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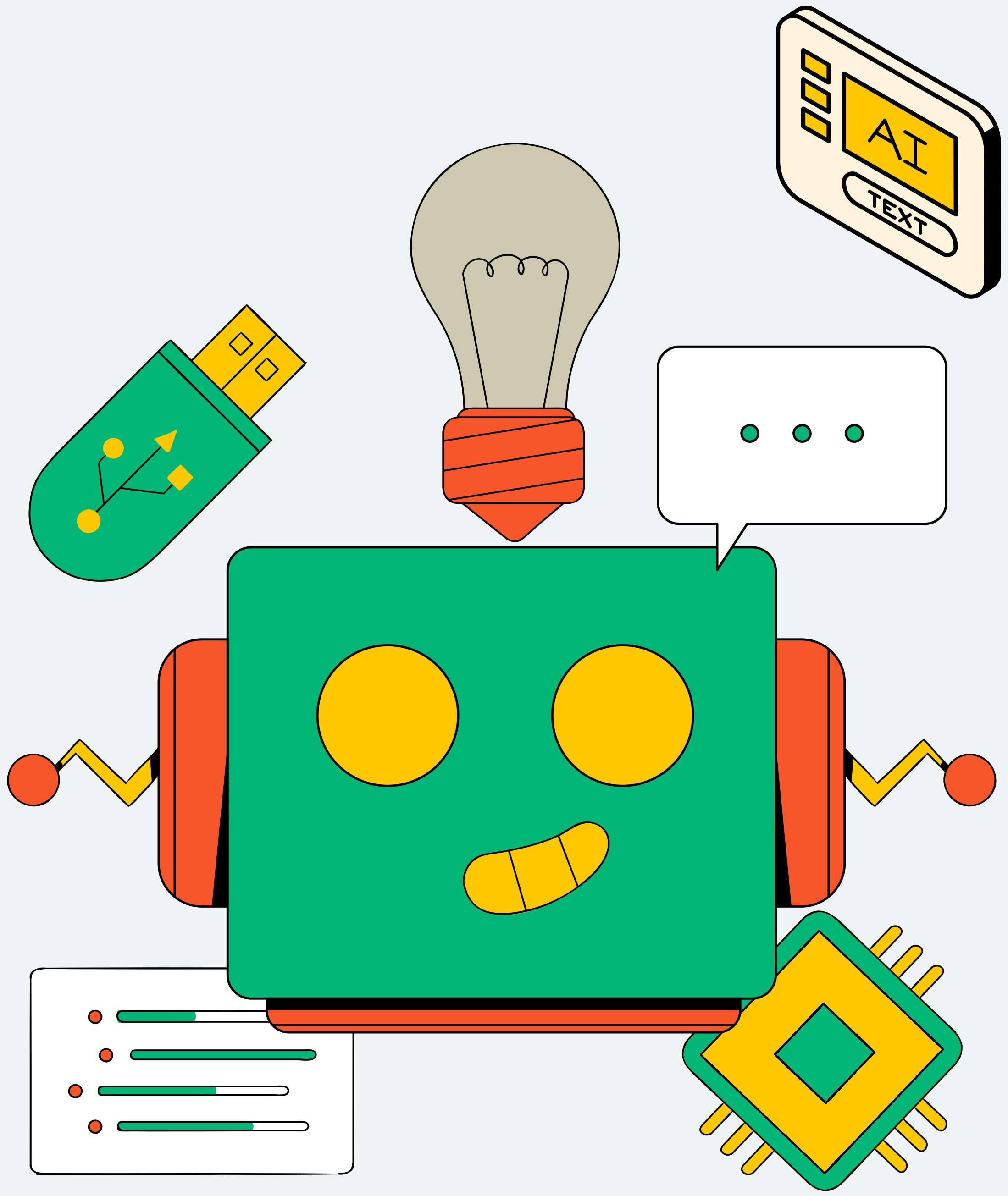
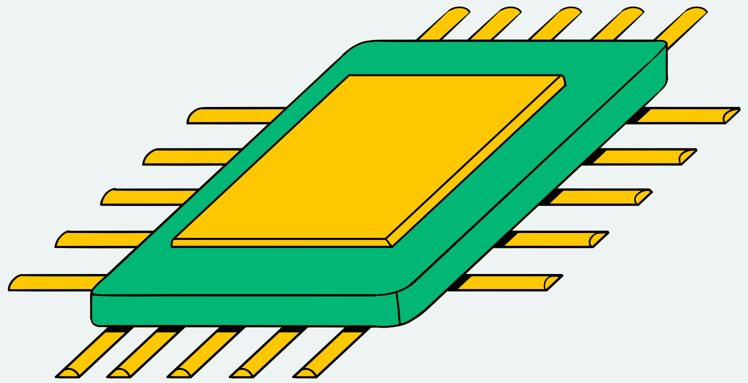


TLM3001 DESIGN PROJECT

PROJECT TITLE

PATHPILOT: AUTONOMOUS COURSE FOLLOWER

PRESENTED BY:
JOSEPH SELVA RAJ
(2102883)



PRESENTATION OUTLINE

- **Introduction**
- **Conceptual Design and Implementation**
  - Project Management
  - Hardware Development
  - Software Development
- **Testing, Evaluation and Outlook**
  - Machine Learning Model Selection
  - Testing for Optimal “K” Value
  - Prototype Testing
  - Prototype Evaluation and Outlook
- **Conclusion**

INTRODUCTION

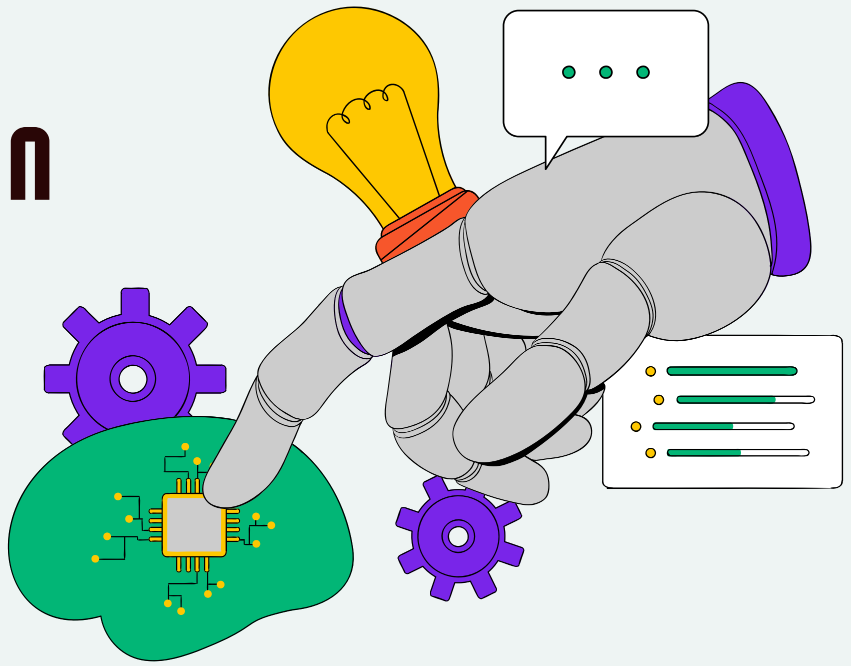
PATHPILOT: INNOVATIVE AUTONOMOUS ROBOT NAVIGATION SOLUTION

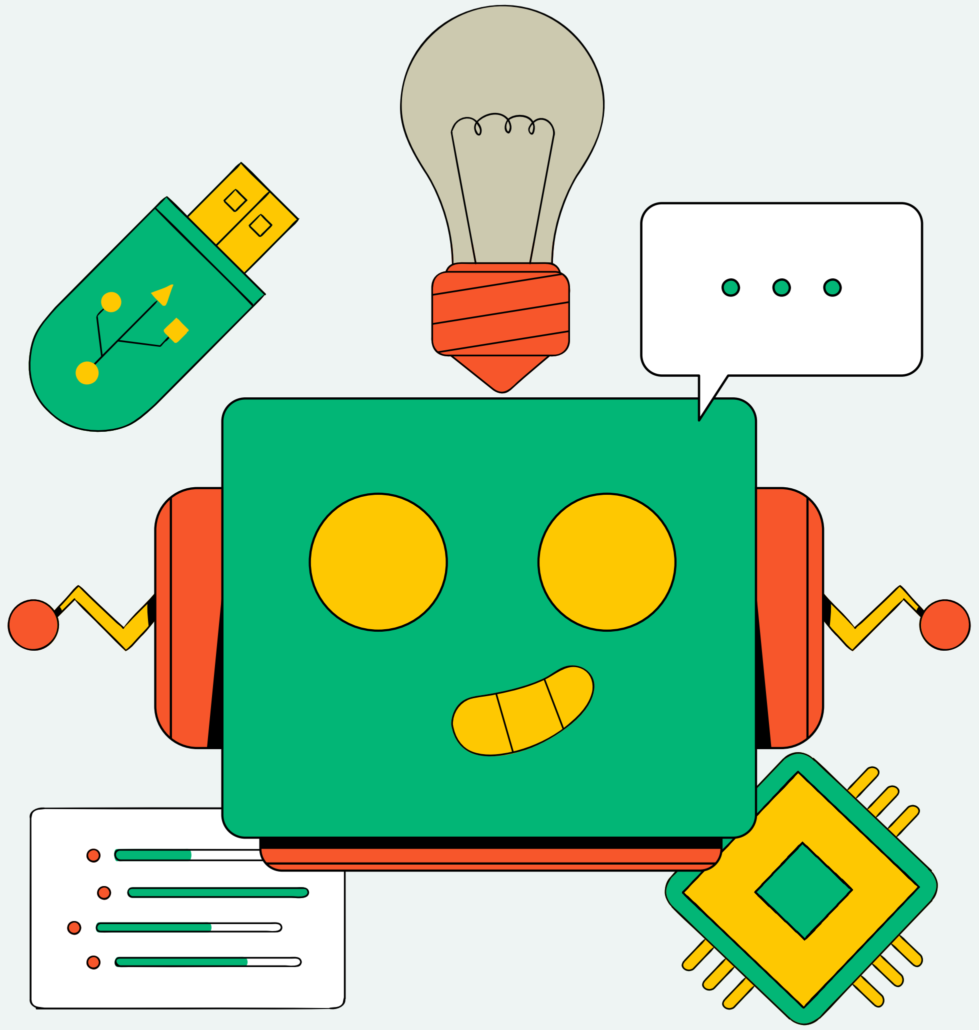
OBJECTIVE:

Provide an cost-effective and adaptable solution to autonomous robot navigation.

