



# AUTONOMOUS VEHICLE DESIGN

HOCHSCHULE HAMM-LIPPSTADT, CAMPUS LIPPSTADT

PROTOTYPING AND SYSTEMS ENGINEERING COURSE

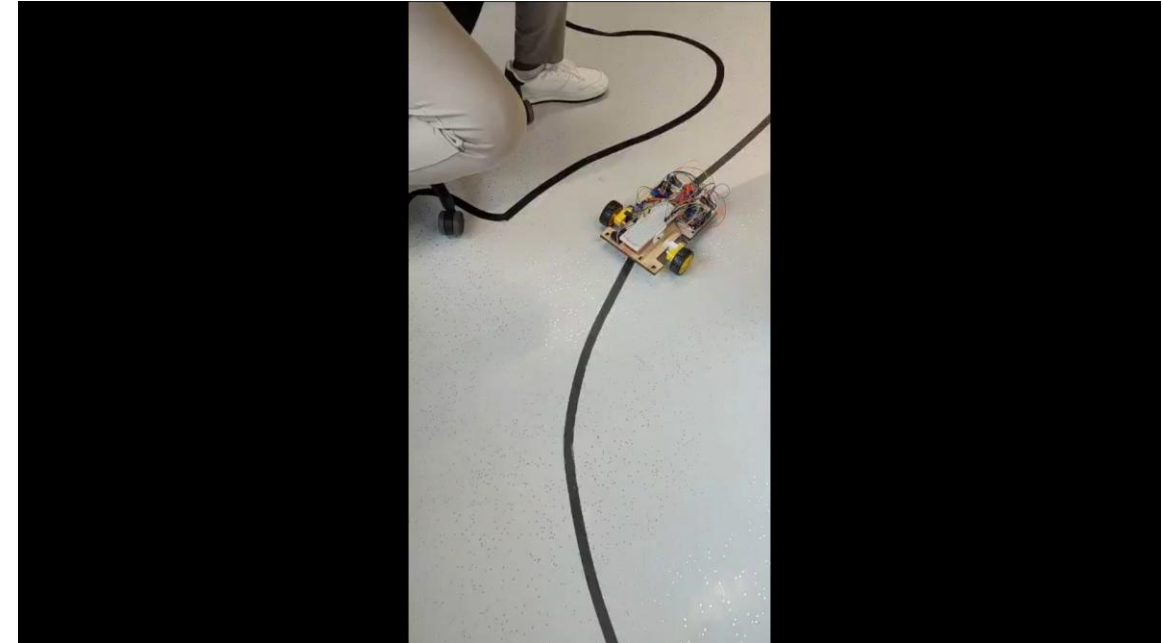
23.06.2025

TEAM B 4


- \*CHIMEZIE DANIEL C.
- \*CHO BERTRAND MUNGU
- \*GHIMIRE RIWAJ

# WHAT IS AN AUTONOMOUS VEHICLE ?

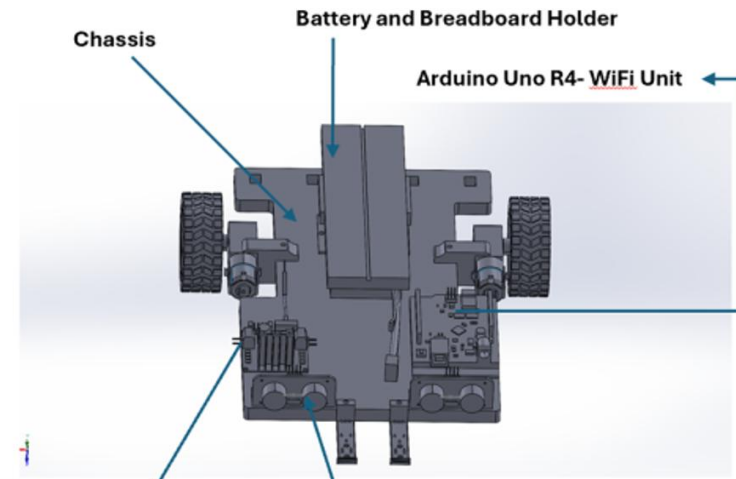
According to IEEE standards association: "An autonomous vehicle is a system capable of sensing its environment and operating without human involvement. Such systems are designed to navigate and perform driving functions without direct human input, using onboard sensors, processors, and actuators" [1].



Play the short video above by:

1. Place your mouse above the black image / select the video pan. Then, press alt+p on a German keyboard.
2. Alternatively, highlight the video pan above, you will see a nub  **above** to play the video manually.

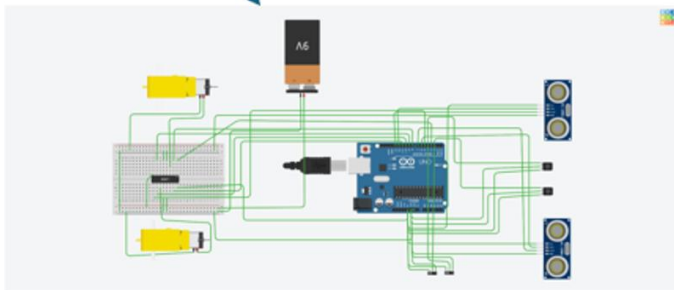
# SYSTEM OVERVIEW



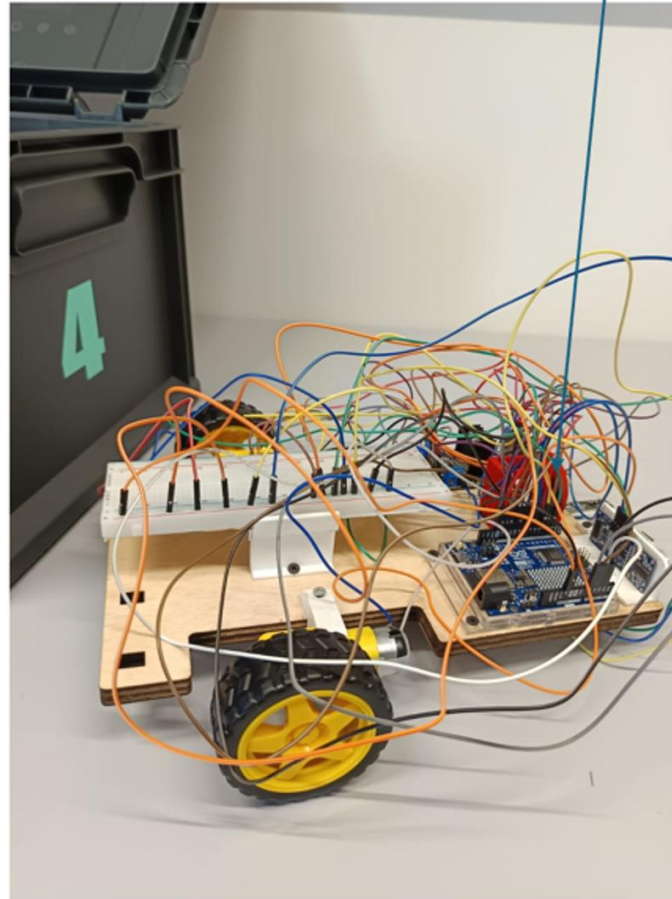
Motor Controller(1 units)

