```python
# Created by arthavnuc

import numpy as np
import heapq
import time
import cv2
from collections import deque
from canvas import Canvas
from helpers import *
import threading
from robot import Robot
from math import hypot


DEBUG = False
# A container to hold multiple time values in key: value pair to be used for analysis at the
termination of program
time_dict = {}

# Defining some colors for visualization in BGR
#  obstacle space
# WHITE denotes free space
WHITE = (255, 255, 255)
# final path tracing
RED = (0, 0, 255)
# explored nodes
GREEN = (0, 255, 0)
NAVY_BLUE = (42, 27, 13)

BLUE = (255, 0, 0)


file = open("logs.txt", "w")


class DataQueue:
    def __init__(self, max_size=100):
        self.queue = deque()
        self.max_size = max_size
        self.lock = threading.Lock()

    def put(self, item):
        with self.lock:
            if len(self.queue) == self.max_size:
                self.queue.popleft()
            self.queue.append(item)

    def get(self):
        with self.lock:
            if self.queue:
                return self.queue.popleft()
            return None

    def get_all(self):
        with self.lock:
            items = list(self.queue)
            self.queue.clear()
            return items


class Search:
    """
    Search class encapsulating the A* algorithm.
    """

    def __init__(self, robot, canvas):
        # A container to store nodes in dictionary. The dict to store only unique nodes
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        self.goal_reached = False
        self.nodes_dict = {}
        self.path: list[Node] = []
        # A container to store the nodes
        self.queue = []
        self.robot: Robot = robot
        self.canvas: Canvas = canvas
        self.search_start = self.get_start()
        self.search_goal = self.get_goal()
        self.search_last_node = None
        self.robot.RPM1, self.robot.RPM2 = self.get_wheel_rpms()
        # self.search_start = Point(500, HEIGHT - 300, -90)
        # self.search_goal = GoalPt(5000, HEIGHT - 3000, 150)

    def get_start(self):
        print("Enter Start Coordinates (x y):")
        while True:
            try:
                x_s, y_s, theta_s = map(
                    int,
                    input(
                        f"Start (x y θ) [Note: (0 ≤ x ≤ {self.canvas.width - 1}), (0 ≤ y ≤
{self.canvas.height - 1}), (-180 ≤ θ < 180)]: "
                    ).split(),
                )

                if not (0 <= x_s < self.canvas.width and 0 <= y_s < self.canvas.height):
                    print("Coordinates are out of bounds... Try again")
                    continue

                if self.canvas.is_colliding(
                    round(x_s), round(self.canvas.height / 2 - y_s)
                ):
                    print("Start position is colliding... Try again")
                    continue

                if not (-180 <= theta_s < 180):
                    print("Orientation is out of bounds... Try again")

                print(
                    f"Start point validated: Start (x y θ) = ({x_s}, {y_s}, {theta_s})"
                )
                return Point(x_s, self.canvas.height / 2 - y_s, theta_s)

            except ValueError:
                print("Error: Enter three numbers separated by a space")

    def get_goal(self):
        print("Enter Goal Coordinates (x y):")
        while True:
            try:
                x_g, y_g, radius = map(
                    int,
                    input(
                        f"Goal (x y R) [Note: (0 ≤ x ≤ {self.canvas.width - 1}), (0 ≤ y ≤
{self.canvas.height - 1})]: "
                    ).split(),
                )

                if not (0 <= x_g < self.canvas.width and 0 <= y_g < self.canvas.height):
                    print("Coordinates are out of bounds... Try again")
                    continue

                if self.canvas.is_colliding(
                    round(x_g), round(self.canvas.height / 2 - y_g)
                ):
                    print("Goal position is colliding... Try again")
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                    continue

                print(f"Goal point validated: Goal (x y R) = ({x_g}, {y_g}, {radius})")
                return GoalPt(x_g, self.canvas.height / 2 - y_g, radius)

            except ValueError:
                print("Error: Enter three numbers separated by a space")

    def get_wheel_rpms(self):
        while True:
            try:
                RPM1, RPM2 = map(
                    float,
                    input(f"Enter Wheel RPMs (RPM1 RPM2) (must be > 0): ").split(),
                )

                if RPM1 <= 0 or RPM2 <= 0:
                    print("RPM values cannot be non-positive")
                    continue

                print(f"Wheel RPMs validated: (RPM1 RPM2) = ({RPM1}, {RPM2})")
                return RPM1, RPM2

