Autonomous Car Intersection Simulation Project

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Contents

Abstract

This project aims to investigate some of the aspects involving traffic management with autonomous vehicles. In particular, we want to know how it can be possible to regulate self driving cars through an intersection, and if it is possible to achieve this without a centralised controller and the use of communication. We will run a simulation of an intersection with self driving cars and discuss our findings, comparing different methodologies and related work.

1 Introduction

The idea of having autonomous agents has existed in science fiction literature for hundreds of years and can also be traced back to ancient mythology. The ideas and concepts of autonomous agents are hence not something entirely new, but rather something that has been refined over the course of a lot of years. However the technology has just recently reached a state where a lot of the underlying challenges to autonomous agents can be solved somewhat efficiently. Self driving cars are becoming more and more a reality, and they will be an important presence in the near future. By automising vehicle control, traffic management can arguably be made more efficient in many ways, starting with throughput but also in other aspects, like fuel management and emissions control.

In this paper we will focus on what it takes to make autonomous automobiles efficient in passing intersections.

Initially we had a look at what other researchers had been doing the recent decade and quickly realised that there was a pattern. The same groups keep appearing in the literature when having the focus on autonomous vehicles and intersections.

To put everything in context we will start by presenting some of the challenges that are present when trying to efficiently solve the task of managing vehicles in an intersection. Followed by different control paradigms. These paradigms will be presented in relation to existing solutions to match the theory to their practical implementation.

1.1 Motivation

The theory we have touched upon is from multiple fields of engineering. One field is within traffic engineering, namely intersection management. The other is within the field of robotics, namely robot control.

1.1.1 Intersection Management

The field of intersection management tries to deal with the challenges arising when trying to organize multiple entities to efficiently pass through a critical zone.
The challenge to solve is to go from origin to destination while not colliding with other entities.

In the real world these challenges are solved by defining a set of rules and designing the critical zones such that it is trivial to determine from where entities might enter and leave the zone and what entity has priority over the others.

Different templates exist for solving these tasks efficiently and these templates can differ from nation to nation, however our starting point is rooted in the way that traffic is handled in Europe which is kind of homogenous.

The commonalities used are traffic-legislation and intersections. Traffic-legislation contains a set of rules that makes it easy to determine what entity has a higher priority within critical sections (intersections).
Intersections are also designed in such a way that agents have an easier task at deciding priorities. This includes tools such as traffic lights, road markings and/or signs.

The intersection models that we are interested in are 4 way cross-intersections both with and without the use of traffic lights. This is due to the fact that these types of intersections are the most common ones in our local area. Additionally a smaller intersection still follows the same rules and can be seen as a 4 way intersection where traffic never arrives from or travels to one of the ways.

1.1.2 Control Paradigms

We use the term agents for robots or other actors moving within an environment.
We use the term environment as being synonymous to the world in which the agent is confined. The following will contain short presentations of the three canonical ways of doing robot control, based on the theory presented in the textbook The Robotics Primer[1], and chapters 12 to 15 on the subject.

Reactive Control which is also coined Sense-Act is a paradigm that acts directly on sensory input.
In our research we did not stumble upon any systems using purely reactive controllers, which we found interesting. This is due to the fact that the simplicity of the interaction with the environment should make pure reactive controllers quite safe. Simple schemes for collision avoidance are trivial to implement using pure reactive controllers.
An example of such a controller can be expressed quite simple using only a frontal sensor. The rule could be phrased as while this sensor does not register

anything in front of the vehicle for a certain distance accelerate else brake. The strength of this paradigm is that its highly reactive to the environment. There are no complex layers inbetween.

In contrast to the above paradigm there exits a paradigm named *deliberate control*, or alternatively Sense-Plan-Act. Compared to the reactive control it introduces a layer of planning. The additional step however requires more information about the environment.

Any change to the environment would also invalidate the current plan as this is not factored in. This is computationally heavy since it senses, plans a step, executes the step and starts over. A plan can consist of multiple steps which are required to reach a goal.

The third canonical way of doing robot control is a hybrid of the two above, and hence it is also referred to as *hybrid control*. It resides somewhere in the middle where it has abstractions of routines using reactive controllers - but uses a higher level mechanism to combine these for advanced control schemes.

Most of the research that has been conducted on intersection management systems for autonomous vehicles tends to prefer centralised systems that can handle traffic requests. Particularly relevant is the research of two major groups in this area: the researchers at the University of Texas at Austin, and an international group of researchers composed by members of the Massachusetts Institute of Technology (MIT), the Swiss Institute of Technology (ETHZ), and the Italian National Research Council (CNR).