Ultrasonic Sensor (2 units)

Parts connection layout



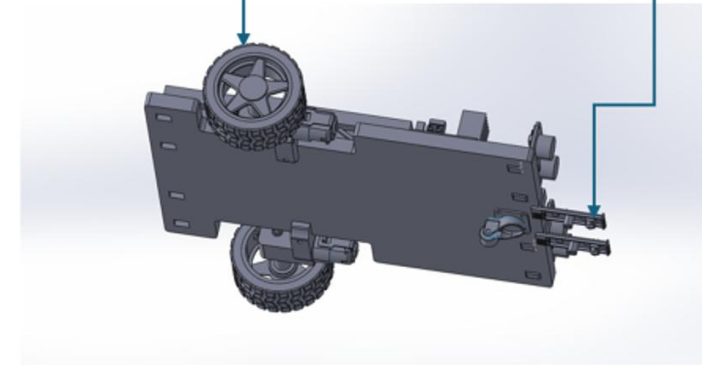
Colour Sensor in red (1 unit)



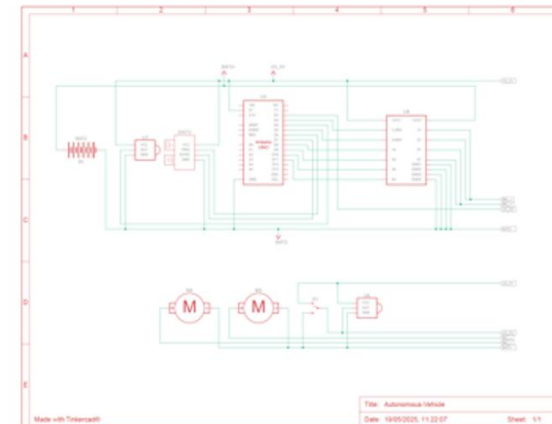
Physically assembled parts for testing

Motor Tyres (2 Units)

IR Sensor (2 units)

