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Homework Assignment 3
RBE 550 Motion Planning
Valet Parking

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1 Introduction

In this assignment **Valet Parking** we consider three different vehicles Differential drive robot with unicycle model kinematics, a Car with Ackermann Steering kinematics and Truck with Truck-Trailer Kinematics. We develop a planner considering the non-holonomic constraints.

2 Overview of Vehicles & Kinematics

2.1 Differential Drive Robot

Differential drive robot or Skid-steer drive is basically having a caster wheel in front which provides the necessary contact with surface. The rear left and right wheels provide the propulsion to move ahead.
These robots do not need a instantaneous curvature of radius to rotate rather it can rotate on spot it uses Balkcom-Mason Curves for its motion model.
Here, v_r and v_l are the linear velocities of right and left wheel respectively, L is wheelbase of the robot and r is radius. L = 0.4 and R = 0.1 .

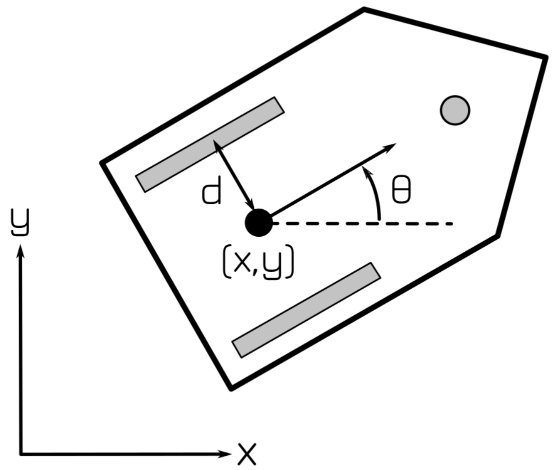


Figure 1: Differential Drive Kinematic Model

$$\dot{x} = \frac{R}{2}(v_r + v_l)\cos(\theta) \tag{1}$$

$$\dot{y} = \frac{R}{2}(v_r + v_l)\sin(\theta) \tag{2}$$

$$\dot{\theta} = \frac{R}{L}(v_r - v_l) \tag{3}$$

Non-holonomic constraints differential drive are

$$\dot{x}\sin(\theta) - \dot{y}\cos(\theta) \tag{4}$$

2.2 Car

The Ackermann steering kinematics is used in the Car. Here the rear wheels provide the forward propulsion with steering ϕ maneuvered with front wheels linked together. Car-Ackermann steering robot cannot do zero

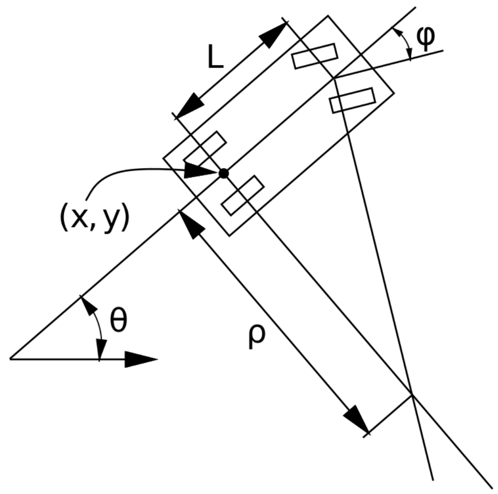


Figure 2: Ackermann Steering Kinematics

radius on-spot turning. It requires ICR Instaneous Radius of Curvature. We consider WheelBase L = 2.8 meters, Width = 3.0 meters with maximum steering angle to 0.6 rads (34 degrees).

$$\dot{x} = v\cos(\phi) \tag{5}$$

$$\dot{y} = v\sin(\phi) \tag{6}$$

$$\dot{\phi} = \omega \tag{7}$$

Non-holonomic constraints for ackermann steering are

$$\dot{x}\sin(\phi) - \dot{y}\cos(\phi) \tag{8}$$

2.3 Truck-Trailer

Truck-trailer configuration is very common in material movement scenarios in large-scale warehouses/manufacturing units, where a Tug Robot carries along the multiple trailers from the source point to destination w.r.t to its tact-time of production and manufacturing.

$$\dot{\theta}_0 = \frac{v}{L}\tan(\phi) \tag{9}$$

$$\dot{x} = v\cos(\theta_0) \tag{10}$$

$$\dot{y} = v\sin(\theta_0) \tag{11}$$

$$\dot{\theta}_1 = \frac{v}{d}\sin(\theta_0 - \theta_1) \tag{12}$$

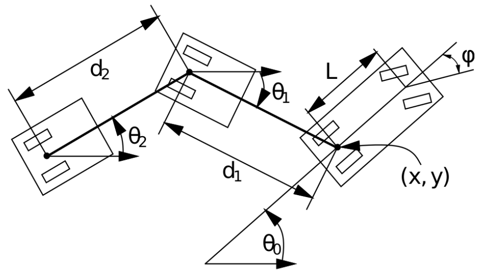


Figure 3: Ackermann Truck with a Trailer

3 Planner Approach

3.1 Hybrid A*

For planning we consider Hybrid A* search as it transits in continous space rather than discrete space with considering kinematic constraints. Hybrid A* is extension of A* which is optimal, deterministic and complete We have the search space of the State space for Differential drive and Car robot as **X** = (x, y θ) and for Truck trailer we have additional state of trailer-theta θ_1, so we have **X** = (x, y θ, θ_1).