            except ValueError:
                print("Invalid input. Please enter numeric values for RPMs.")

    def reached_goal(self, x, y, goal: GoalPt):
        """
        Termination condition if robot reached the goal region, In this Project ignoring the
goal theta  so basically robot can be in any orientation in goal region
        :param x: Current X coordinate
        :param y: Current Y coordinate
        :param goal: Goal region (X,Y,Radius)
        :return: Boolean
        """
        if (x - goal.x) ** 2 + (y - goal.y) ** 2 < goal.radius**2:
            return True
        else:
            return False

    def plotter(self, dataq: DataQueue, stop_event: threading.Event):
        canvas_copy = self.canvas.canvas.copy()
        while not stop_event.is_set():
            new_data = dataq.get_all()
            if new_data:
                for x, y in new_data:
                    cv2.circle(
                        canvas_copy,
                        (int(x), int(y)),
                        5,
                        RED,
                        5,
                    )
                scaled_canvas = cv2.resize(
                    canvas_copy,
                    (
                        int(self.canvas.width * self.canvas.multiplier),
                        int(self.canvas.height * self.canvas.multiplier),
                    ),
                    interpolation=cv2.INTER_AREA,
                )
                cv2.imshow(f"Map Scaled {self.canvas.multiplier} times", scaled_canvas)

            if cv2.waitKey(1) & 0xFF == ord("q"):
                break

        cv2.waitKey(0)
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        cv2.destroyAllWindows()

    def heuristic(self, node: Point, goal):
        """
        Heuristic function for A*. Since C-space is R^2 using Euclidean distance
        Args:
            node: point 1
            goal: point 2

        Returns: Euclidean distance between node and goal

        """
        return hypot(goal.x - node.x, goal.y - node.y)

    def a_star(self):
        """
        Main function for A* algorithm. All the valid actions are defined here. The robot is
non-holonomic and consists of 8 actions given as an differential RPM pair:
        This includes (RPM1, 0), (0, RPM1), (RPM2, 0), (0, RPM2), (RPM1, RPM2), (RPM2, RPM1),
(RPM1, RPM1), (RPM2, RPM2)
        Args:
            start: start point(X,Y,Theta) in graph
            goal: goal region (X,Y,Radius) in graph
        Returns: Boolean: True is an optimal path is found, False otherwise
        """
        # start_time = time.perf_counter()

        # Create grid of x, y coordinates
        stop_event = threading.Event()
        data_queue = DataQueue()
        plotter_thread = threading.Thread(
            target=self.plotter,
            args=(data_queue, stop_event),
        )
        plotter_thread.start()

        self.nodes_dict.clear()
        start_node = Node(
            self.search_start.x, self.search_start.y, self.search_start.theta, 0
        )
        start_node.total_cost = self.heuristic(self.search_start, self.search_goal)
        valid_actions = self.robot.valid_actions

        print(f"Start:{start_node}")
        print(f"Goal:{self.search_goal}")
        heapq.heappush(self.queue, start_node)
        self.goal_reached = False
        self.nodes_dict = {
            Point(start_node.x, start_node.y, start_node.theta): start_node
        }

        early_exit = False
        try:
            while self.queue:
                if early_exit:
                    break

                node: Node = heapq.heappop(self.queue)
                # TODO do we need this ??
                if self.reached_goal(node.x, node.y, self.search_goal):
                    self.nodes_dict["last"] = node
                    self.search_last_node = node
                    self.goal_reached = True
                    print(f"Goal found at {node}")
                    break

                if DEBUG:
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                    print(f"Exploring node: {node}")
                    file.write(f"Exploring node: {node}\n")

                for act_idx, action in enumerate(valid_actions):
                    waypoints, cost = action(node)
                    # Check waypoints and endpoint for collisions with the obstacles or the wall
                    is_colliding = False
                    is_wp_near_goal = False
                    wp_goal_idx: int = None
                    for wp_idx, wp in enumerate(waypoints):
                        data_queue.put((wp.x, wp.y))
                        if self.canvas.is_colliding(round(wp.x), round(wp.y)) or not (
                            0 <= wp.x < self.canvas.width
                            and 0 <= wp.y < self.canvas.height
                        ):
                            is_colliding = True