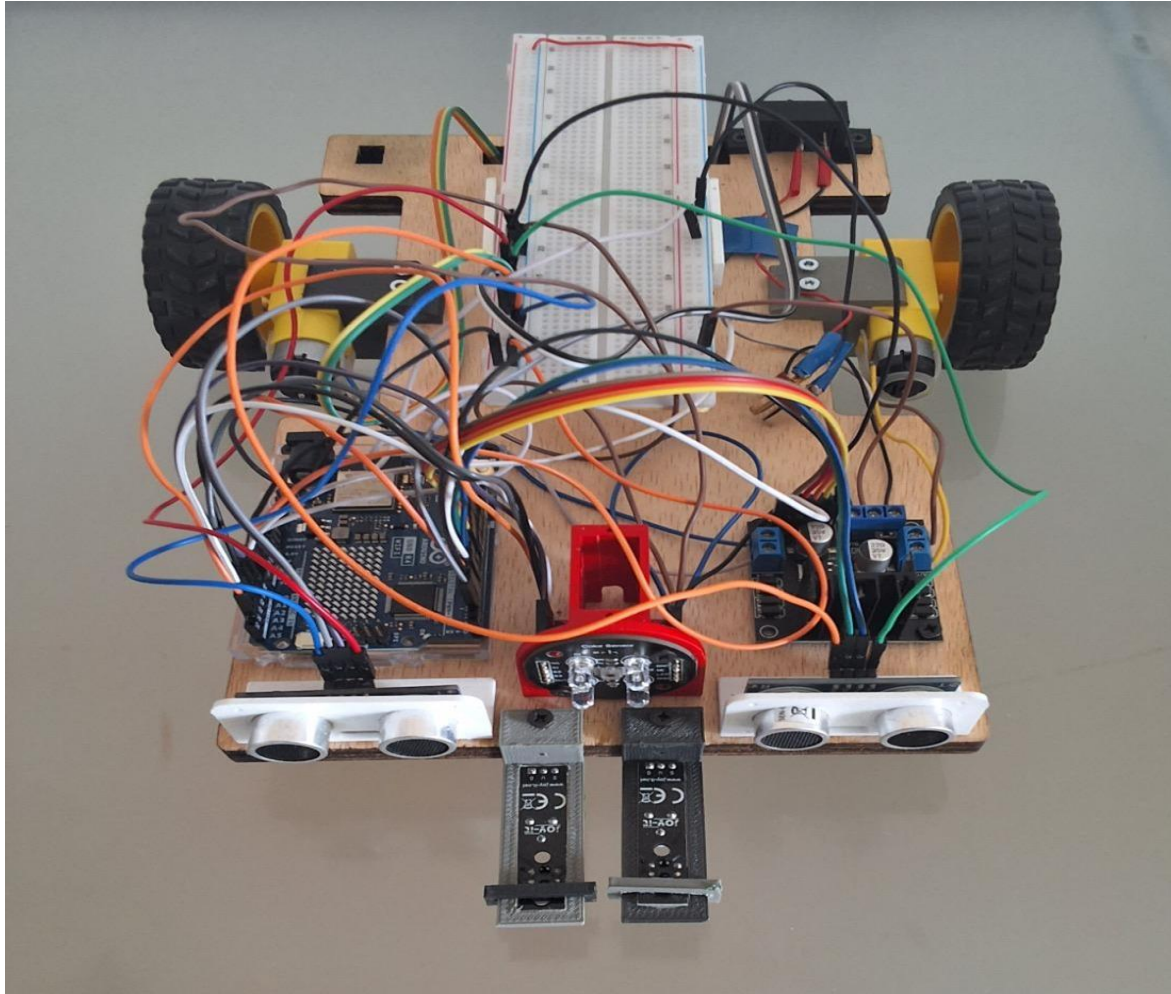


Wiring Plan





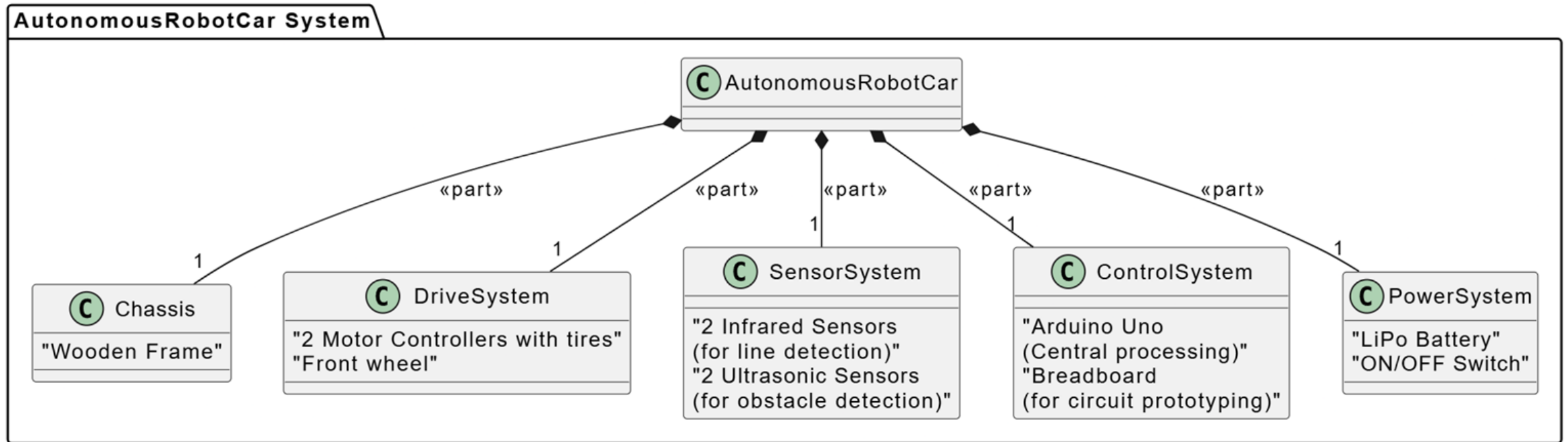
# PROJECT OBJECTIVE



- Autonomous Vehicle should follow a lane using IR sensors
- Detects and avoids obstacles using ultrasonic sensors
- Makes navigation decisions autonomously with color sensor input
- Arduino Uno based with standard robotics components