KEY COMPONENTS:

Embedded System,
Software,
Machine Learning,
LiDAR Sensor





Motivation: Current systems face challenges in affordability, computational requirements, and environmental sensitivity, hindering widespread adoption. This project aims to redefine the landscape by offering a cost-effective solution with adaptable and robust navigation capabilities.

CONCEPTUAL DESIGN AND IMPLEMENTATION

CONCEPTUAL DESIGN AND IMPLEMENTATION (PROJECT MANAGEMENT)

PROJECT PHASES

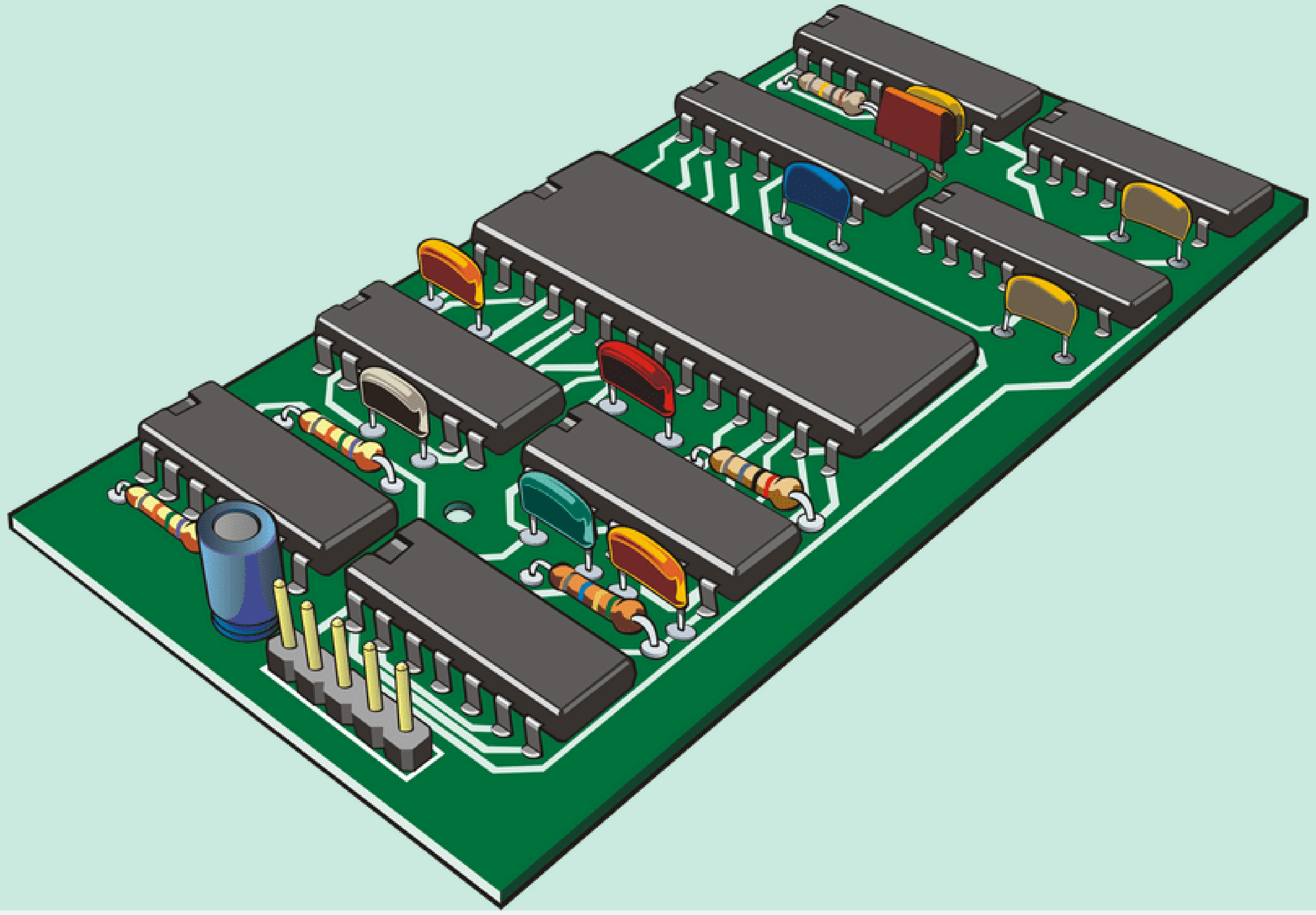
Training Phase: Collection of training data

- User assumes control of the robot through Bluetooth and an Android application, driving it through the course to collect crucial training data.
- Android application, Arduino software, PathPilot's embedded system.

Testing Phase: Deployment of machine learning model

- Training of classification model.
- Depolyment of classification model in PathPilot robot.
- Evaluation functionality under various conditions.

CONCEPTUAL DESIGN AND IMPLEMENTATION (HARDWARE DEVELOPMENT)



ROBOT HARDWARE DEVELOPMENT

HARDWARE ASSEMBLY:

- Designed and assembled robotic platform to support software functionalities.
- Included components: LiDAR sensor, ultrasonic sensor, motor driver, Bluetooth module, SD Module and Arduino.

DESIGN FEATURES:

- Integrated voltage divider circuit to adapt voltage levels for Bluetooth module.
- LiDAR sensor motor is powered seperately to protect sensor's operation.
- Safety switch enables user to break batery connection during a malfunction.

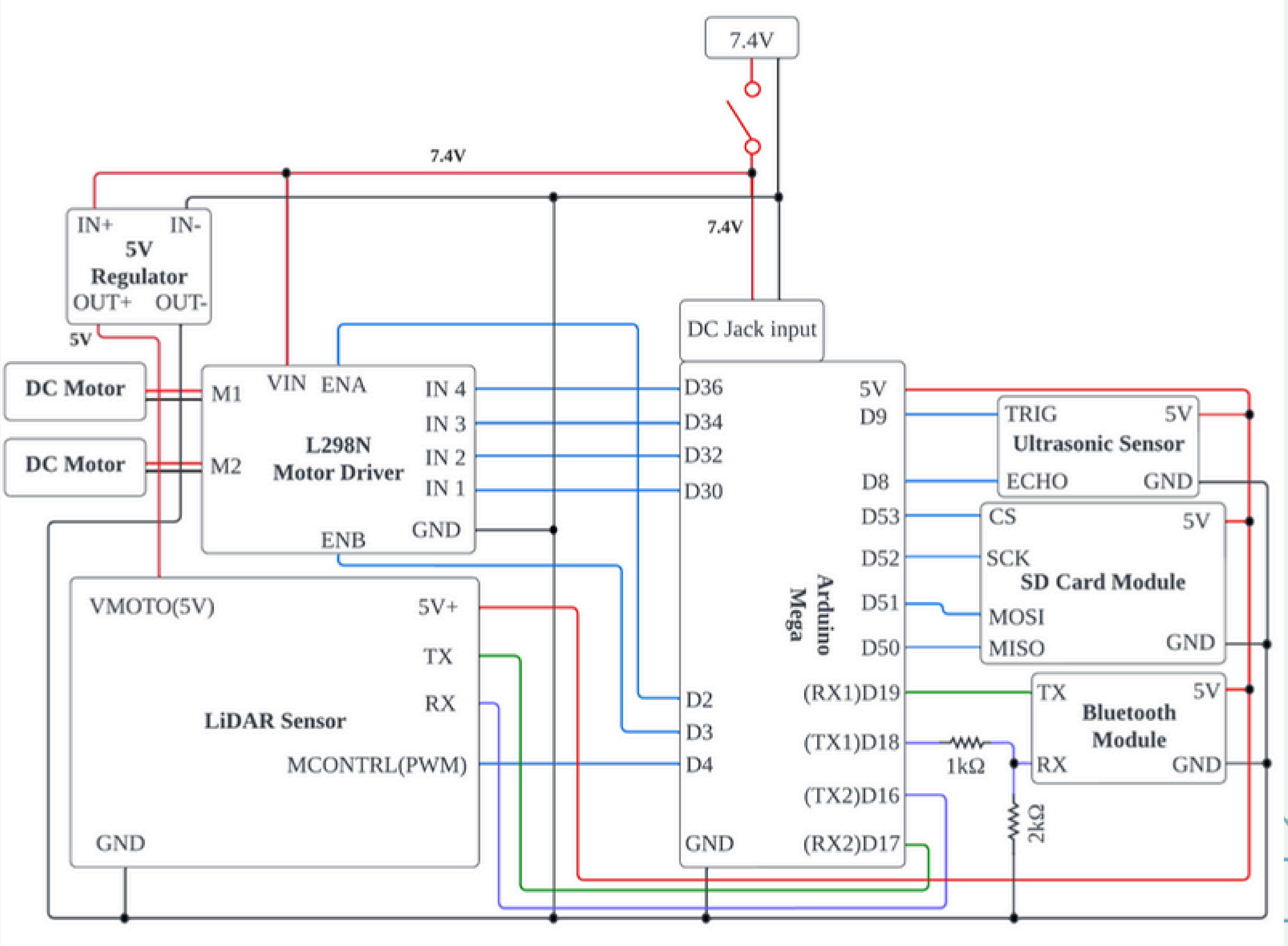
PRECISE ASSEMBLY:

- Meticulous soldering and connection of components to prevent operational issues.