At the University of Texas, Kurt Dresner and Peter Stone developed AIM, Autonomous Intersection Management, a reservation-based system built around a detailed communication protocol able to coordinate movement of self driving cars through intersections [2]. Through a simulation they are able to demonstrate the potential of this system to outperform current intersection control mechanism: traffic lights and stop signs. In the simulation, the intersection center is divided into a n x n grid of reservation tiles. Through a "first come, first served" policy, approaching vehicles make a request to the system to reserve the space-time they need to cross the intersection. Their trajectory is then computed by the system and if the requesting vehicle at any time occupies a reservation tile that is already in use, the request is rejected. The vehicle will then continue requesting until it can pass.

A similar approach is also followed by the international group of MIT, ETHZ and CNR researchers. They developed a centralised slot-based intersection [3]. In their simulations, cars adjust their velocities in approaching the intersection in order to arrive and cross at a given slot of time that is made available for them. This system also involves communication between vehicles and a centrlised controller.

In particular we were inspired by Dresner and Stone[2], which explores the

same area as us.
Dresner and Stone, define certain criteria that need to be met for the interactions between intersection and multiple agents to be deemed succesfull. They name properties such as *autonomy for every agent*,*realistic sensor models*, *deadlock avoidance*,*safety* and *efficiency*, which we adopt into our model.

They mention more properties - such as protocol standardization, low communication complexity and Incremental Deployability, which we deem less important due to our approach.

1.1.3 Problem Statement

The previously obtained insights about robot control, intersection management and previous research led us to the following plan of attack:

> The goal is to explore the possibility of building a decentralized system which can guide autonomous cars through intersections. The current research and solutions we have found are focused around centralized systems.
>
> Centralized systems rely alot on scheduling and coordination in a 'global' scale, while the decentralized system we envision would be built on a reactive approach which is centered around local state.
>
> We would like to build a prototype using the decentralized approach and compare results to an existing centralized solution.

2 Implementation

- Presentation of our model.
- Intersection w/wo traffic lights. Cars going straight vs. cars turning.
- Car model and sensor modelling (sick vs simplified directional).
- Graph for navigation.
- Reactive controller.
- Special rules (right hand).
- Sensor range limitation based on braking distance considerations.
- SimScale to RealWorldScale

2.1 The World Model

As observed in the real world, multiple intersection models exist, three lane and 4 lane intersections are the most common ones. The style can be either with the roundabout approach, which essentially rules out the left turn complication or a traditional 4 lane intersection where going left crosses the opposing traffics lane.

In our model we mainly focus on a single lane 4 way intersection.

insert simple intersection images - maybe graph images from unity

We represent these intersection models using an underlying directed graph. A car agent in our environment is seeded with information about its origin and its destination. These points are vertices in our graph. Every combination of origin and destination pair has one path.

While this does not provide alot of flexibility in straying from the path, the simplicity makes the model really easy to implement and adjust.

2.1.1 The traffic lights

This is an attempt to mimic traffic light regulated intersections. The lights change at intervals chosen in regards to our experiences with intersections. These values can vary alot from intersection to intersection - and are highly influenced by traffic flow during the day. We settled on 20 second windows.

2.2 The Car Model

The way the car has been modelled is using a interface which essentially contains actions such as accellerating or decellerating, braking, and turning left or right. This abstraction simplifies the step of going from a virtual model to a physical one with robot actors. This interface is the used by the controller. This seperation makes it simple to develop multiple types of controllers.

3 Experiments

we have some fixed parameters such as light control on or off. Mimics intersection lights.
Whether simulated vehicles are able to turn or not.
We have different max speeds - 60 or 40 km per hour approach. This translates to lower speeds during turns (roughly half).

tests are different combinations of above parameters. And results are measured in collisions, cars spawned, cars reaching destination, and time before deadlock.
Deadlock is the situation where cars have been stuck for a period of time in the 'intersection zone' without entering or leaving.

4 Discussion

Discuss experimental results. Shortcomings of model. Improvements for further tests.

5 Conclusion

References

[1] Maja J. Mataric. *The Robotics Primer*. MIT Press, 2007.

[2] Kurt Dresner and Peter Stone. A multiagent approach to autonomous intersection management. 1905.

[3] Remi Tachet, Paolo Santi, Stanislav Sobolevsky, Luis Ignacio Reyes-Castro, Emilio Frazzoli, Dirk Helbing, and Carlo Ratti. Revisiting street intersections using slot-based systems. 1905.