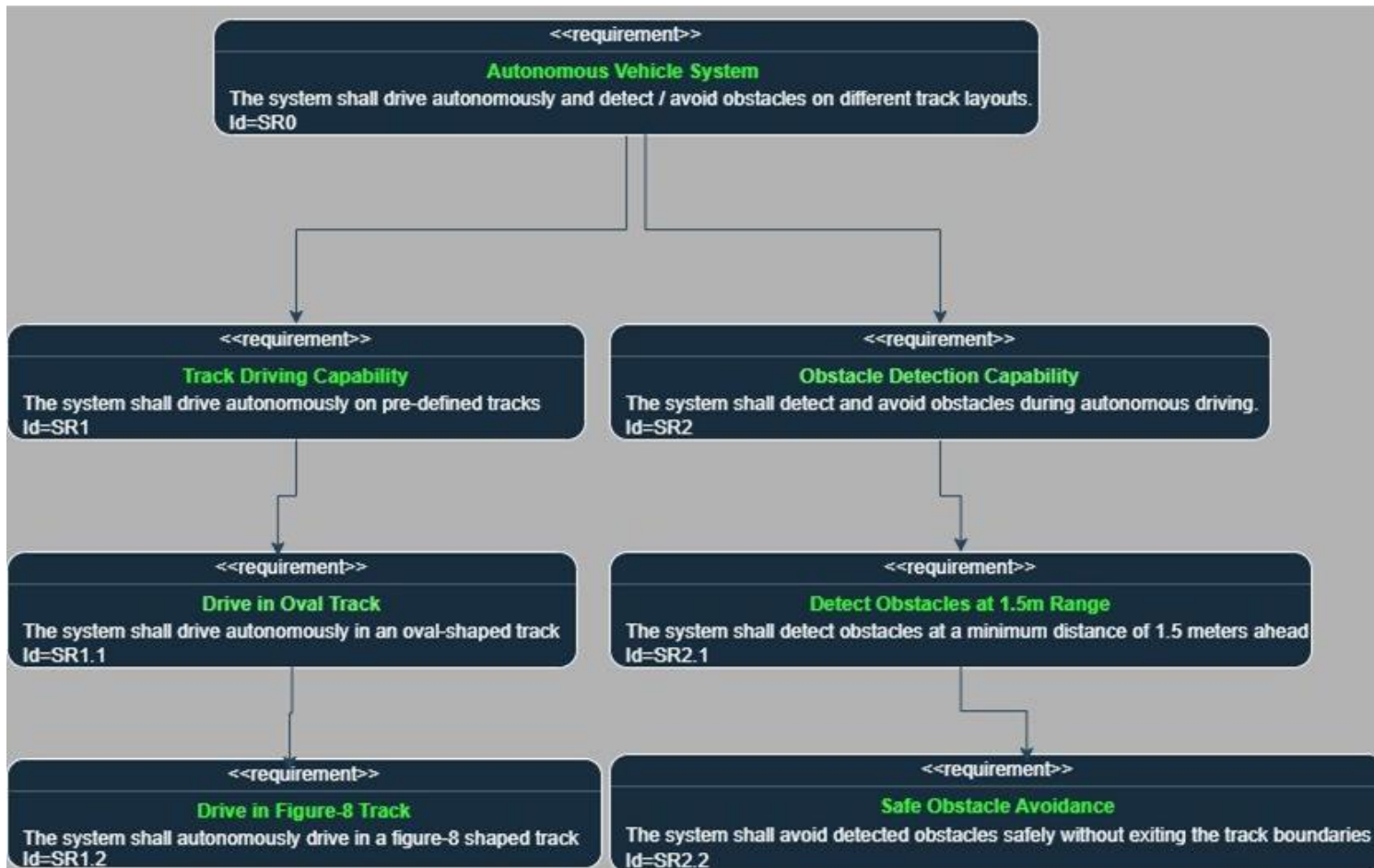
# SYSTEMS ENGINEERING DIAGRAMS

## 1. System Architecture (SysML BDD)



# SYSTEMS ENGINEERING DIAGRAMS

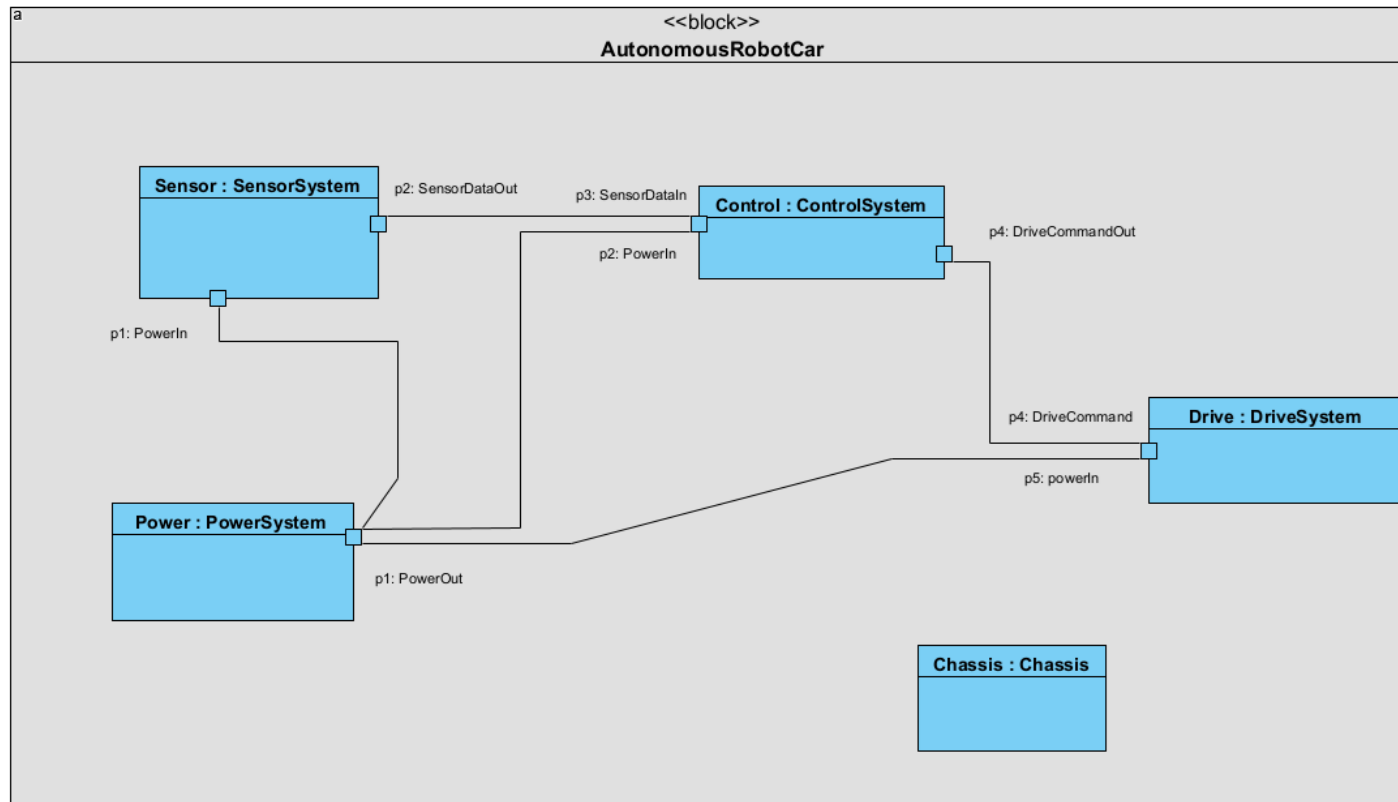
## 2. Requirement diagram



# SYSTEMS ENGINEERING DIAGRAMS

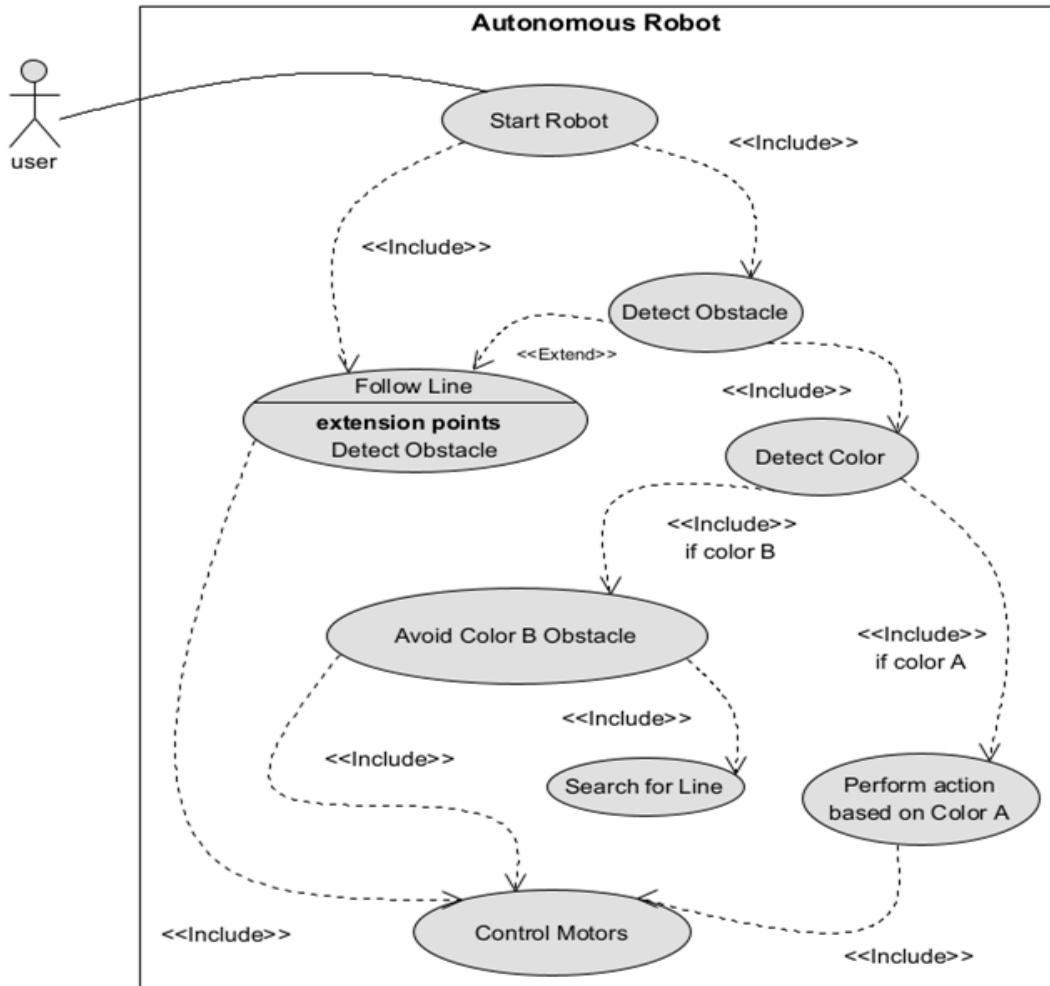
## 3. Internal Block Diagram

ibd [Package Block Definition Diagram Internal Block Diagram]



