Multi-Trailer Truck Parking Problem

* RBE 550 Course Project Proposal

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***Abstract*—One of the most challenging tasks for truck drivers is maneuvering the truck-trailer system in different parking scenarios. In this project, we aim to develop and test path planning algorithms for this application and verify via simulations of their performance as per different metrics. We believe this project has the potential to be applied in areas of autonomous driving or driving assist.**

I. Introduction

Trailer parking is a crucial aspect of the transportation industry. The traditional methods of trailer parking are time-consuming and require human intervention. Autonomous vehicles have been a hot topic in recent years, with significant advancements in technology making them a more feasible option for everyday use. One of the challenges facing autonomous vehicles is parking, especially for large vehicles such as trailers. Trailer parking is a complex task that requires precise and accurate parking skills. With the increasing demand for autonomous vehicles, the development of autonomous trailer parking is becoming increasingly important. In this project, we propose to develop a path-planning system for autonomous trailer parking. This system will be capable of navigating a trailer through a yard or parking area and successfully parking it in a designated spot.

II. Background

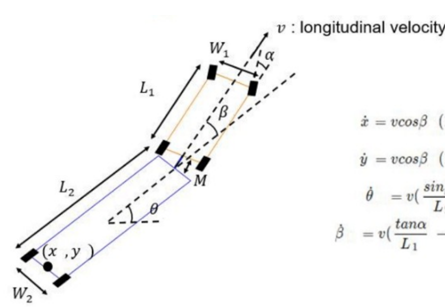
One of the most challenging tasks for truck drivers is maneuvering the truck-trailer system in different parking scenarios. The problem of parking comes under the domain of planning with kinematic constraints or non-holonomic constraints. A non-holonomic constraint is a non-integrable constraint. That is, for this problem, they are of velocity constraint type. For the trailer truck model, the kinematic model is already prevalent in the literature as noted here [4]. The reason why this problem is hard to solve is because of the limited configurations the obstacles allow for the trailer truck to access, as a result, solutions should be of the form wherein the truck should go back and forth in the same place, with just tiny adjustments in its heading to create the possibility of going into the parking space. There have been some research papers, which describe novel algorithms to solve this problem such as [5]. Though there aren't many reports of stress testing these algorithms against other algorithms as well as extending this problem to the multi-trailer case.

III. Methodology

In this project, we will be building on top of a mathematical model of a 1-trailer system where there is one pulling truck and 1 trailer being pulled by it. The trailer is hinged at the center of the rear axle of the pulling truck. The Kinematic model for the 1-trailer system defined by [1] is used in this project (shown in figure 1). The model simplifies 4 wheels to 1 turning wheel at the center. As the speed of the trailer when parking will be low, this approximate assumption is very accurate. This model will first be extended to the 2-trailer system and then multi-trailer systems will be explored based on the result of the 2-trailer system.

For the path planning of the truck-trailer system, we will be using a number of path-planning algorithms such as hybrid A*, MPC-RRT, etc. to compare and provide an analysis of the effectiveness of different algorithms. The major challenge, which determines the efficacy of these algorithms is to take into account the non-holonomic constraints of the model along with the constraints of the map.

We will be simulating our model in a 2d grid in a known environment. The algorithm will know all the relevant information such as the location of other vehicles, parking spots, and obstacles. This information will be processed to generate a feasible path for the trailer. All the algorithms will be able to avoid obstacles and maneuver the environment with non-holonomic constraints in place.



$$\dot{x} = v\cos\beta\ \left(1 + \frac{M_1}{L_1}\tan\beta\ \tan\alpha\right)\cos\theta$$
$$\dot{y} = v\cos\beta\ \left(1 + \frac{M_1}{L_1}\tan\beta\ \tan\alpha\right)\sin\theta$$
$$\dot{\theta} = v\left(\frac{\sin\beta}{L_2} - \frac{M_1}{L_1 L_2}\cos\beta\ \tan\alpha\right)$$
$$\dot{\beta} = v\left(\frac{\tan\alpha}{L_1} - \frac{\sin\beta}{L_2} + \frac{M_1}{L_1 L_2}\cos\beta\ \tan\alpha\right)$$