                            break

                        # Not colliding, but check for the cornercase where the waypoint itself is the near the Goal
                        if self.reached_goal(wp.x, wp.y, self.search_goal):
                            is_wp_near_goal = True
                            wp_goal_idx = wp_idx
                            break

                    if is_colliding:
                        if DEBUG:
                            print(
                                f"Collision detected while exploring {node}, discarding action {act_idx}"
                            )
                            file.write(
                                f"Collision detected while exploring {node}, discarding action {act_idx}\n"
                            )
                        continue  # At least one waypoint is colliding, so exclude this action and proceed with the next one

                    if is_wp_near_goal:
                        # The waypoint is near the goal, so add it as a node and proceed
                        wp_goal: WayPoint = waypoints[wp_goal_idx]
                        wp_goal_node: Node = Node(
                            wp_goal.x,
                            wp_goal.y,
                            wp_goal.theta,
                            node.c2c + wp_goal.edgecost,
                        )
                        wp_goal_node.total_cost = wp_goal_node.c2c + self.heuristic(
                            Point(wp_goal_node.x, wp_goal_node.y, wp_goal_node.theta),
                            self.search_goal,
                        )
                        wp_goal_node.visited = True
                        wp_goal_node.parent = node
                        wp_goal_node.waypoints = waypoints[:wp_goal_idx]
                        self.nodes_dict["last"] = wp_goal_node
                        self.nodes_dict[
                            Point(wp_goal_node.x, wp_goal_node.y, wp_goal_node.theta)
                        ] = wp_goal_node
                        self.search_last_node = wp_goal_node
                        print(f"Goal found near waypoint at {wp_goal_node}")
                        if DEBUG:
                            file.write(f"Goal found near waypoint at {wp_goal_node}\n")
                        early_exit = True
                        self.goal_reached = True
                        break
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                    # Check in dictionary if the node exists at the point, else create a new
node at the last waypoin
                    next_node = self.nodes_dict.get(
                        Point(
                            waypoints[-1].x,
                            waypoints[-1].y,
                            waypoints[-1].theta,
                        ),
                        Node(
                            waypoints[-1].x,
                            waypoints[-1].y,
                            waypoints[-1].theta,
                            0,
                        ),
                    )
                    if (next_node.c2c > node.c2c + cost) or not next_node.visited:
                        # Updating total cost to ctoc with heuristic, total cost and parent
and marking it as visited
                        next_node.c2c = node.c2c + cost
                        next_node.total_cost = next_node.c2c + self.heuristic(
                            Point(next_node.x, next_node.y, 0), self.search_goal
                        )
                        next_node.visited = True
                        next_node.parent = node
                        heapq.heappush(self.queue, next_node)
                        self.nodes_dict[
                            Point(next_node.x, next_node.y, next_node.theta)
                        ] = next_node
                        next_node.waypoints = waypoints
                        if DEBUG:
                            print(f"Added node: {next_node}")
                            file.write(f"Added node: {next_node}\n")
                    elif DEBUG:
                        print(
                            f"Discarded node: {next_node} because {next_node.visited == False}
and {next_node.c2c > node.c2c + cost}"
                        )
                        file.write(
                            f"Discarded node: {next_node} because {next_node.visited == False}
and {next_node.c2c > node.c2c + cost}\n"
                        )

        except KeyboardInterrupt:
            pass

        finally:
            stop_event.set()
            plotter_thread.join()
            cv2.destroyAllWindows()
            print("Program terminated.")

        if not self.goal_reached:
            print(f"No path found! Queue: {self.queue}")
            return False
        return True

    def backtrack_path(self):
        """
        Backtracks from the goal to the start using the dict
        """