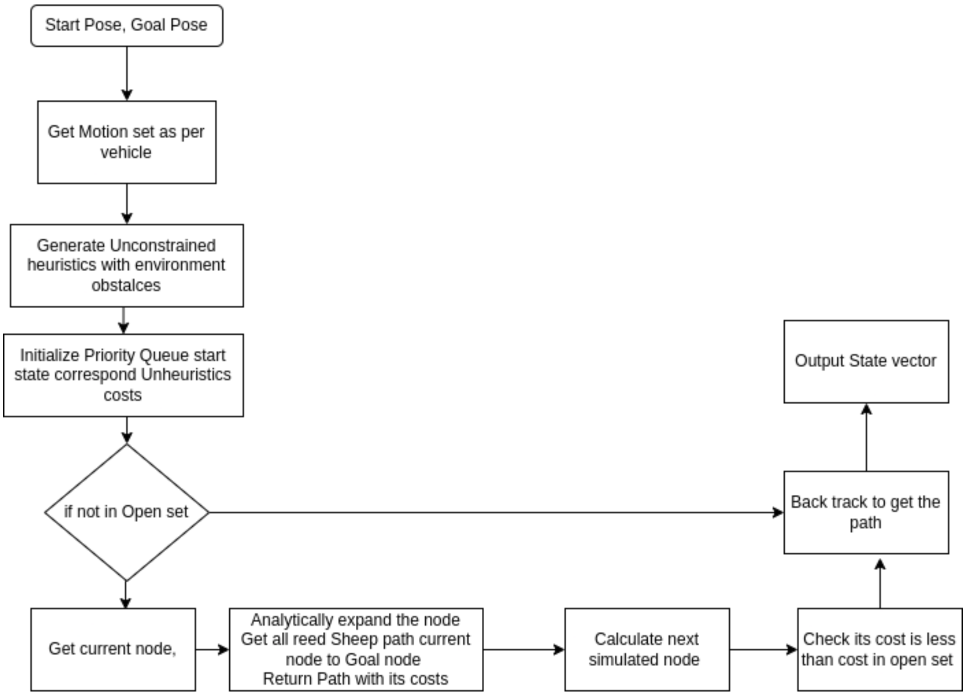


Figure 4: Planner Block diagram

HA* does not consider velocity into account but considers the non-holonomic constraints imposed by the vehicle. It generates 6 succeeding vertices one forward with 3 motion sets as maximum steering angle , no steering , minimum steering angle similarly in reverse.

3.1.1 Node expansion

HA* search starts with start pose x_s getting the 6 successor vertices we consider the shorter arc length to get higher resolution of kinematically optimal solutions. We consider various costs like Reverse cost, Direction Change cost, Steering angle cost and we do consider another cost for Truck trailer is the Jack-knife cost where the truck trailer get stuck into sciscors configuration.
Once we get the simulation node considering the motion set generated in node expansion we analytically expand the node w.r.t to the motion model given the kinematic equation for respective vehicle
NOTE
We experimented with usage of Motion primitives as shown in Fig. 4 which connect the vertex (nodes) in specific manner and disadvantage is that they needs to be computed beforehand.

3.1.2 Analytical expansion

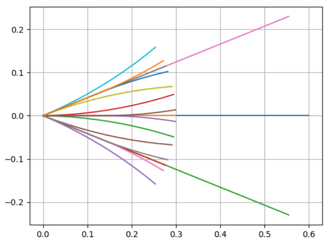
We calculate all the curves from start pose to goal pose using Reed Shepps curves which are further checked for obstalces in the environment and collision.

3.1.3 Collision checking

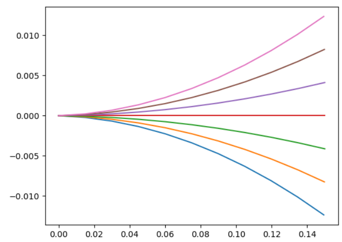
Obstacles are defined with points added in a KD-tree where we query the simulated nodes for obstacles after validating its kinematics constraints

3.1.4 Heuristics

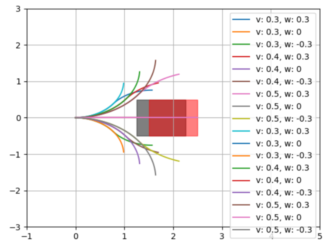
We consider two of the following Heuristics for calculating the costs and pruning.