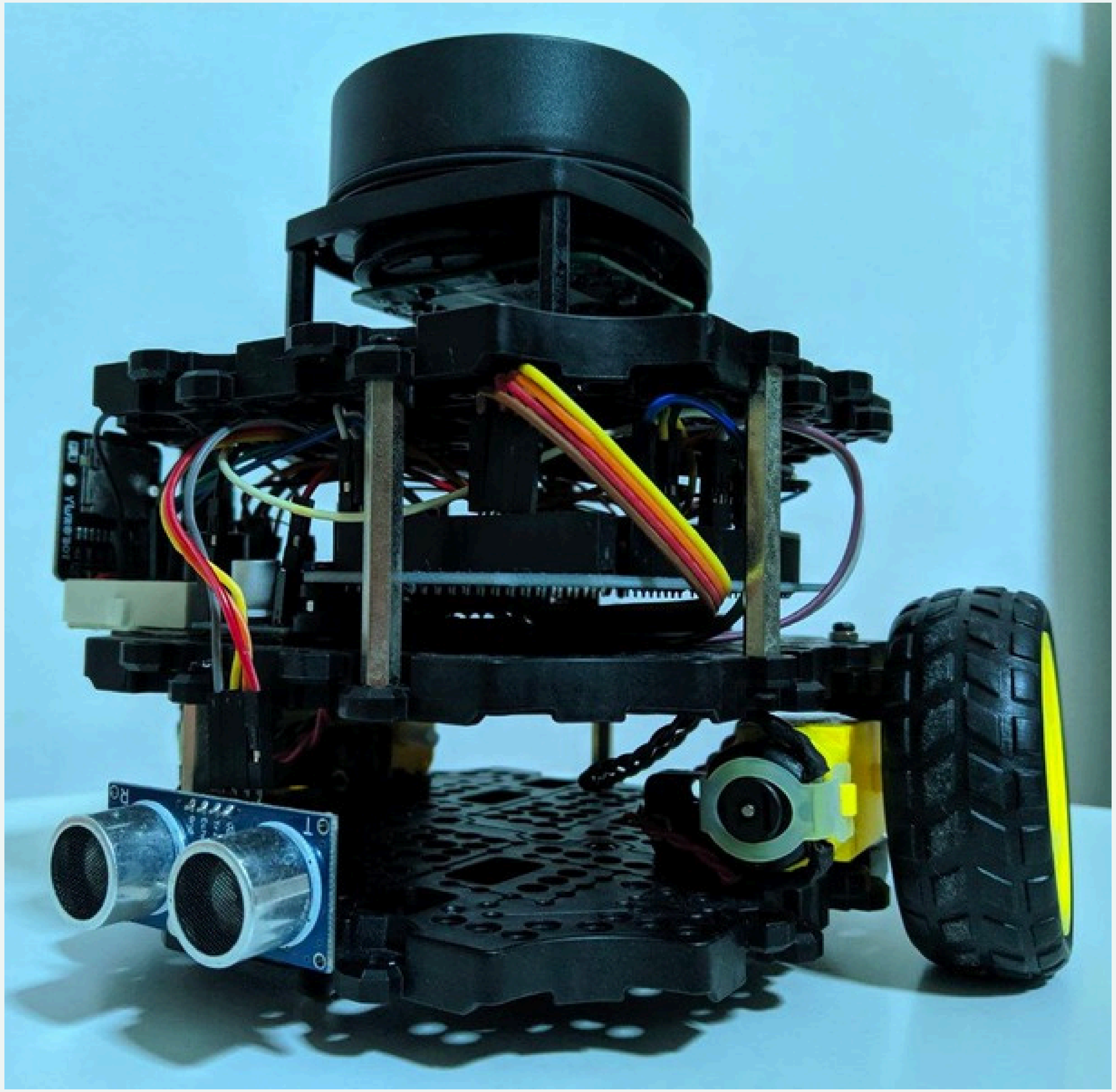
KEY FINDINGS/ ISSUES:

- Initial design with 12.6V 3-cell LiPo battery led to overheating issues and failure to power Lidar sensor.
- Switched to a 7.4V 2-cell LiPo battery to prevent overheating and ensure proper sensor functioning.

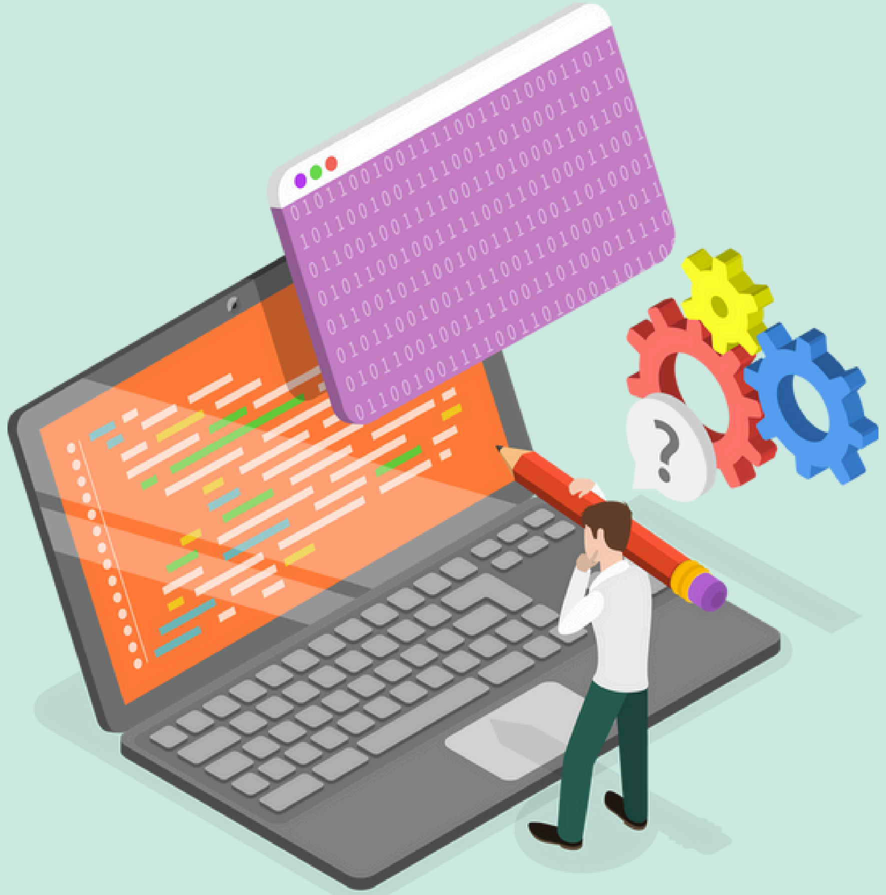
ROBOT HARDWARE DEVELOPMENT



ROBOT HARDWARE DEVELOPMENT



CONCEPTUAL DESIGN AND IMPLEMENTATION (SOFTWARE DEVELOPMENT)



ANDROID APPLICATION DEVELOPMENT

KEY FEATURES:

- Bluetooth communication for seamless interaction with the robot for data collection.
- Control for initiating and halting LiDAR sensor data recording and motor control.

USER-FRIENDLY INTERFACE:

- Intuitive design to facilitate easy operation and control with vibration touch feedback.

SiT
Show Bluetooth Devices
AI
Data Recording
Forward Left
Forward Right
STOP
Backward Left
Backward Right

ARDUINO SOFTWARE (TRAINING PHASE)

FUNCTIONALITY:

- Facilitates communication with Android app via Bluetooth.
- Controls robot motors.
- Captures and store LiDAR sensor data to a SD card.

DESIGN EMPHASIS:

- Integration with essential components like LiDAR sensor, motor driver, bluetooth and SD Card module.
- Modular approach for code organisation and readability.

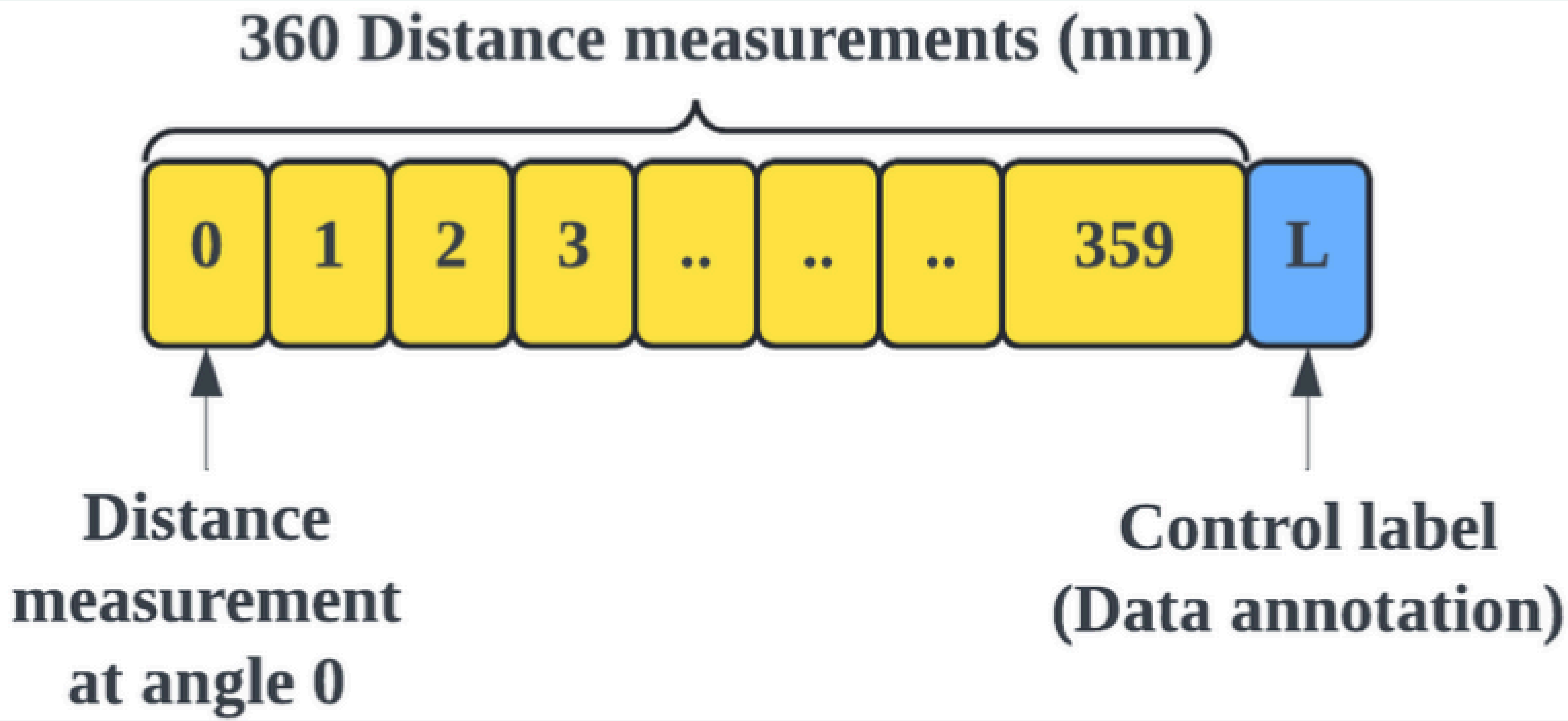
ARDUINO

KEY FEATURES:

- Implementation of 5.5Hz timer interrupt for construction and writing of data strings from LiDAR sensor to SD card.

- The data strings are annotated with control labels corresponding to motor commands during data collection.