        start_time = time.perf_counter()
        path = []
        # Backtracking using the parent in node
        g = self.nodes_dict.pop("last")
        for _ in iter(int, 1):
            path.append(g)
            if g.parent.x == self.search_start.x and g.parent.y == self.search_start.y:
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                break
            g = g.parent
        path.append(g)
        path.reverse()
        end_time = time.perf_counter()
        time_dict["Backtracking"] = end_time - start_time
        self.path: list[Node] = path

    def animate_search(self):
        """
        Visualizes the explored nodes of graph.
        """
        if not self.goal_reached:
            return

        canvas_copy = self.canvas.canvas.copy()
        cv2.circle(
            canvas_copy,
            (round(self.search_start.x), round(self.search_start.y)),
            15,
            GREEN,
            15,
        )
        cv2.circle(
            canvas_copy,
            (round(self.search_goal.x), round(self.search_goal.y)),
            self.search_goal.radius,
            BLUE,
            5,
        )

        for point, node in self.nodes_dict.items():
            for wp in node.waypoints:
                cv2.circle(canvas_copy, (int(wp.x), int(wp.y)), 5, RED, 5)

            scaled_canvas = cv2.resize(
                canvas_copy,
                (
                    round(self.canvas.width * self.canvas.multiplier),
                    round(self.canvas.height * self.canvas.multiplier),
                ),
                interpolation=cv2.INTER_AREA,
            )
            cv2.imshow(f"Map Scaled {self.canvas.multiplier} times", scaled_canvas)
            if cv2.waitKey(1) & 0xFF == ord("q"):
                break

        for node in self.path:
            for wp in node.waypoints:
                cv2.circle(canvas_copy, (round(wp.x), round(wp.y)), 20, NAVY_BLUE, 20)

            scaled_canvas = cv2.resize(
                canvas_copy,
                (
                    round(self.canvas.width * self.canvas.multiplier),
                    round(self.canvas.height * self.canvas.multiplier),
                ),
                interpolation=cv2.INTER_AREA,
            )
            cv2.imshow(f"Map Scaled {self.canvas.multiplier} times", scaled_canvas)
            time.sleep(0.1)
            if cv2.waitKey(1) & 0xFF == ord("q"):
                break

        cv2.waitKey(0)
        cv2.destroyAllWindows()
```

```python
from helpers import *
from math import sin, cos, sqrt, pi as PI, radians, degrees
import numpy as np
from scipy.spatial.transform import Rotation as R

class Robot:
    def __init__(self, wheel_radius, robot_radius):
        self.dt = 0.1
        self.R = wheel_radius
        self.L = robot_radius
        self.r = self.L / 2
        self.RPM1 = 50
        self.RPM2 = 100
        self.valid_actions = [
            self.sharp_right_R1,
            self.sharp_left_R1,
            self.straight_R1,
            self.sharp_right_R2,
            self.sharp_left_R2,
            self.straight_R2,
            self.gradual_turn_R1R2,
            self.gradual_turn_R2R1,
        ]

    def transform_map_to_robot(self,x,y,yaw):
        # ---- Pose in Frame A ----
        position_A = np.array([x, y, 0.0])
        orientation_A = R.from_euler('xyz', [0, 0, yaw], degrees=True).as_matrix()

        # Homogeneous transformation matrix of pose in A
        T_pose_in_A = np.eye(4)
        T_pose_in_A[:3, :3] = orientation_A
        T_pose_in_A[:3, 3] = position_A

        # ---- Transform from Frame A to Frame B ----
        # Example: Frame B is rotated and translated w.r.t Frame A
        rotation_AB = R.from_euler('xyz', [-180, 0, 0], degrees=True).as_matrix()
        translation_AB = np.array([0, 0, 0])

        T_AB = np.eye(4)
        T_AB[:3, :3] = rotation_AB
        T_AB[:3, 3] = translation_AB

        # Now transform the pose from frame A to frame B
        T_pose_in_B = np.linalg.inv(T_AB) @ T_pose_in_A

        # Extract the new position and orientation
        position_B = T_pose_in_B[:3, 3]
        orientation_B = R.from_matrix(T_pose_in_B[:3, :3]).as_euler('xyz', degrees=True)

        return position_B[0], position_B[1], orientation_B[2]


    def transform_robot_to_map(self,x,y,yaw):
        # ---- Pose in Frame A ----
        position_A = np.array([x, y, 0.0])
        orientation_A = R.from_euler('xyz', [0, 0, yaw], degrees=True).as_matrix()

        # Homogeneous transformation matrix of pose in A
        T_pose_in_A = np.eye(4)
        T_pose_in_A[:3, :3] = orientation_A
        T_pose_in_A[:3, 3] = position_A

        # ---- Transform from Frame A to Frame B ----
        # Example: Frame B is rotated and translated w.r.t Frame A
        rotation_AB = R.from_euler('xyz', [180, 0, 0], degrees=True).as_matrix()
        translation_AB = np.array([0, 0, 0])
```