(a) Grid Based Motion Primitves



(b) Uniform Motion Primitives



(c) Motion primitives with Obstacles

Figure 5: Experiments with predefined motion primitives

- Constrained Heuristics considers the kinematics of the vehicle with Reeds-shepp curves it also considers the turning radius and ensures the vehicle goes towards goal.
- Unconstrained Heuristic neglects vehicle and consider only obstacles. It calculates the Euclidean distance heuristic.

4 Results

Here the Green pose is source and Red pose is destination. The black color rectangles are obstalces.

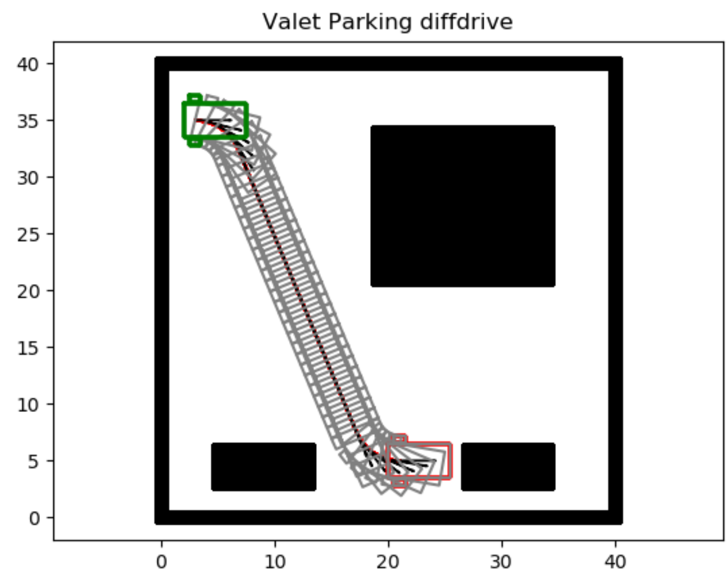


Figure 6: Planning Differential Drive

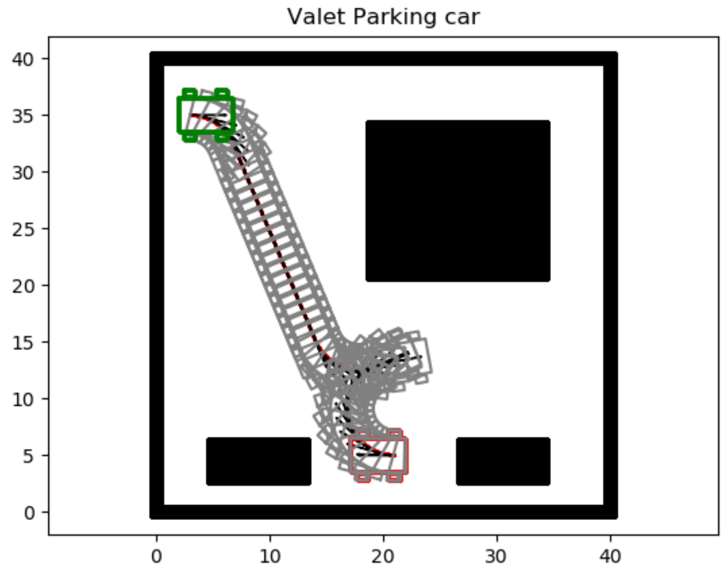


Figure 7: Planning Ackermann Car

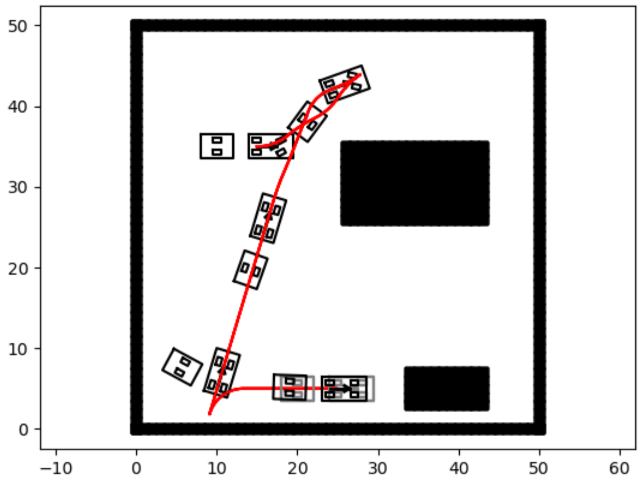


Figure 8: Planning Truck trailer

5 Conclusions

Using Hybrid Astar along with reed-shepps curves considering the non-holonomic kinematic constraints provides admissible and optimal paths for planning.Please check the output gif animation generated provided in the submision

6 Biblography

Literatur

[1] K. Kurzer, 'Path Planning in Unstructured Environments: A Real-time Hybrid A* Implementation for Fast and Deterministic Path Generation for the KTH Research Concept Vehicle', Dissertation, 2016.

[2] Zhou, H. (2020). CurvesGenerator. GitHub repository. Retrieved from https://github.com/zhm-real/CurvesGenerator