	IR Sensor	Digital Input	GPIO 35	Line tracking

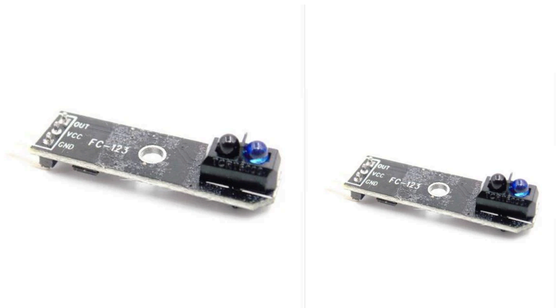


Figure 19: Infrared Sensor Module (TCRT5000).

https://www.canadarobotix.com/products/2083?srsltid=AfmBOop_q9u0PAMFcmZqt9e3eSONwApQ4pBY7NrtoxAYWDP50xhnEpfk

9.8.4 Side IR Sensors (Branch Detection) – 2 Units

Two individual IR sensors are mounted on the left and right of the chassis which were mounted looking straight downward to detect surfaces for Tape intersection patterns.

Side IR Sensors mounted 90 degree straight looking downward, IR sensors were mounted 15 mm above the floor. Each was hot glued to the side body of the robot.

Table 14: Two Side IR Pin configuration.

Sensor Position	Sensor Type	Signal Type	GPIO Pin	Function
Side Left IR	IR Sensor	Digital Input	GPIO 36	Branch detection
Side Right IR	IR Sensor	Digital Input	GPIO 39	Branch detection

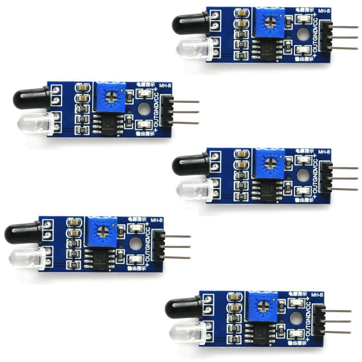


Figure 20: IR Infrared Obstacle Avoidance Sensor Module.

https://www.amazon.ca/Gikfun-Infrared-Obstacle-Avoidance-EK1254x5C/dp/B07FFM7DYQ/

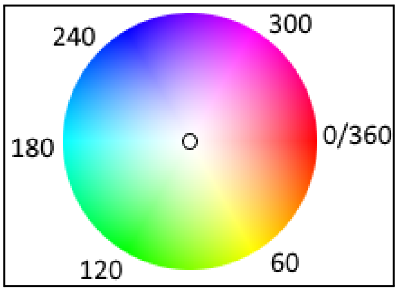
9.8.5 TCS34725 RGB Color Sensor (Color Box Detection) – 1 Unit

The TCS34725 color sensor is mounted on the underside of the robot to detect red and blue color boxes on the surface and trigger the pillbox dispensing mechanism. Which needs 3.3V and I2C connection.

Sensor mounted on the underside of the chassis facing downward using two 3D pin holders.

Table 15: TCS34725 RGB color sensor Pin configuration.

Component	Signal	ESP32 Pin	Type	Description
Color Sensor (TCS34725)	SDA	GPIO 21	I2C Data	Serial data line
Color Sensor (TCS34725)	SCL	GPIO 22	I2C Clock	Serial clock line
Color Sensor (TCS34725)	VCC	3.3V	Power	Supply voltage
Color Sensor (TCS34725)	GND	GND	Ground	Common reference



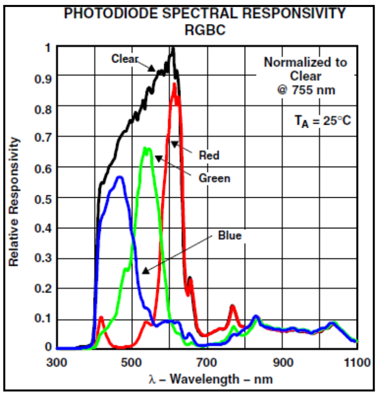


Figure 20: TCS34725 Color Sensor, color sensitivity and the photodiode RGB responsivity.

https://lygte-info.dk/project/ColorSensorTCS34725Library%20UK.html

9.8.6 Ultrasonic Sensors (Collision Avoidance) – 2 Units

Two HC-SR04 ultrasonic sensors were mounted on the front of the robot structure to detect incoming obstacles and also other robots to prevent collision and stop and correct the heading direction.
Both sensors are attached into the fit holder 3D printed housing fixed, 50mm above the surface floor.

Table 16: HC-SR04 ultrasonic sensor Pin configuration.

Sensor Position	Signal	ESP32 Pin	Type	Function
Front Sensor	TRIG	GPIO 17	Digital Output	Trigger pulse
Front Sensor	ECHO	GPIO 5	Digital Input	Distance measurement
Secondary Sensor	TRIG	GPIO 32	Digital Output	Trigger pulse
Secondary Sensor	ECHO	GPIO 33	Digital Input	Distance measurement

Figure 20: HC-SR04 ultrasonic.
https://www.amazon.ca/Ultrasonic-HC-SR04-Distance-Measuring-Transducer/dp/B077P72HG7/

9.8.7 Servo Motors (Dispensing Mechanism) – 2 Units

Two 20KG High Torque RC Servo, Servo Motors used to actuate the dispensing mechanism, there are Two separate dispensing mechanical team designs to be able dispense different circular and rectangular pillboxes.

Table 17: 20KG High Torque RC Servo Pin configuration.

Component	Signal	ESP32 Pin	Signal Type	Function
Main Servo	PWM	GPIO 18	PWM Output	Pill dispensing
Gate Servo	PWM	GPIO 19	PWM Output	Secondary mechanism

Figure 21: 20KG High Torque RC Servo

https://www.amazon.ca/dp/B0FBGC39DS?ref

9.8.8 Summary of Sensor Mounting

Component	Mounting Method	Height / Position	Fasteners / Fixing Method
H-Bridge PCB	Mounted in placeholder soldered wiring	15 mm above chassis floor	Fixed in holder solder + electrical tape
MP1584 Buck Converter	Mounted in placeholder soldered wiring	On chassis (localized placement)	Fixed in holder solder + electrical tape
Bottom IR Sensors (×2)	3D-printed bracket	15 mm above floor	M2 screws (bottom only)
Side IR Sensors (×2)	Angled bracket	30mm height, 90 degree downward	Hot glue (adhesive mount)
RGB Color Sensor (TCS34725)	Integrated 3D-printed slot (press-fit)	20 mm	Press-fit (no screws)
Ultrasonic Sensors (×2)	3D-printed housing (snap/press-fit)	Frontbumper, 50 mm	Press-fit into housing
Servo1	Rigid mechanical mount	Side dispensing module	M3 screws
Servo2	Rigid mechanical mount	Aligned with gate mechanism	M3 screws