COLLECTION OF TRAINING DATA



COLLECTION OF TRAINING DATA RESULT

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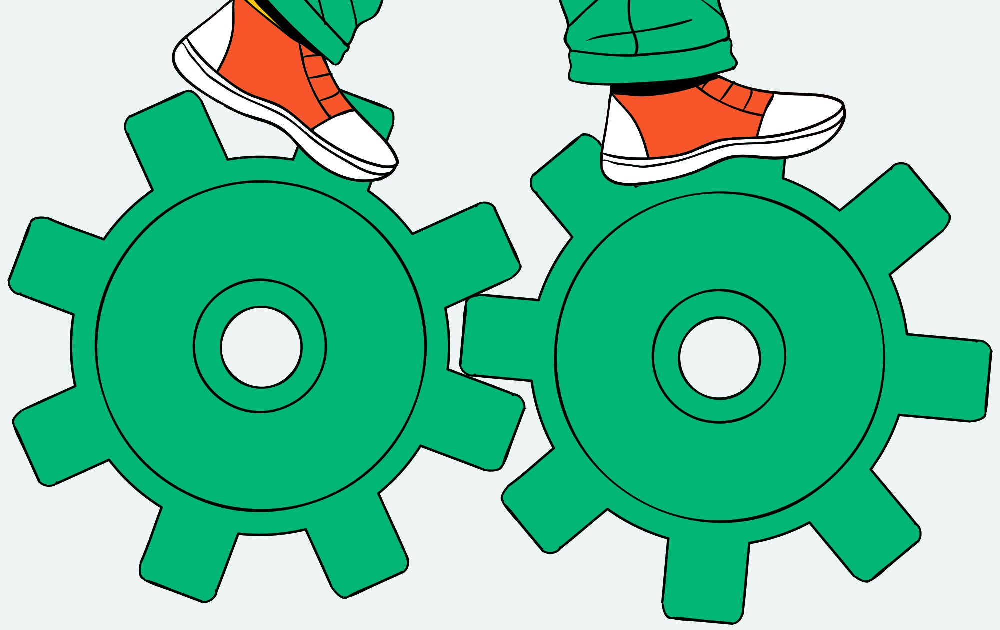
MACHINE LEARNING MODEL TRAINING SOFTWARE PROCESS



DATA CLEANING

- Removal of data strings that were annotated with unwanted control labels.

TRAINING & TEST SET

- Separate distance measurements as input, control label as output.
- Spilt dataset intro training & testing set (80/20 ratio).

FEATURE SELECTION

- Get “k” number of selected features.
- Selected features are the most informative LIDAR measurement angles (indexes) for the prediction of the control label.

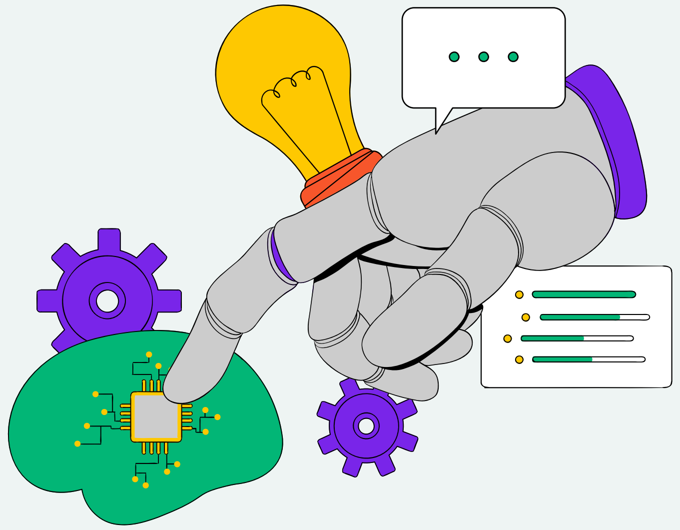
TRAIN MODEL

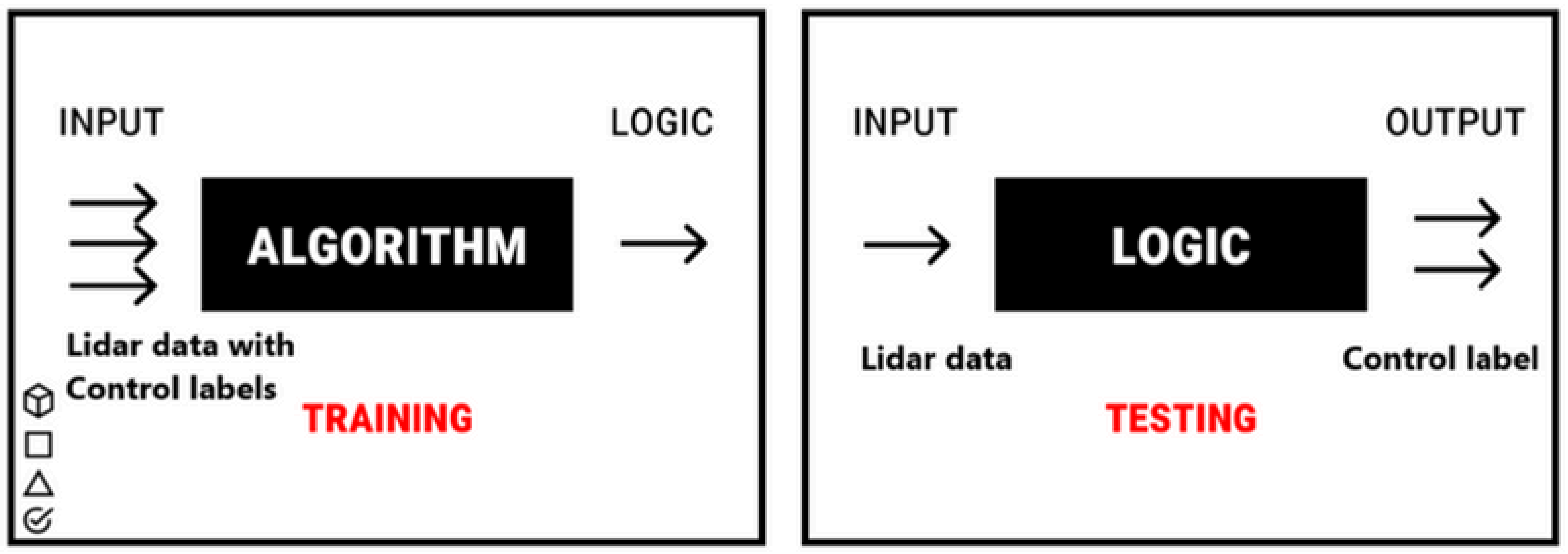
- Train model with selected features of training set.
- Trained model will take in a string of distance measurements and output the control label.

EXPORT MODEL

- Ultilization of the “micromlgen” library to export trained model to a C language header file for depolyment in the Arduino microcontroller.

TRAINING OF MODEL (OVERVIEW)





ARDUINO SOFTWARE (TESTING PHASE)

FUNCTIONALITY:

- Read data from LiDAR sensor.
- Get prediction of control label from trained model.
- Controls robot motors.
- Obstacle detection.

DESIGN EMPHASIS:

- Integration with essential components like LiDAR sensor, ultrasonic sensor and motor driver.
- Modular approach for code organisation and readability.