# SYSTEMS ENGINEERING DIAGRAMS

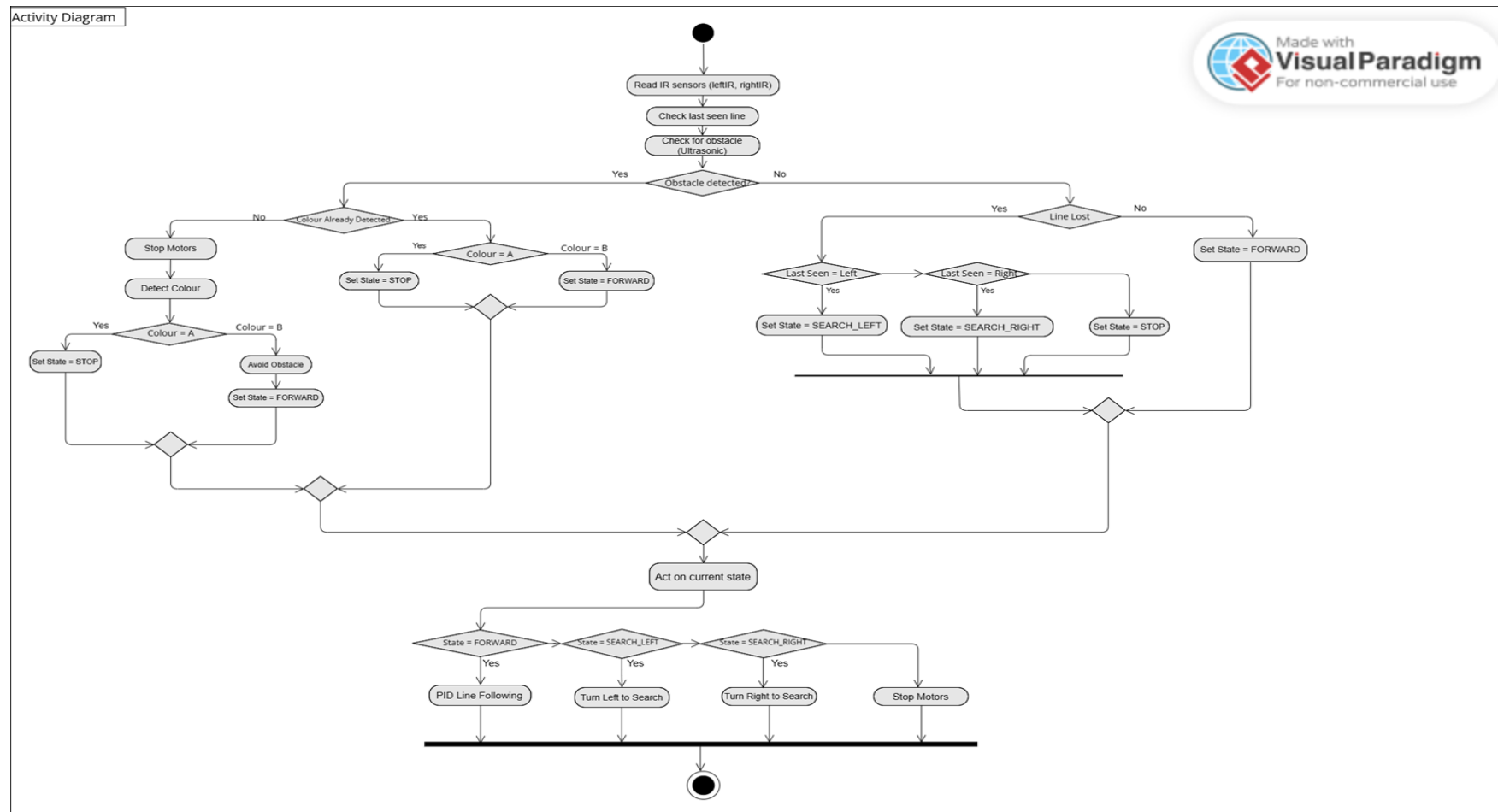
## 4. Use Case Diagram





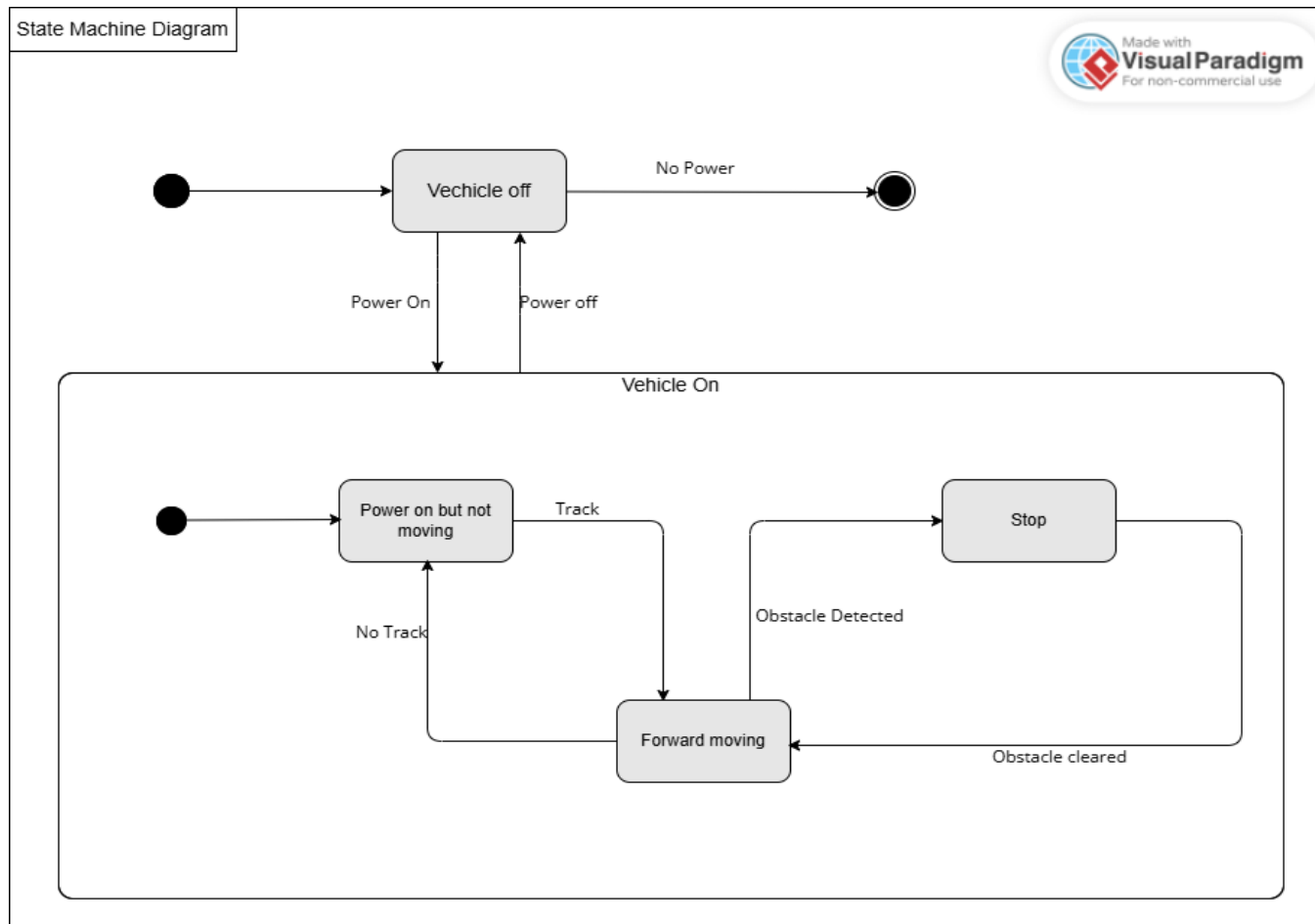
# SYSTEMS ENGINEERING DIAGRAMS

## 5.0 Activity Diagram



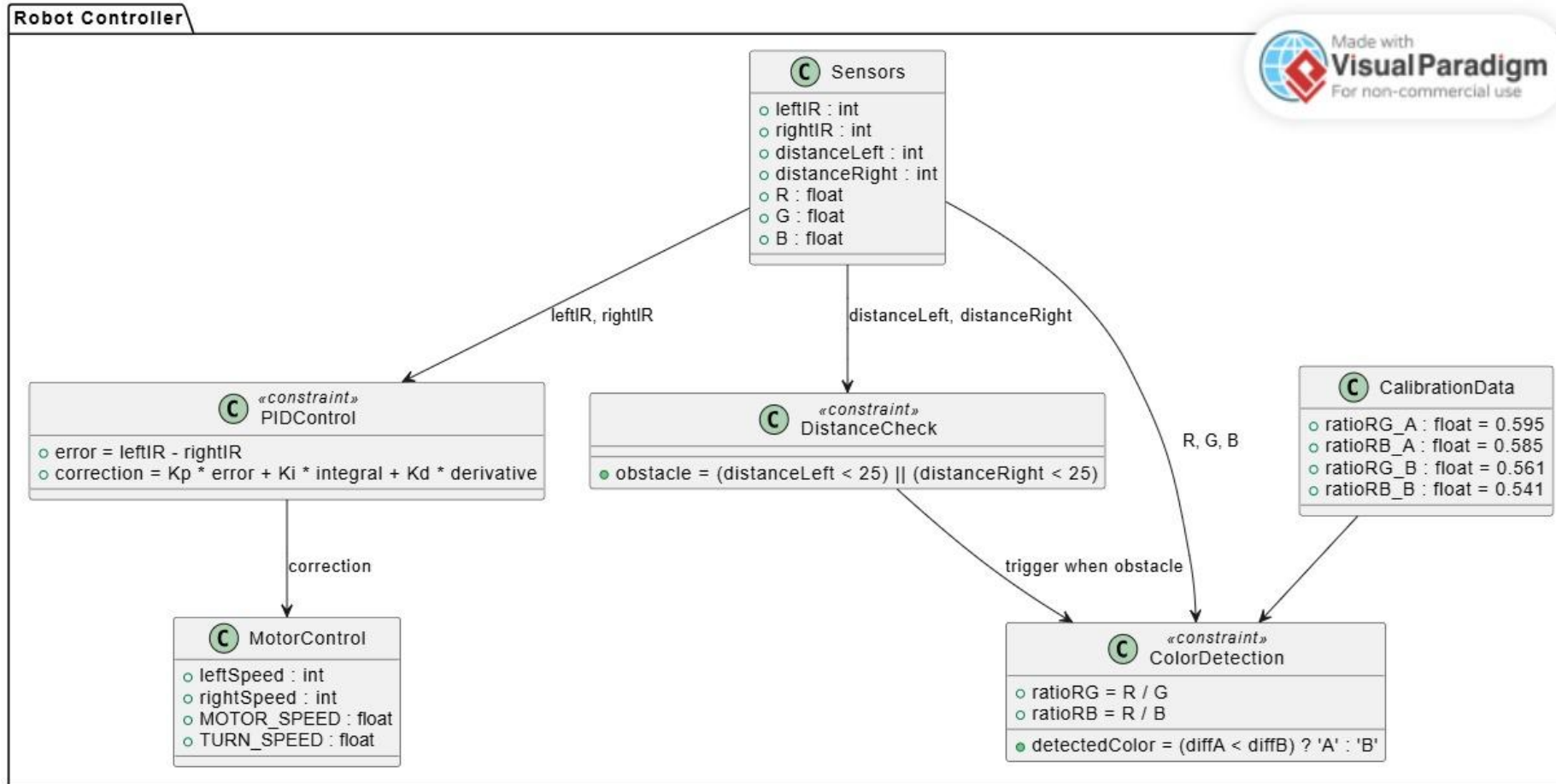
# SYSTEMS ENGINEERING DIAGRAMS

## 6.0 State Machine Diagram

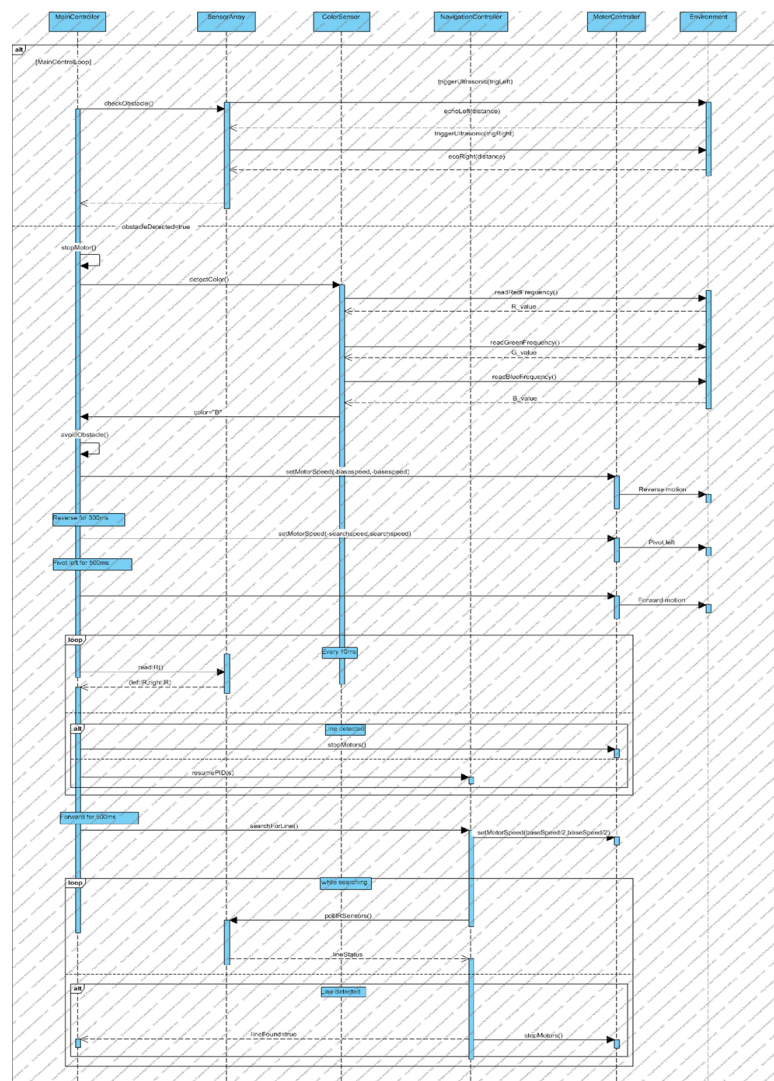


# SYSTEMS ENGINEERING DIAGRAMS

## 7.0 Parametric Diagram



## 8.0 Sequence Diagram

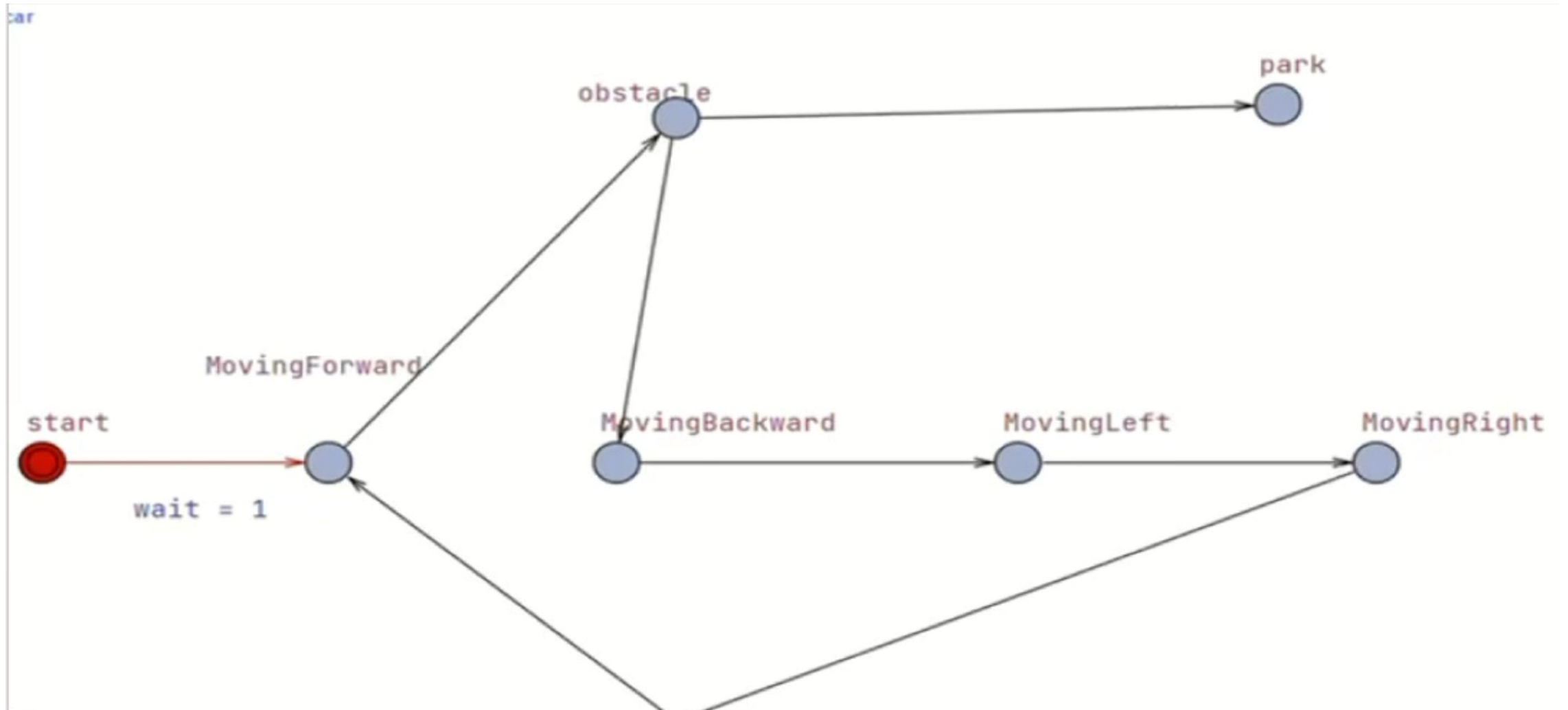




# **CODING, TESTING AND IMPLEMENTATION**



## UPAAL ANALYSIS



## Implementation Snapshot-Movement Logic

```
6
7 void MovementController::updateState(bool obstacleDetected, char lastDetectedColor, MovementState& currentStateRef, LastSeen& lastSeenRef) {
8     bool leftIR = leftIRSensor.isLineDetected();
9     bool rightIR = rightIRSensor.isLineDetected();
10
11     if (leftIR && !rightIR) lastSeenRef = LEFT;
12     else if (rightIR && !leftIR) lastSeenRef = RIGHT;
13
14     if (obstacleDetected && lastDetectedColor == 'A') {
15         currentStateRef = STOP;