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        T_AB = np.eye(4)
        T_AB[:3, :3] = rotation_AB
        T_AB[:3, 3] = translation_AB

        # Now transform the pose from frame A to frame B
        T_pose_in_B = np.linalg.inv(T_AB) @ T_pose_in_A

        # Extract the new position and orientation
        position_B = T_pose_in_B[:3, 3]
        orientation_B = R.from_matrix(T_pose_in_B[:3, :3]).as_euler('xyz', degrees=True)

        return position_B[0], position_B[1], orientation_B[2]


    # Function to get the angular velocity from RPM
    def rpm_to_rad_ps(self, RPM):
        return (2 * PI * RPM) / 60

    # Defining set of actions based on wheel RPMs
    def action(self, node, RPM_RW, RPM_LW):
        # Convert the units from RPM to radians/second

        rx,ry,ryaw = self.transform_map_to_robot(node.x, node.y, node.theta)
        u_l = self.rpm_to_rad_ps(RPM_LW)
        u_r = self.rpm_to_rad_ps(RPM_RW)
        edgecost = 0
        x_i = rx
        y_i = ry
        theta_i = radians(ryaw)

        waypoints:list[WayPoint] = []
        for _ in np.arange(0, 1, 0.1):
            dx = 0.5 * self.R * (u_l + u_r) * cos(theta_i) * self.dt
            dy = 0.5 * self.R * (u_l + u_r) * sin(theta_i) * self.dt
            dtheta = (self.R / self.L) * (u_r - u_l) * self.dt
            dcost = sqrt(dx**2 + dy**2)
            edgecost += dcost
            x_i += dx
            y_i += dy
            theta_i = radians(principal_theta(degrees(theta_i) + degrees(dtheta)))
            tx,ty,tyaw = self.transform_robot_to_map(x_i, y_i, degrees(theta_i))

            waypoints.append(WayPoint(tx,ty,tyaw, edgecost))
        return waypoints, edgecost

    def sharp_right_R1(self, node):
        return self.action(
            node, self.RPM1, 0
        )  # Pivoting right by applying RPM1 on the left wheel and 0 on the right wheel

    def sharp_left_R1(self, node):
        return self.action(
            node, 0, self.RPM1
        )  # Pivoting left by applying 0 on the left wheel and 0 on the right wheel

    def straight_R1(self, node):
        return self.action(
            node, self.RPM1, self.RPM1
        )  # Move straight by applying RPM1 on both wheels

    def sharp_right_R2(self, node):
        return self.action(
            node, self.RPM2, 0
        )  # Pivoting right by applying RPM2 on the left wheel and 0 on the right wheel

    def sharp_left_R2(self, node):
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        return self.action(
            node, 0, self.RPM2
        )  # Pivoting left by applying 0 on the left wheel and RPM2 on the right wheel

    def straight_R2(self, node):
        return self.action(
            node, self.RPM2, self.RPM2
        )  # Move straight by applying RPM2 on both wheels

    def gradual_turn_R1R2(self, node):
        return self.action(
            node, self.RPM1, self.RPM2
        )  # Turn by applying RPM1 on right wheel and RPM2 on left wheel

    def gradual_turn_R2R1(self, node):
        return self.action(
            node, self.RPM2, self.RPM1
        )  # Turn by applying RPM2 on right wheel and RPM1 on left wheel