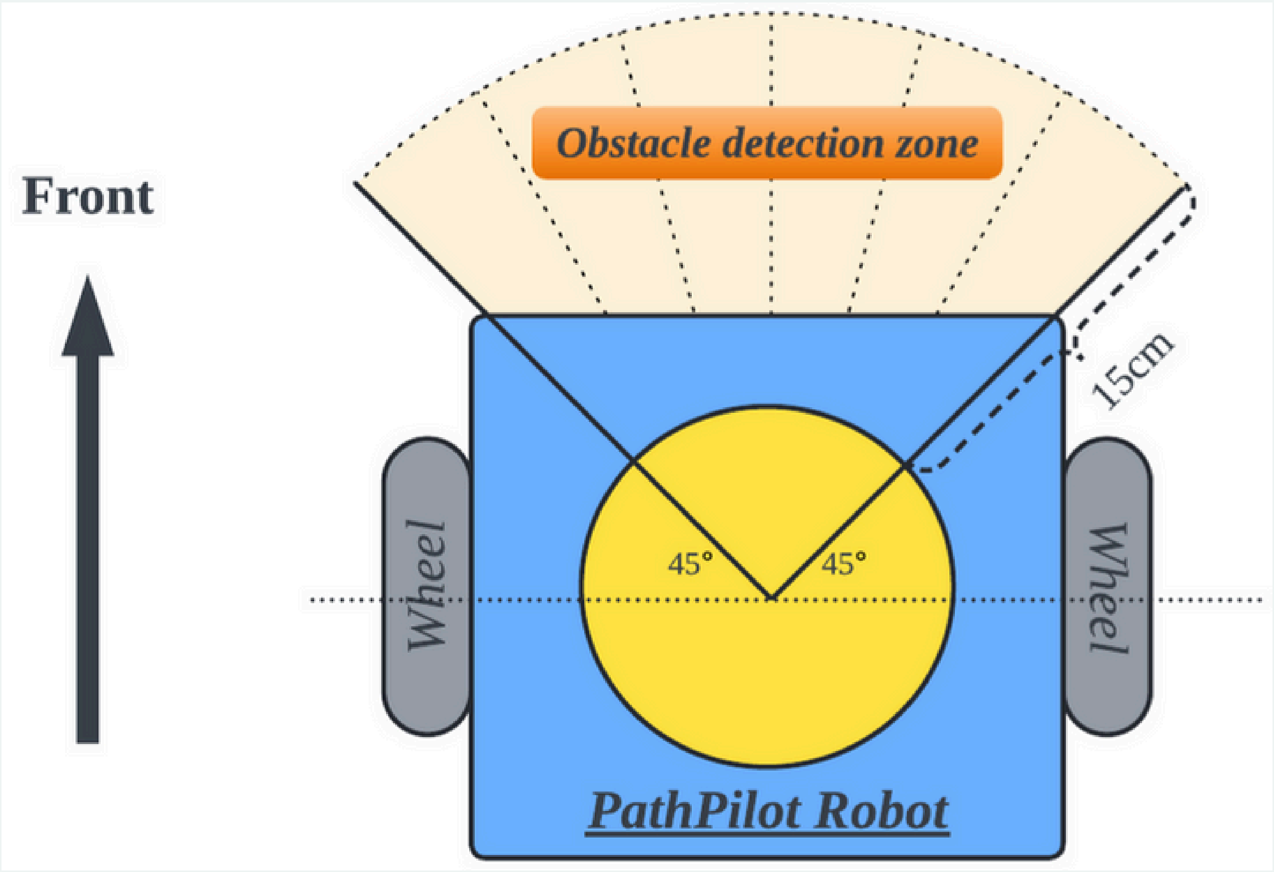
ARDUINO

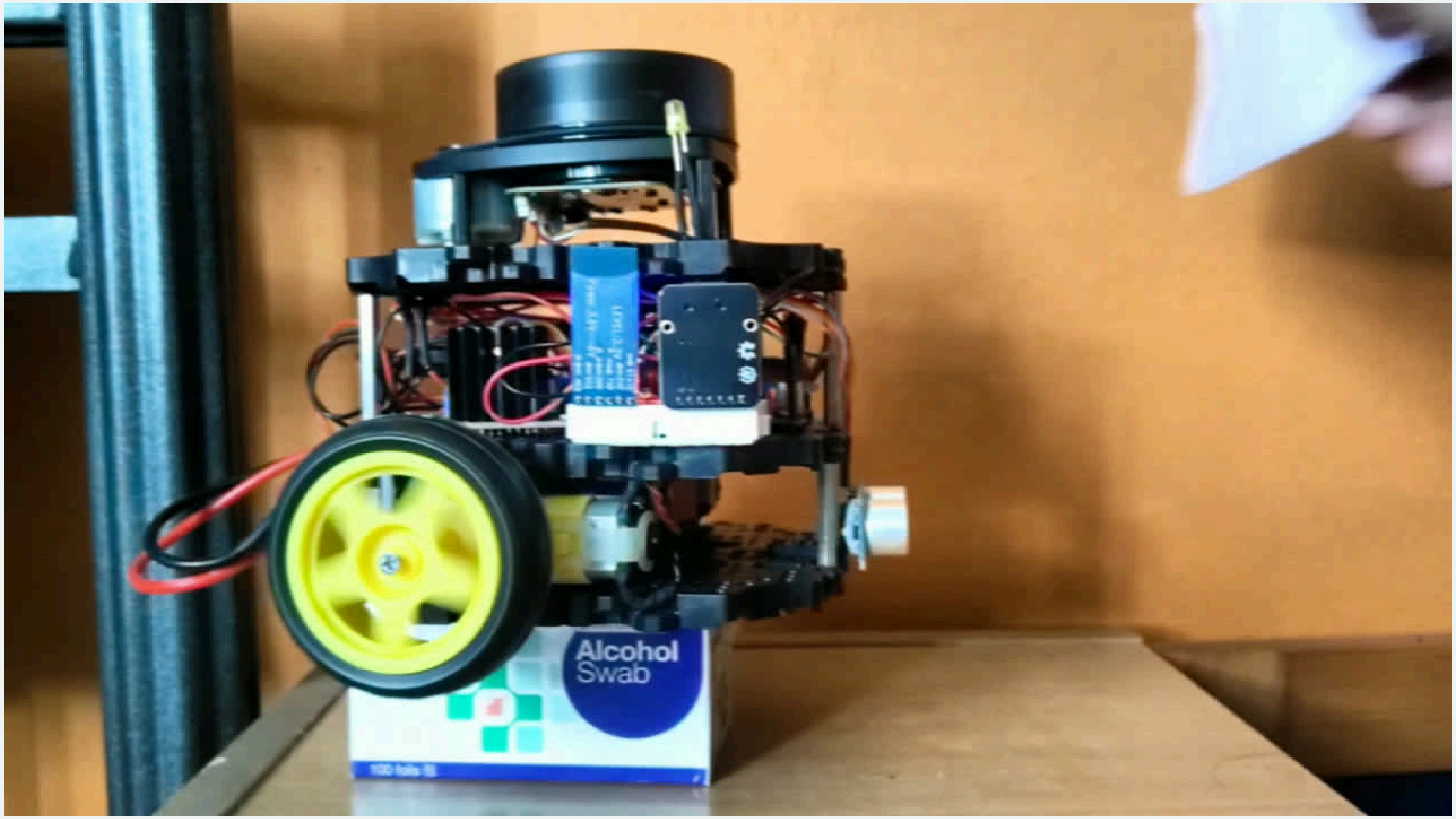
KEY FEATURES:

- Implementation of 5.5Hz timer interrupt for the capture and processing of data from LiDAR sensor to the trained model.

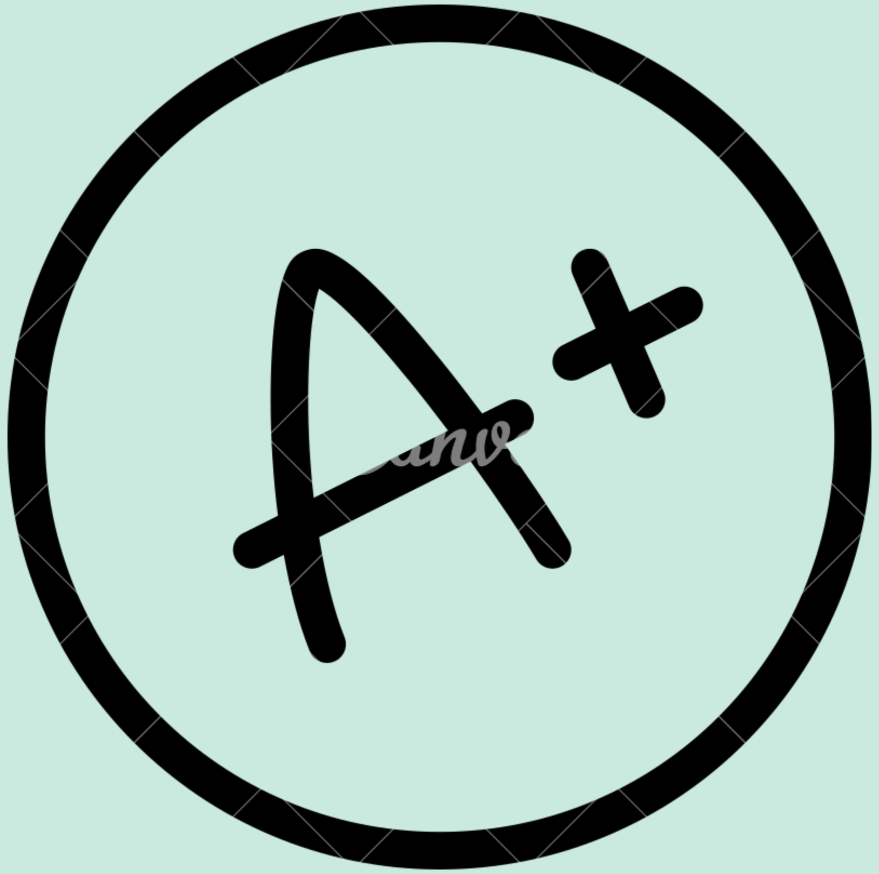
- Control of robot's movement based on model's output.

OBSTACLE DETECTION ZONE





MAIN RESULT (FUNCTIONALITY)