16     } else if (obstacleDetected && lastDetectedColor == 'B') {
17         currentStateRef = FORWARD;
18     } else if (!leftIR && !rightIR) {
19         if (lastSeenRef == LEFT) currentStateRef = SEARCH_LEFT;
20         else if (lastSeenRef == RIGHT) currentStateRef = SEARCH_RIGHT;
21         else currentStateRef = STOP;
22     } else {
23         currentStateRef = FORWARD;
24     }
25 }
```

## Implementation Snapshot- Act on Movement State

```
26
27 void MovementController::act(MovementState state) {
28     switch (state) {
29     case STOP:
30         motorController.stop();
31         break;
32
33     case FORWARD: {
34         int error = leftIRSensor.isLineDetected() - rightIRSensor.isLineDetected();
35         float correction = pid.compute(error);
36
37         int leftSpeed = constrain(baseSpeed - correction, 0, 255);
38         int rightSpeed = constrain(baseSpeed + correction, 0, 255);
39         motorController.setSpeed(leftSpeed, rightSpeed);
40         break;
41     }
42
43     case SEARCH_LEFT:
44         motorController.setSpeed(-searchSpeed, searchSpeed);
45         break;
46
47     case SEARCH_RIGHT:
48         motorController.setSpeed(searchSpeed, -searchSpeed);
49         break;
50     }
51 }
```

## Implementation Snapshot- Setup code with setup function example

```
58
59 void setup() {
60     Serial.begin(9600);
61
62     // Initialize hardware components
63     leftIRSensor.begin();
64     rightIRSensor.begin();
65     leftUltrasonic.begin();
66     rightUltrasonic.begin();
67     colorSensor.begin();
68     leftMotor.begin();
69     rightMotor.begin();
70
71     motorController.stop();
72     obstacleChecker.setColorCalibration(colorA, colorB);
73 }
74
```

```
5
6 void Motor::begin() {
7     pinMode(_enPin, OUTPUT);
8     pinMode(_in1Pin, OUTPUT);
9     pinMode(_in2Pin, OUTPUT);
10 }
11
```

```
7 void ColorSensor::begin() {
8     pinMode(_s0, OUTPUT);
9     pinMode(_s1, OUTPUT);
10    pinMode(_s2, OUTPUT);
11    pinMode(_s3, OUTPUT);
12    pinMode(_outPin, INPUT);
13
14    digitalWrite(_s0, HIGH);
15    digitalWrite(_s1, LOW);
16 }
17
```