#
#
# r = Robot(33,287)
# ll,dd = r.action(Node(0,0,90,0),5,5)
#
# for node in ll:
#     print(node)
```

```python
from math import sqrt

LIN_QUANT = 200
ANG_QUANT = 10


# Point container class
class Point:
    """
    Point class to represent a point in a 2D space. This data structure is also used in as key
in dict so the thresholding happens here
    """

    def __init__(self, x, y, theta):
        self.x = x
        self.y = y
        self.theta = principal_theta(theta)
        print(LIN_QUANT,ANG_QUANT,"HIIII")
    def move(self, dx, dy, dtheta):
        self.x += dx
        self.y += dy
        self.theta += dtheta

    def __hash__(self):
        """Quantize x and y to a 1 mm grid"""
        quantized_x = round(self.x / LIN_QUANT) * LIN_QUANT
        quantized_y = round(self.y / LIN_QUANT) * LIN_QUANT
        # Quantize theta to bins of 30 degrees
        quantized_theta = round(self.theta / ANG_QUANT) * ANG_QUANT
        return hash((quantized_x, quantized_y, quantized_theta))

    def __eq__(self, other):
        """Two nodes are considered equal if they are within 0.5 units and their theta
difference is ≤ 30 degrees."""
        if isinstance(other, Point):
            euclidean_distance = sqrt((self.x - other.x) ** 2 + (self.y - other.y) ** 2)
            theta_diff = abs(self.theta - other.theta)
            theta_diff = min(
                theta_diff, 360 - theta_diff
            )  # Normalize to range [0, 180]
            return euclidean_distance <= LIN_QUANT and theta_diff <= ANG_QUANT
        return False

    def __str__(self):
        """utility function to print Point directly"""
        return f"Point({self.x}, {self.y}, {self.theta})"


class WayPoint(Point):
    def __init__(self, x, y, theta, edgecost):
        super().__init__(x, y, theta)
        self.edgecost = edgecost

    def __str__(self):
        return f"WayPoint({self.x}, {self.y}, {self.theta}, {self.edgecost})"


# Node container class
def principal_theta(theta):
    """
    Function to find principal theta of a given theta i.e. theta should always be in (-180,180]
    Args:
        theta: theta to be converted

    Returns: normalised theta

    """
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    theta = (theta + 180) % 360 - 180  # Ensures theta is in (-180, 180]
    return theta


class Node:
    """
    A node structure to be used in graph. It represents a valid configuration of robot in
search graph
    """

    def __init__(self, x, y, theta, c2c):
        self.x = x
        self.y = y
        self.theta = principal_theta(theta)
        self.c2c = c2c
        self.waypoints: list[WayPoint] = None
        self.total_cost = 0
        self.parent = None
        self.visited = False

    # used for duplicate key finding in dict
    def __hash__(self):
        """Quantize x and y to a 1 mm grid"""
        quantized_x = round(self.x / LIN_QUANT) * LIN_QUANT
        quantized_y = round(self.y / LIN_QUANT) * LIN_QUANT
        # Quantize theta to bins of 10 degrees
        quantized_theta = round(self.theta / ANG_QUANT) * ANG_QUANT
        return hash((quantized_x, quantized_y, quantized_theta))

    def __eq__(self, other):
        """Two nodes are considered equal if they are within 0.5 units and their theta
difference is ≤ 30 degrees."""
        if isinstance(other, Node):
            euclidean_distance = sqrt((self.x - other.x) ** 2 + (self.y - other.y) ** 2)
            theta_diff = abs(self.theta - other.theta)
            theta_diff = min(
                theta_diff, 360 - theta_diff
            )  # Normalize to range [0, 180]
            return euclidean_distance <= LIN_QUANT and theta_diff <= ANG_QUANT
        return False

    def __lt__(self, other):
        if isinstance(other, Node):
            return self.total_cost < other.total_cost
        return False

    def __str__(self):
        """Utility function to print Node directly"""
        return f"Node(x={self.x}, y={self.y}, θ={self.theta}, c2c={self.c2c}, totalcost=
{self.total_cost})"