DEPLOYMENT OF TRAINED MODEL

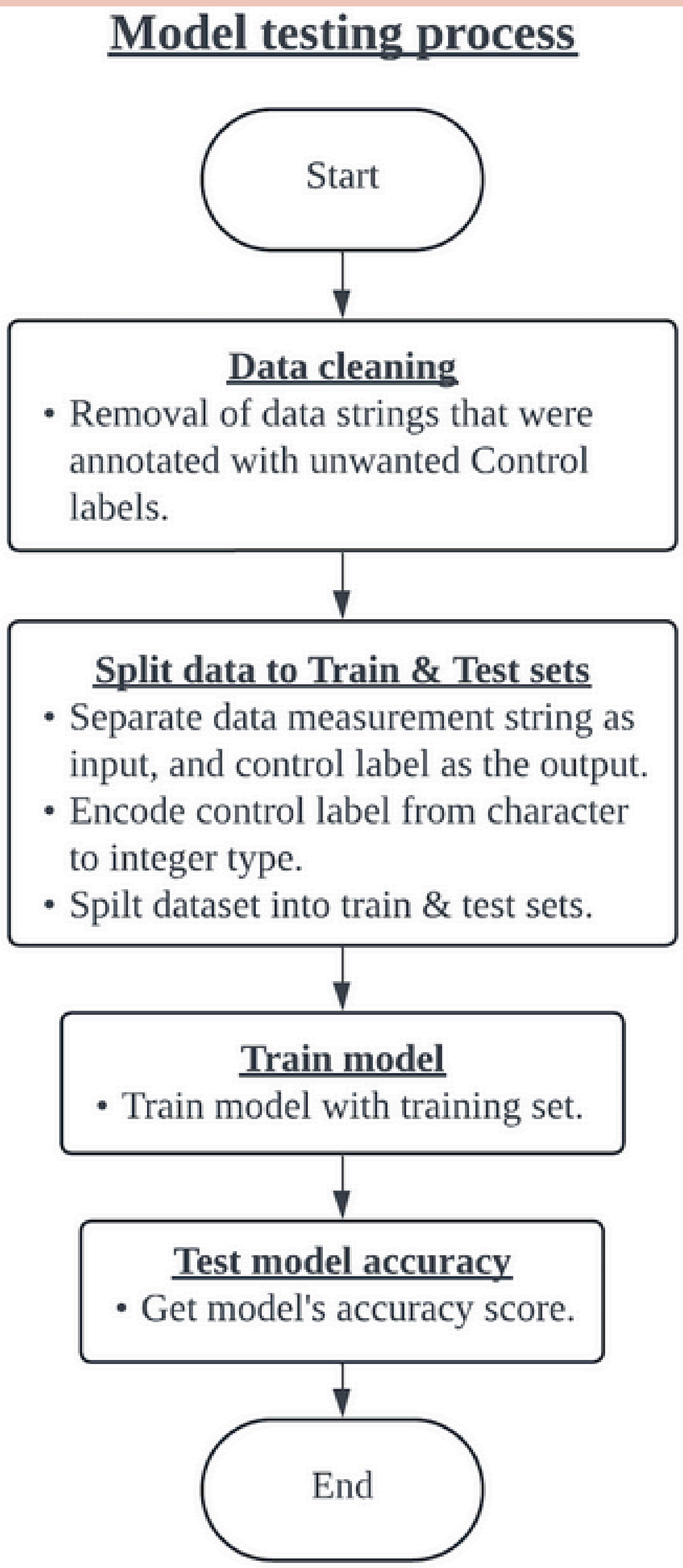
TESTING AND EVALUATION

TESTING AND EVALUATION
1.MODEL SELECTION

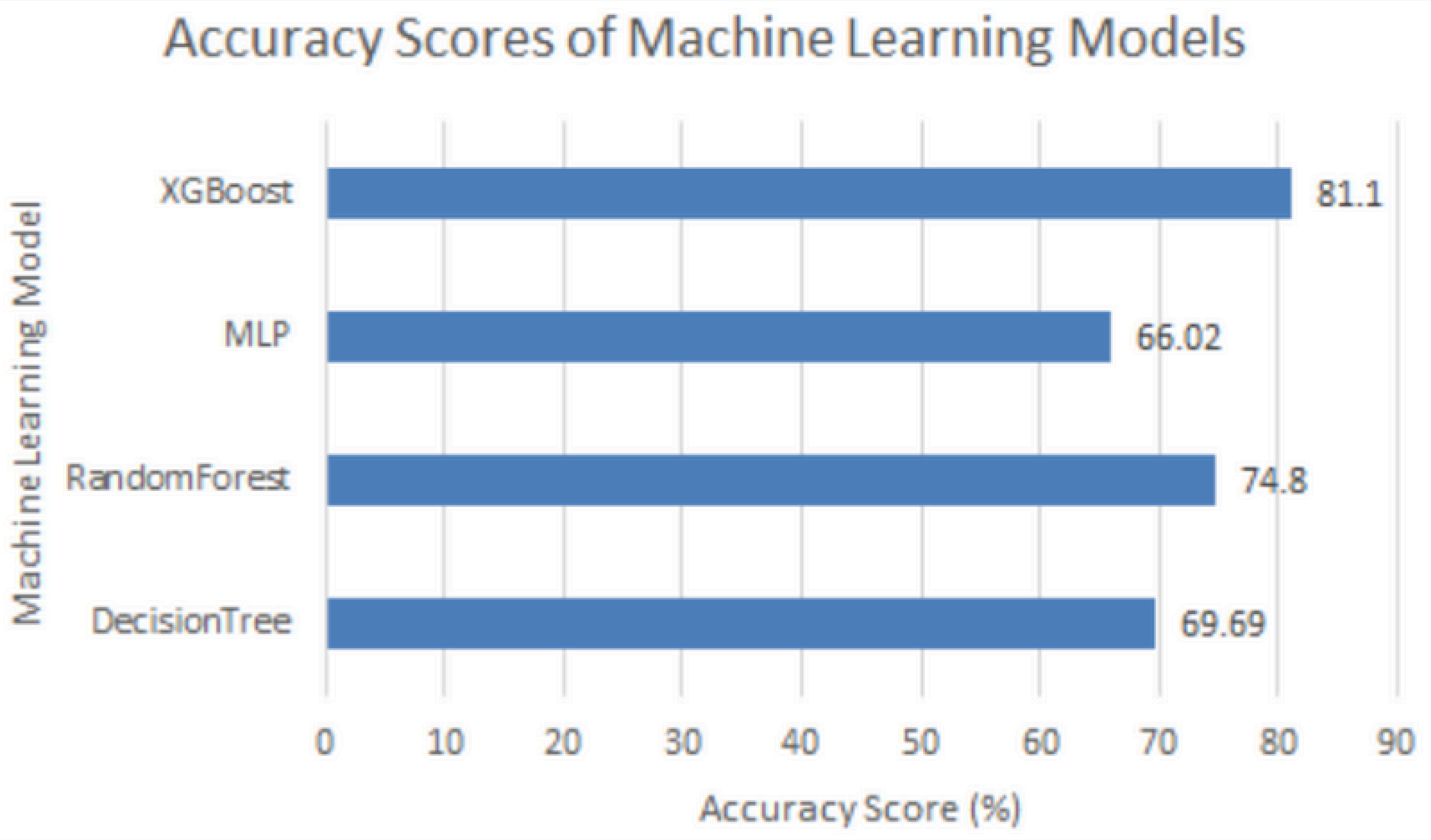
SELECTION OF MACHINE LEARNING MODEL

Testing and Evaluation Process of Machine Learning Models:

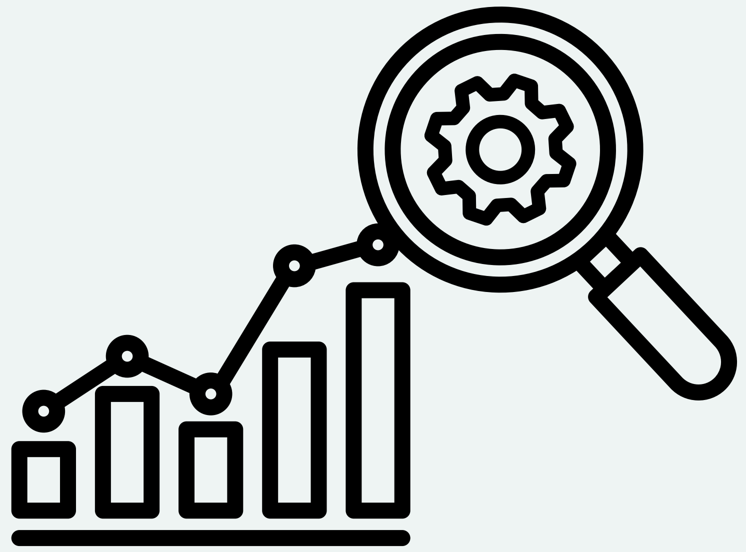
- **Objective**: Evaluate four machine learning models for deployment in the PathPilot robot.
- **Models tested and evaluated:** DecisionTree, RandomForest, MLP, and XGBoost.
- **Tools Used:** Scikit-learn library for supervised learning.
- **Training Dataset:** Evaluated with the same dataset collected during the project's training phase.



TESTING OF MACHINE LEARNING MODELS (RESULT)



- Based on the result, **XGBoost** scored the **highest accuracy**, thus it was selected to be deployed in the PathPilot robot.



TESTING AND EVALUATION
2.TESTING FOR OPTIMAL K VALUE

OPTIMIZING MODEL WITH FEATURE SELECTION

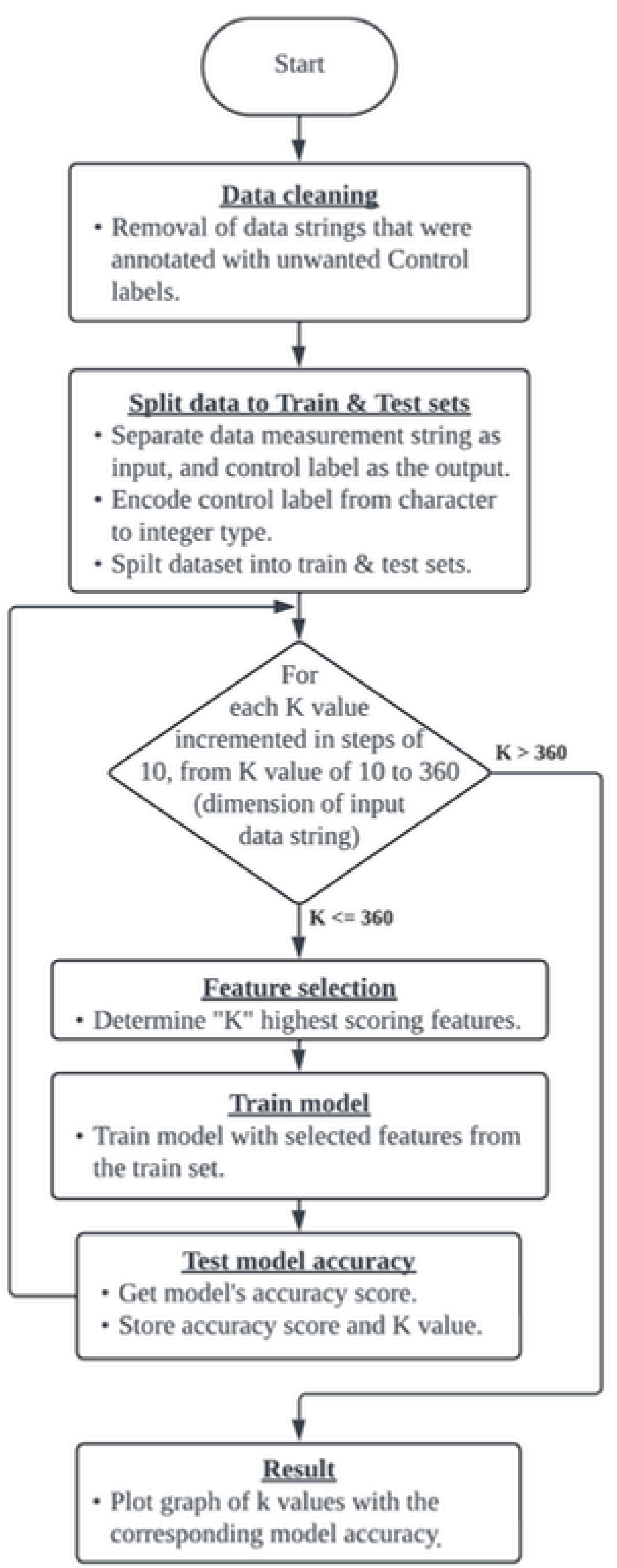
Enhancing Model Performance with Optimal K Value:

- **Feature Selection:** Determine best K using SelectKBest (ANOVA F-value between the label and the feature).

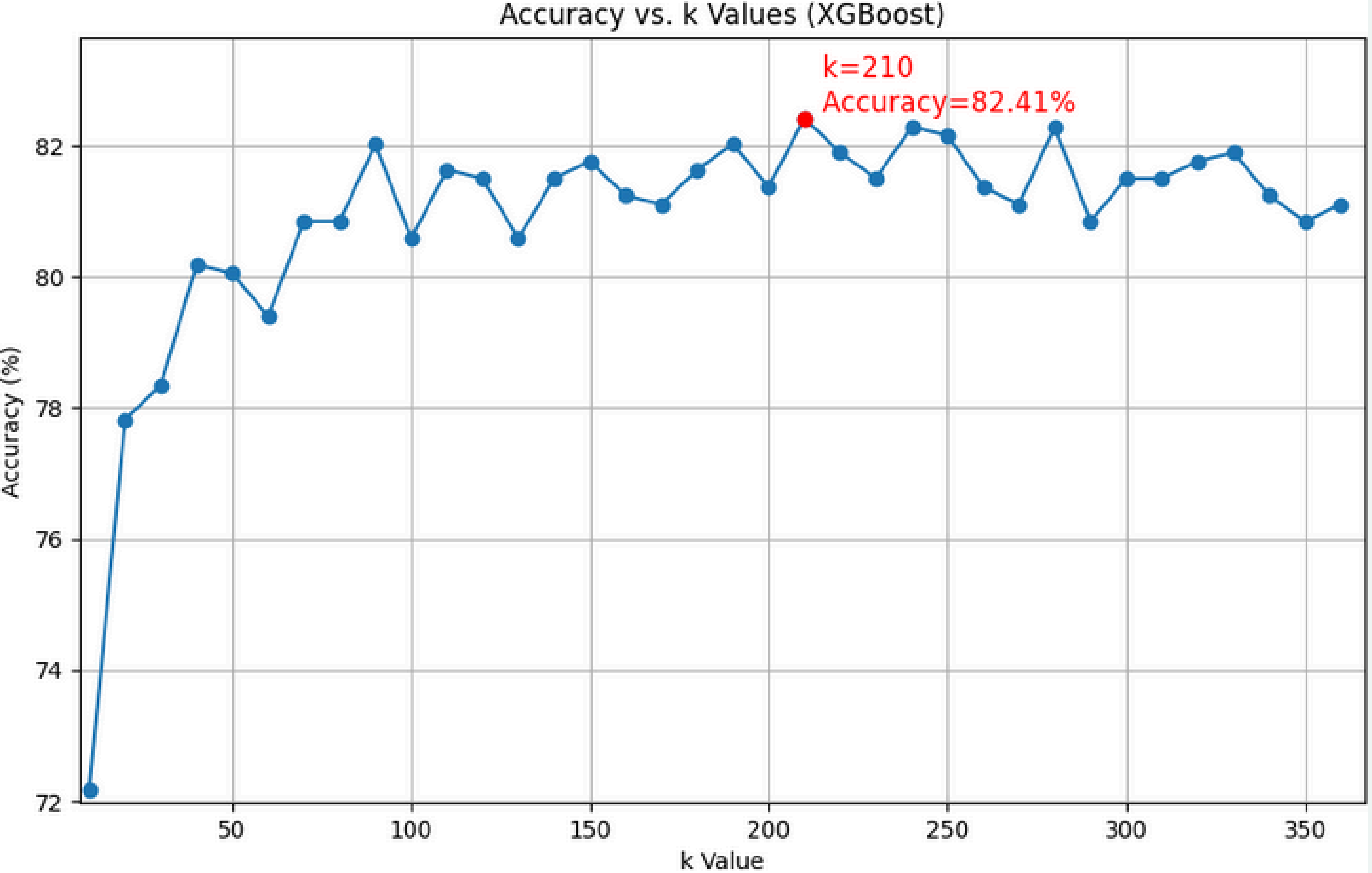
- Ensures that only the most informative distance measurements, determined by their angles (selected features), are considered for predicting the control label.