## Implementation Snapshot- Inside Loop

```
74
75 void loop() {
76     // Check for obstacles
77     obstacleChecker.check();
78
79     if (obstacleChecker.isObstacleDetected()) {
80         motorController.stop();
81         delay(100);
82         obstacleChecker.check(false); // Check color while stopped
83
84         char color = obstacleChecker.getLastDetectedColor();
85         if (color == 'A') {
86             Serial.println("Action: STOP for Color A");
87         } else if (color == 'B') {
88             Serial.println("Action: AVOID OBSTACLE for Color B");
89             obstacleHandler.handleObstacle();
90         }
91     }
92
93     // Update movement state (IR + obstacle + color)
94     movementController.updateState(
95         obstacleChecker.isObstacleDetected(),
96         obstacleChecker.getLastDetectedColor(),
97         movementController.getCurrentStateRef(),
98         movementController.getLastSeenRef()
99     );
100
101     // Act based on current movement state
102     movementController.act(movementController.getCurrentState());
103 }
104
```



## Implementation Snapshot- Obstacle Checker and Detecting Color

```
7
8 void ObstacleChecker::setColorCalibration(const ColorCalibration& a, const ColorCalibration& b) {
9     colorA = a;
10    colorB = b;
11 }
12
13 bool ObstacleChecker::isObstacleDetected() const {
14     return obstacleDetected;
15 }
16
17 char ObstacleChecker::getLastDetectedColor() const {
18     return lastDetectedColor;
19 }
20
21 void ObstacleChecker::check(bool shouldStopBeforeColorDetection) {
22     unsigned long currentMillis = millis();
23     if (currentMillis - lastCheck < interval) return;
24
25     lastCheck = currentMillis;
26
27     int distanceLeft = leftUltrasonic.getDistance();
28     int distanceRight = rightUltrasonic.getDistance();
29     bool obstacleNow = (distanceLeft > 0 && distanceLeft < 25) ||
30     || || || || || || || (distanceRight > 0 && distanceRight < 25);
31
32     if (obstacleNow && !colorDetectedThisCycle) {
33         if (shouldStopBeforeColorDetection) {
34             Serial.println("Obstacle detected. Waiting before detecting color...");
35             delay(100); // Give robot time to settle if caller already stopped it
36         }
37
38         lastDetectedColor = colorSensor.detectColor(colorA, colorB);
39         colorDetectedThisCycle = true;
40     } else if (!obstacleNow) {
41         colorDetectedThisCycle = false;
42         lastDetectedColor = 'N';
43     }
44
45     obstacleDetected = obstacleNow;
46 }
47
```

## Implementation Snapshot- PID Logic

```
5  
6 float PIDController::compute(float error) {  
7     float derivative = error - _previousError;  
8     _integral += error;  
9     float output = _kp * error + _ki * _integral + _kd * derivative;  
10    _previousError = error;  
11    return output;  
12 }  
13  
14 void PIDController::reset() {  
15     _previousError = 0;  
16     _integral = 0;  
17 }  
18 |
```

## Implementation Snapshot- Set Motor Speed

```
12 void Motor::setSpeed(int speed, Direction direction) {
13     if (direction == Direction::FORWARD) {
14         digitalWrite(_in1Pin, HIGH);
15         digitalWrite(_in2Pin, LOW);
16     } else {
17         digitalWrite(_in1Pin, LOW);
18         digitalWrite(_in2Pin, HIGH);
19     }
20
21     analogWrite(_enPin, constrain(abs(speed), 0, 255));
22 }
23
24 void Motor::stop() {
25     analogWrite(_enPin, 0);
26     digitalWrite(_in1Pin, LOW);
27     digitalWrite(_in2Pin, LOW);
28 }
29
```

## Implementation Snapshot- Color sensor

```
18 char ColorSensor::detectColor(const ColorCalibration& colorA, const ColorCalibration& colorB) {
19     const int samples = 5;
20     long rSum = 0, gSum = 0, bSum = 0;
21
22     for (int i = 0; i < samples; i++) {
23         int r = readFrequency(LOW, LOW);
24         int g = readFrequency(HIGH, HIGH);
25         int b = readFrequency(LOW, HIGH);
26
27         rSum += r;
28         gSum += g;
29         bSum += b;
30
31         delay(100);
32     }
33
34     float rAvg = rSum / (float)samples;
35     float gAvg = gSum / (float)samples;
36     float bAvg = bSum / (float)samples;
37
38     float ratioRG = rAvg / gAvg;
39     float ratioRB = rAvg / bAvg;
40
41     Serial.println("-----");
42     Serial.print("R="); Serial.print(rAvg, 1);
43     Serial.print(" G="); Serial.print(gAvg, 1);
44     Serial.print(" B="); Serial.print(bAvg, 1);
45     Serial.print(" | RatioRG="); Serial.print(ratioRG, 3);
46     Serial.print(" RatioRB="); Serial.println(ratioRB, 3);
47
48     float diffA = abs(ratioRG - colorA.ratioRG) + abs(ratioRB - colorA.ratioRB);
49     float diffB = abs(ratioRG - colorB.ratioRG) + abs(ratioRB - colorB.ratioRB);
50
51     if (diffA < diffB) {
52         Serial.println("Detected Color: A");
53         Serial.println("-----");
54         return 'A';
55     } else {
56         Serial.println("Detected Color: B");
57         Serial.println("-----");
58         return 'B';
59     }
```

## Challenges and solutions

### 1. IR Sensor Calibration

- ❑ *Issue*: Unreliable black tape detection
- ❑ *Fix*: Adjusted angle + threshold calibration

### 2. Ultrasonic Sensor Range

- ❑ *Issue*: Inconsistent obstacle readings
- ❑ *Fix*: Tuned to 2-400 cm range + noise filtering

### 3. Color Sensor Stability

- ❑ *Issue*: Fluctuating RGB values
- ❑ *Fix*: Averaged readings + ratio normalization

### 4. Motor Control @ 12V

- ❑ *Issue*: Uncontrollable speed
- ❑ *Fix*: Unmasked enable pins + PWM limits

### 5. Line Following PID

- ❑ *Issue*: Jerky turns
- ❑ *Fix*: Implemented PID ( $K_p=10.0$ ,  $K_i=0.00$ ,  $K_d=10.0$ )



## Conclusion and Future Projections

### Conclusion

- Successfully built an autonomous vehicle using:
  - Infrared sensors
  - Ultrasonic sensors
  - color sensor
- System operated without human intervention using Arduino-based control.
- Demonstrated stable navigation, responsive obstacle handling, and consistent performance on a contrast-based track.

### Future Work

- Machine Learning Integration
- Vision System Enhancement



## Reference

[1] IEEE Standards Association, *Autonomous Systems Framework Working Group: P2040 Draft Standard for Framework for Autonomous Systems*, IEEE, 2020. [Online]. Available: <https://standards.ieee.org>



THANK  
YOU !