# Container to store goal
class GoalPt:
    """
    Goal pt class to hold X Y Radius of goal point
    """

    def __init__(self, x, y, radius):
        self.x = x
        self.y = y
        self.radius = radius

    def __str__(self):
        return f"GoalPt(x={self.x}, y={self.y}, radius={self.radius})"
```

```python
import numpy as np
import cv2
import time
BLACK = (0, 0, 0)
GREY = (128, 128, 128)


# class to create canvas having obstacle and boundaries
class Canvas:
    def __init__(self, width, height, buffer=2, multiplier=1):
        self.multiplier = multiplier
        self.width = width
        self.height = height
        self.buffer = buffer
        # using 3D array for color visualization in opencv mat
        #  WHITE canvas
        self.canvas = np.ones((self.height, self.width, 3), dtype=np.uint8) * 255

        print("Preparing Canvas")
        self._draw_borders()
        self._draw_obstacles()

    # Function to draw borders on canvas
    def _draw_borders(self):
        cv2.rectangle(
            img=self.canvas,
            pt1=(0, 0),
            pt2=(self.width, self.height),
            color=BLACK,
            thickness=self.buffer,
        )

    # Function to visualise the canvas for debugging
    def _visualize_canvas(self):
        resized = cv2.resize(
            self.canvas,
            (int(self.width * self.multiplier), int(self.height * self.multiplier)),
            interpolation=cv2.INTER_AREA,
        )
        cv2.imshow("img", resized)
        cv2.waitKey(0)
        cv2.destroyAllWindows()

    # Function calling each type of obstacle to be drawn
    def _draw_obstacles(self):
        for x in range(self.width):
            for y in range(self.height):
                if self.is_inside_obstacle(x, y):
                    self.canvas[y, x] = BLACK
                elif self.is_inside_buffer(x, y):
                    self.canvas[y, x] = GREY

    def is_inside_obstacle(self, x, y):
        pillar1 = (1000 <= x <= 1100) and (500 <= y <= 3000)
        pillar2 = (2100 <= x <= 2200) and (0 <= y <= 2500)
        pillar3 = (3200 <= x <= 3300) and (0 <= y <= 1250)
        pillar4 = (3200 <= x <= 3300) and (1750 <= y <= 3000)
        pillar5 = (4300 <= x <= 4400) and (500 <= y <= 3000)
        return any(
            [
                pillar1,
                pillar2,
                pillar3,
                pillar4,
                pillar5,
            ]
        )
```

```python
    def is_inside_buffer(self, x, y):
        pillar1 = (1000 - self.buffer <= x <= 1100 + self.buffer) and (
            500 - self.buffer <= y <= 3000
        )
        pillar2 = (2100 - self.buffer <= x <= 2200 + self.buffer) and (
            0 <= y <= 2500 + self.buffer
        )
        pillar3 = (3200 - self.buffer <= x <= 3300 + self.buffer) and (
            0 <= y <= 1250 + self.buffer
        )
        pillar4 = (3200 - self.buffer <= x <= 3300 + self.buffer) and (
            1750 - self.buffer <= y <= 3000
        )
        pillar5 = (4300 - self.buffer <= x <= 4400 + self.buffer) and (
            500 - self.buffer <= y <= 3000
        )
        return any(
            [
                pillar1,
                pillar2,
                pillar3,
                pillar4,
                pillar5,
            ]
        )

    def is_colliding(self, x, y):
        return (
            self.canvas[y, x][0] == BLACK[0]
            and self.canvas[y, x][1] == BLACK[1]
            and self.canvas[y, x][2] == BLACK[2]
        ) or (
            self.canvas[y, x][0] == GREY[0]
            and self.canvas[y, x][1] == GREY[1]
            and self.canvas[y, x][2] == GREY[2]
        )
```