- **Steps:**
  a. Data Cleaning & Split (80/20 ratio)
  b. Iterate K Values: From 10 to 360 in steps of 10
  c. Train XGBoost Model & Test Accuracy

Finding optimal K value program flow

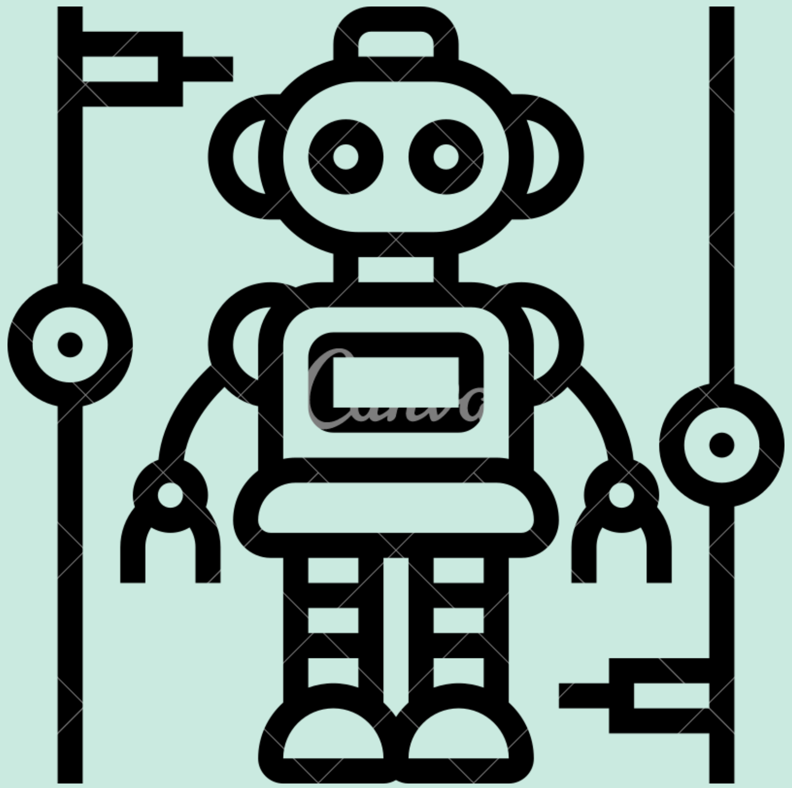


OPTIMIZING MODEL WITH FEATURE SELECTION (RESULT)



- Based on the result, the optimal K value of **210** was identified.
- Optimal K value will be used in training of model for PathPilot.
- Accuracy of model improved by **1.31%**.

TESTING AND EVALUATION
3.PROTOTYPE TESTING



FUNCTIONALITY TESTING OVERVIEW

Overview of PathPilot Functionality Testing:

- **Course Layouts Tested:**
  - Circle, Square, B-Shaped.
  - Wall Color: White for optimal LiDAR performance.

- **Test conditions:**
  - **Data Size:** 45MB (15 MB per course, 10 minutes driving).
  - **Model:** XGBoost with 82.41% accuracy.
  - **PWM value:** 90.

FUNCTIONALITY TESTING - RESULT

PathPilot Functionality Testing:

- **Testing Result:**
  - Successfully navigated all courses
  - Demonstrated adaptability with combined dataset

Course layout	Able to transverse for 30mins without crashing?
Circle	Yes
Square	Yes
"B" shaped	Yes

ROBUSTNESS TESTING AT DIFFERENT MOTOR SPEEDS

Robustness of PathPilot's navigation capabilities:

- **Objective:** To evaluate the robustness of PathPilot's navigation capabilities, the system repeated the Functionality Testing at varying motor speeds.
- **Testing Result:**
  - **Key Observation:** Delayed reaction at corners when PWM ≥ 200 due to LiDAR scan rate limitations.

Motor speed (PWM)	Able to transverse for 30mins without crashing?
50	Yes
100	Yes
150	Yes
200	No
255	No

RELIABILITY TESTING

Reliability testing in changing environmental conditions:

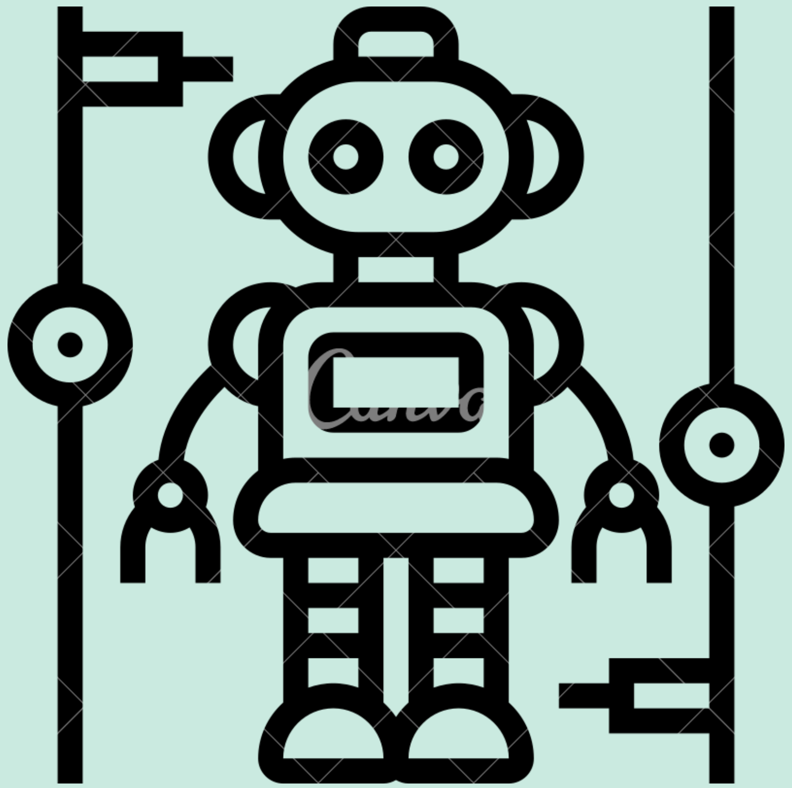
- **Objective:** Evaluate PathPilot's reliability in different environmental conditions.
- **Testing procedure:** Repeat of Functionality & Robustness Tests at 16 LUX (dark) and 150 LUX (bright).
- **Testing Results:**
  - **Consistent Performance:** Achieved same results, reliable across different environments.

OBSTACLE DETECTION TESTING

Testing of PathPilot's Obstacle Detection Capability:

- **Objective:** To verify PathPilot's obstacle detection capability in different environmental condition.
- **Testing procedure:** Placing obtacles within PathPilot's obstacle detection zone at 16 LUX (dark) and 150 LUX (bright).
- **Testing Results:** Effective obstacle detection in both scenarios.

TESTING AND EVALUATION
4.PROTOTYPE EVALUATION & OUTLOOK



EVALUATION OVERVIEW

Overview of PathPilot Evaluation:

- **Criteria:** Affordability, Adaptability, Robustness, Reliability.
- **Goal:** Cost-effective, efficient, and reliable navigation system.

Key Achievements:

- **Affordability:**
  - **Comparison:** 44% more affordable than TurtleBot
  - **Efficiency:** Arduino microcontroller and TinyML frameworks

Main System Component	TurtleBot 3	Cost (TurtleBot 3)	PathPilot	Cost (PathPilot)
Microcontroller/Processor	Raspberry Pi 4	$99.90	Arduino Mega	$23.40
Sensors	LiDAR	$143.40	LiDAR	$143.40
	Raspberry Pi camera	$54.60	NA	NA
Total Cost		**$297.90**		**$166.80**

EVALUATION OVERVIEW

Overview of PathPilot Evaluation:

- **Adaptability:**
  - **Performance:** Successfully navigates diverse layouts.
  - **Independence:** Operates without external cues.

- **Robustness:**
  - **Motor Speeds & Environments:** Consistent performance.
  - **LiDAR Limitation:** Minor reaction delay at high speeds.

- **Reliability:**
  - **Lighting & Obstacle Detection:** Accurate across conditions.

OUTLOOK

Enhanced Technology Integration:

- **Advanced Sensors and LiDAR:**
  - Integrate new sensors to boost perception capabilities.
  - Explore improved LiDAR technology to address scan rate limitations at higher speeds.
- **Machine Learning Optimization:**
  - Implement more sophisticated algorithms for better decision-making and accuracy.
  - Utilize real-time data processing for enhanced performance.