Fig. 1. Kinematic model of trailer truck

IV. Project Status Update

Overview: We chose pygame to create a simulation environment. Initially, the Ackerman steering model was used to simulate the motion of a car. This was extended to one trailer system. The dynamics of the trailer-truck system was simulated using the acceleration model. Due to the complexity of higher dimensions, we decided to go with the constant acceleration model. In the current simulation the update rate is set at 10 Hz. And in the current state the trailer-truck is being operated using inputs from the keyboard. In the same environment rectangular static obstacles, were placed for sanity checks of the final environment.

Challenges faced: We extended our work post the timeline by us, to create a graph of the configuration space to apply algorithms like Djikstra or BFS, to set a baseline. But due to the 'curse of dimensionality' computational power and memory requirements for creating a complete graph of the 6-dimensional configuration space (x, y, velocity, trailer angle, trailer-truck angle, steering angle) is very high.

Way Forward: We are currently on track as per our timeline and we are exploring and learning about the algorithms which we can apply to our simulations.

Contributions: Rohin S: Has contributed to the selection and learning of pygame as the simulation environment by creating a base model of a car. Raj K: Has contributed to using and coding the trailer-truck kinematics based on Ackerman model. Varun G: Has contributed to debugging for the simulation and exploration of using configuration space and creating a graph for the problem

V. Goals

1) Develop a path-planning algorithm capable of handling multiple trailers in compact spaces
2) Algorithm should consider the kinematics of the system
3) Algorithm should take into account non-holonomic constraints while navigating and avoiding obstacles
4) To evaluate the performance of the algorithm and demonstrate its feasibility, such as:
   (i) Time taken to generate the path
   (ii) After the path is generated, the time taken to reach the end goal.

VI. Timeline

- ~~February 17: Simulation setup to be ready along with trailer truck system, which has the kinematic model included.~~
- March 10: Single trailer solution to be ready for at least one algorithm (Hybrid-A*).
- March 24: Multi-trailer system solution to be ready for at least one algorithm.
- April 07: Multiple algorithms to be stress tested (at least Hybrid A*, Cl-RRT [5]).
- April 21: Tested under dynamic/unknown obstacles and report/presentation to be developed for submission.

VII. Work Division

Our plan is to meet weekly and discuss the upcoming tasks, some of which are listed below but is not fully finalized. At these meetings, we will distribute the work fairly by taking into account teammates' strengths and weaknesses.

1) Initial simulation setup which involves developing the kinematic model of the single trailer truck along with building the map of the environment.
2) Writing the code for the motion planning algorithm in a scripting language of choice.
3) Initial testing of end-to-end workflow to observe if the algorithm is capable of planning a path from start to goal location.
4) Plotting sample graph of the path generated for the initial testing phase.
5) Further development will include building other motion planning algorithms proposed above and integrating them with the simulation
6) Plotting the remaining graphs along with extracting the performance measures.

VIII. Expected Results

The proposed path planning algorithm for autonomous trailer parking will provide a highly effective solution for the challenge of parking trailers in complex environments. The system will be designed to handle multiple trailers in compact spaces with difficult kinematics while considering non-holonomic constraints and obstacle avoidance. A graph of paths generated by the algorithm will be shown, along with the motion of trailers parking in a given goal location. A performance evaluation of different path planning algorithms implemented will be provided to understand the effectiveness of each algorithm.

References

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[5] A. C. Manav and I. Lazoglu, "A Novel Cascade Path Planning Algorithm for Autonomous Truck-Trailer Parking," in IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 7, pp. 6821-6835, July 2022, doi: 10.1109/TITS.2021.3062701.