```python
#!/usr/bin/env python3

import sys
import os

sys.path.append(
    "/home/pranavdm/UMD/Sem-2/ENPM661/Projects/Project-3/Phase2/Git/A-Algorithm-Implementation-
on-TurtleBot3/part1"
)

import rclpy
from rclpy.node import Node as ROS2Node
from geometry_msgs.msg import Twist
from canvas import Canvas
from robot import Robot
from search import Search
from helpers import *
import numpy as np
from math import sqrt, atan2, sin, cos, radians, pi as PI
import time
from scipy.spatial.transform import Rotation as R


WIDTH = 5400
HEIGHT = 3000
MULTIPLIER = 0.25


def transform_map_to_robot(x, y, yaw):
    # ---- Pose in Frame A ----
    position_A = np.array([x, y, 0.0])
    orientation_A = R.from_euler("xyz", [0, 0, yaw], degrees=False).as_matrix()

    # Homogeneous transformation matrix of pose in A
    T_pose_in_A = np.eye(4)
    T_pose_in_A[:3, :3] = orientation_A
    T_pose_in_A[:3, 3] = position_A

    # ---- Transform from Frame A to Frame B ----
    # Example: Frame B is rotated and translated w.r.t Frame A
    rotation_AB = R.from_euler("xyz", [PI, 0, 0], degrees=False).as_matrix()
    translation_AB = np.array([0, -HEIGHT / 2, 0])

    T_AB = np.eye(4)
    T_AB[:3, :3] = rotation_AB
    T_AB[:3, 3] = translation_AB

    # Now transform the pose from frame A to frame B
    T_pose_in_B = np.linalg.inv(T_AB) @ T_pose_in_A

    # Extract the new position and orientation
    position_B = T_pose_in_B[:3, 3]
    orientation_B = R.from_matrix(T_pose_in_B[:3, :3]).as_euler("xyz", degrees=True)

    return position_B[0], position_B[1], orientation_B[2]


def normalize_angle(angle):
    """Normalize angle to the range (-pi, pi]."""
    while angle > PI:
        angle -= 2 * PI
    while angle <= -PI:
        angle += 2 * PI
    return angle

class A_Star_Path(ROS2Node):
```

```
    def __init__(self):
        super().__init__("a_star_path")
        self.cmd_vel_pub = self.create_publisher(Twist, "/cmd_vel", 10)

    def run_search(self):
        # Create the Robot object
        robot = Robot(33, 287)

        # Prepare the canvas
        canvas = Canvas(WIDTH, HEIGHT, round(2 + robot.r), MULTIPLIER)

        # Create the search object and pass the robot and canvas objects
        search = Search(robot, canvas)

        if search.a_star():
            print("Path found!")
            search.backtrack_path()
            velocity_message = Twist()
            dt = robot.dt

            for node in search.path:
                # Publish the twist message
                last_waypoint: WayPoint = None

                for i in range(len(node.waypoints) - 1):
                    x0, y0, theta0 = node.waypoints[i].x, node.waypoints[i].y,
node.waypoints[i].theta
                    x1, y1, theta1 = node.waypoints[i + 1].x, node.waypoints[i + 1].y,
node.waypoints[i + 1].theta

                    dx = x1 - x0
                    dy = y1 - y0
                    ds = sqrt(dx**2 + dy**2)

                    dtheta = normalize_angle(theta1 - theta0)

                    linear_vel = ds / (dt * 1000)
                    angular_vel = dtheta / dt
                    velocity_message.linear.x = linear_vel
                    velocity_message.angular.z = angular_vel
                    self.cmd_vel_pub.publish(velocity_message)
                    time.sleep(dt)

            velocity_message.linear.x = 0.0
            velocity_message.angular.z = 0.0
            self.cmd_vel_pub.publish(velocity_message)


def main(args=None):
    rclpy.init(args=args)
    node = A_Star_Path()
    node.run_search()
    node.destroy_node()
    rclpy.shutdown()


if __name__ == "__main__":
    main()
```