OUTLOOK

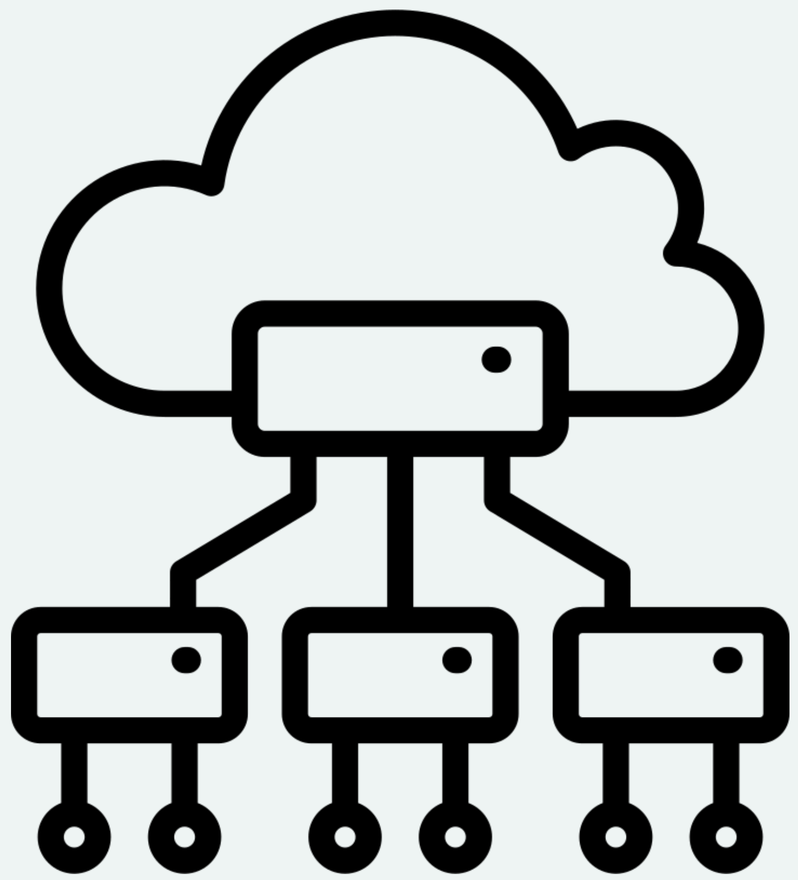
Expanded Applications:

- **Diverse Industry Use Cases:**
  - **Warehouse Automation:** Streamline logistics and inventory management.
  - **Agricultural Robotics:** Improve precision and efficiency in farming.
  - **Security and Surveillance:** Enhance patrolling capabilities with autonomous robots.
  - **Healthcare Robotics:** Enable hospital delivery, corridor cleaning and patient care automation.
  - **Smart Manufacturing:** Automate production lines for increased productivity.
- **Scalability and Adaptability:**
  - Adapt PathPilot for various robot sizes and types, including personal and commercial autonomous vehicles.

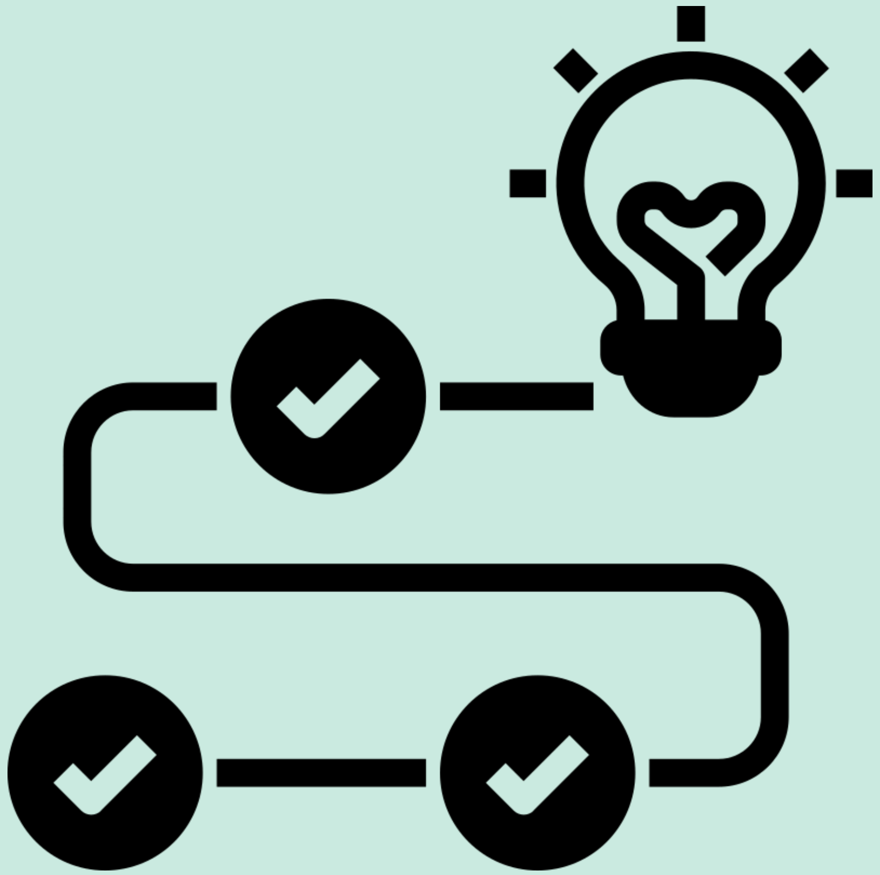
OUTLOOK

Edge Computing and Collaboration:

- **Edge Computing for Real-Time Processing:**
  - Leverage edge servers for centralized processing and coordination.
  - Enhance real-time decision-making across multiple autonomous systems.

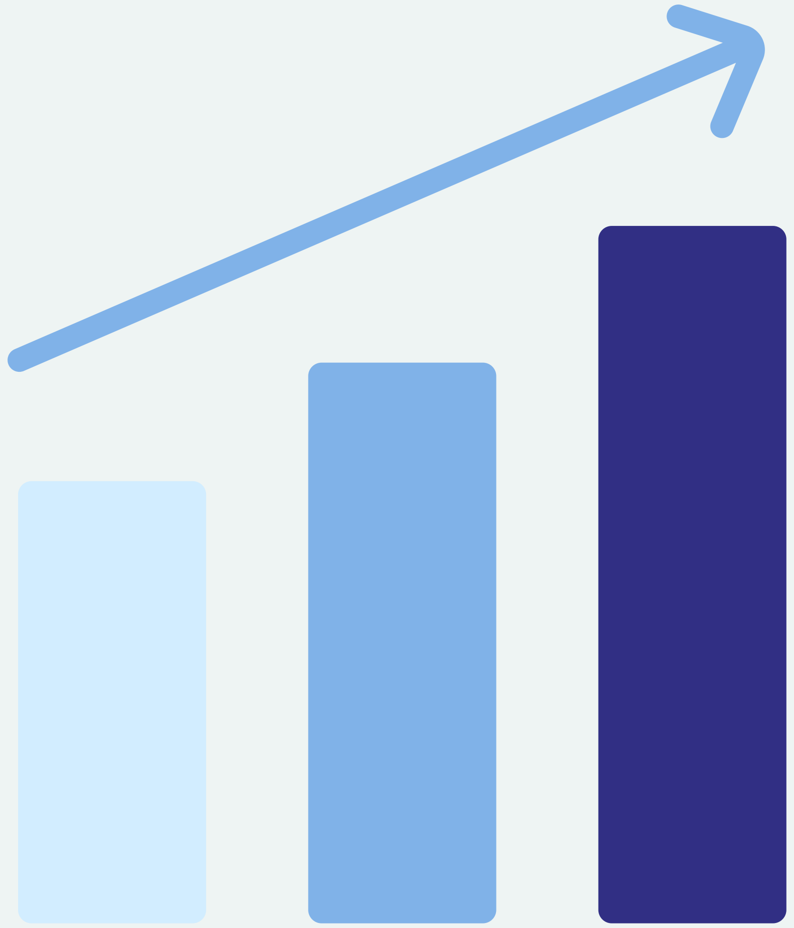


CONCLUSION



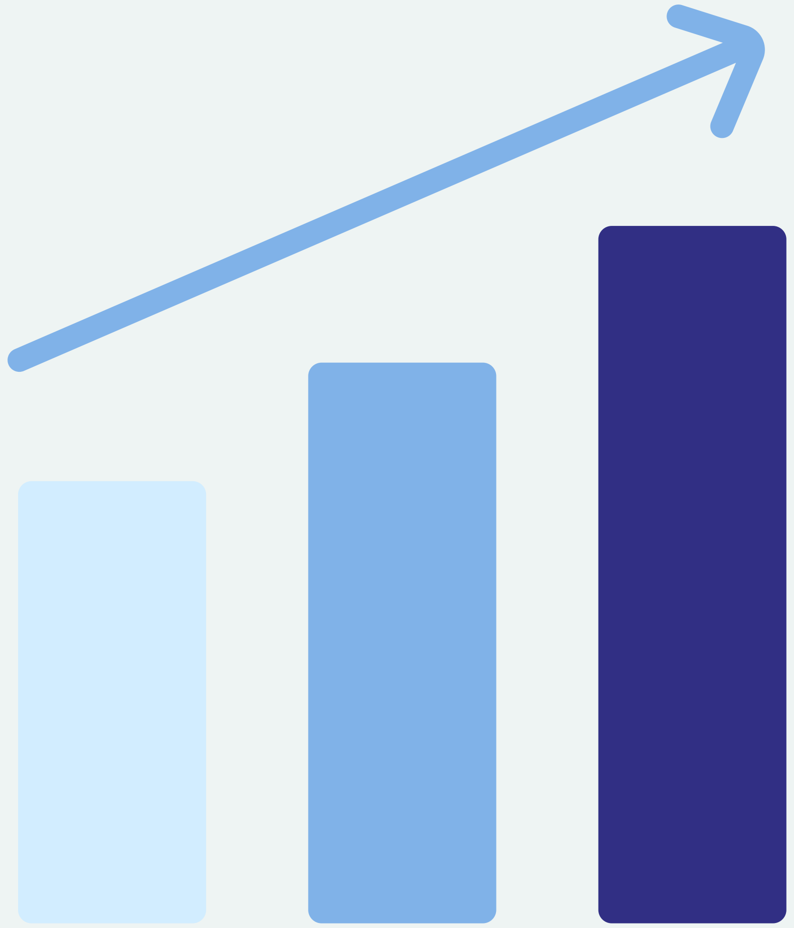
CONCLUSION

- **Key Achievements**
  - **Cost-Effective:**
    - 44% cheaper than alternatives like TurtleBot.
  - **Adaptable:**
    - Navigates diverse environments without external cues.
  - **Robust & Reliable:**
    - Consistent performance across speeds and lighting conditions.



CONCLUSION

- **Future Directions**
  - **Enhancements:**
    - Integrate advanced sensors and machine learning.
  - **Scalability:**
    - Suitable for various robot types and sizes.
  - **Edge Computing:**
    - Centralized processing for real-time decisions.
- **Impact**
  - **Innovative Solution:**
    - Ready for use in industries like warehouse automation, agriculture, and security.



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