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Heuristic based evolution for the coordination of autonomous vehicles in the absence of speed lanes

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ABSTRACT

The current state of the art in the planning and coordination of autonomous vehicles is based upon the presence of speed lanes. In a traffic scenario where there is a large diversity between vehicles the removal of speed lanes can generate a significantly higher traffic bandwidth. Vehicle navigation in such unorganized traffic is considered. An evolutionary based trajectory planning technique has the advantages of making driving efficient and safe, however it also has to surpass the hurdle of computational cost. In this paper, we propose a real time genetic algorithm with Bezier curves for trajectory planning. The main contribution is the integration of vehicle following and overtaking behaviour for general traffic as heuristics for the coordination between vehicles. The resultant coordination strategy is fast and near-optimal. As the vehicles move, uncertainties may arise which are constantly adapted to, and may even lead to either the cancellation of an overtaking procedure or the initiation of one. Higher level planning is performed by Dijkstra's algorithm which indicates the route to be followed by the vehicle in a road network. Re-planning is carried out when a road blockage or obstacle is detected. Experimental results confirm the success of the algorithm subject to optimal high and low-level planning, re-planning and overtaking.

1. Introduction

Since the initiatives of the DARPA Urban Challenge [1] there has been a considerable increase in the interest in the control of autonomous vehicles in traffic scenarios. Engineering the complete vehicle requires decisions to be made over the types of sensors to be employed, their location, sensor data pre-processing and processing, sensor fusion, map building, motion planning, motion control, etc. [2,3]. While these vehicles are able to steer themselves efficiently in the correct manner, less attention is however paid to devising mechanisms for their coordination. That said, advances in Multi-Robot Systems [4,5] present possibilities for multiple robot solutions to such a problem by means of task division and mutual coordination. With the basic assumption that the various robots involved have an open means of communication with each other – either directly or through a common server – algorithms may be devised to ensure the development of an overall optimal strategy.

The basic problem to be dealt with is to move a number of vehicles from their start point to their destination, along the roads which are known a priori. The problem can be seen as a multi-robot path planning problem [6,7]. Approaches taken to solve these problems can be centralized or decentralized [8], however it is clear that decentralized approaches are preferable for most real time and uncertain environments.

The presence of speed lanes is a well-accepted notion in the domain of intelligent vehicles and intelligent transportation systems. Associated planning algorithms generally involve a decision as to the optimal lane of travel and manoeuvring vehicles to their desired speed lane. To the best of our knowledge, there is no significant work on the planning of vehicles in the absence of lanes. This work carries out the task of planning in such a scenario. Further, the presence of different lanes for incoming and outbound traffic is not assumed. The resultant traffic system is hence unorganized where vehicles may have any desired lateral position on the road.

Unorganized traffic can lead to a higher traffic bandwidth in traffic scenarios where vehicles differ largely in their widths and can enable close overtaking. Lane width is computed based on the largest width vehicle which may occupy the road. In a scenario where the traffic consists of a large number of vehicles with smaller widths, the lanes they drive on therefore have a part of the lane underutilized. The underutilized parts of lanes across the width of the road can be used to accommodate extra vehicles, which is only possible if lanes are not followed or the traffic is unorganized. Further, not adhering to lanes means that overtaking can be completed by pushing the other vehicles to the side to get some additional overtaking space. This may result in infeasible overtaking (as per lane based travel) being made feasible and overtaking being

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performed as early as possible. The advantages of close overtaking are realizable in traffic scenarios where vehicles differ largely in their travel speeds.

The advantages of unorganized traffic are demonstrated by means of two examples. Lane splitting (where the motorists drive in-between lanes) is allowed at a number of places where the motorists defy lanes resulting in a better travel plan for themselves, which does not significantly affect other vehicles. Sewall et al. [9] specifically state incorporating lane splitting as one of the future directions of their work. In this paper however we have generalized the notion further to incorporate partial and overlapping lane occupancy by any vehicle or even the removal of lanes all together. The basis for this is that many countries follow unorganized traffic where lanes are not utilized and traffic generally shows a higher bandwidth with diverse vehicles. Take the Indian traffic as an example. The size and speed diversity includes cycles, motor bicycles, 3-wheeled auto rickshaws, cars, buses and trucks. In such cases, smaller vehicles constitute a larger proportion of the traffic. It is common to see vehicles nicely fitting in-between others so as to occupy the entire road resulting in a higher bandwidth. Constant overtaking is common.

Organized traffic, where lanes are followed, has the advantages of a higher degree of safety, clearer intentions of other vehicles and fewer lane changes or lateral movements which result in a more comfortable driving experience and possibly shorter travel distances. Unorganized traffic is more risky and continuous care must be taken as the adjacent vehicles may manoeuvre in a variety of ways which can cause uncertainty [10]. Hence, when most of the vehicles are roughly wide enough to occupy the entire lane and the vehicles have similar preferred speeds, organized traffic is a better choice. However, as speeds and sizes of vehicles become more diverse so the advantages of unorganized traffic become more important.

Not considering lanes necessarily increases the problem of planning and coordination to a large level but provides for a more general solution. The most important problem faced here is in overtaking, due to the requirement for safety under optimal steering conditions, resulting in a small margin for error in efficiency of driving. However, the vehicle may ask other vehicles for support in order to make a close overtake possible. Such a solution is inspired from observed driving in low width high density roads, especially where vehicles vary in speeds to a large degree – English country lanes are a good example!

Whilst driving along straight roads may be a relatively straightforward affair, making efficient turns for most crossings, or other natural turnings of the road, requires expertise. Turning too close to the inner boundary may require reducing the speed, at the same time turning along the outer boundary may make the path too long and sub-optimal. In this paper, we try to do the same by using a Bezier based motion planning linked with a genetic algorithm for the optimization procedure. The genetic algorithm is adapted to work on real time scenarios by using a space-time approach modelling of different vehicles and a global referenced individual representation. A genetic algorithm is probabilistically optimal and probabilistically complete and can work in continuous spaces. The objectives of efficiency and safety can be easily knit to a single objective function for evolutionary optimization. Road scenarios have limited possible homotopies for a vehicle, which translates to a limited modality of the fitness landscape (given the fact that a repair operator is designed which maps every possible trajectory to a reasonable looking, feasible and short trajectory). For a limited modality fitness landscape, the optimal solution can be found reasonably early or, to put it another way, the probability of finding the optimal solution is high. Here, assumptions are made on a limited number of obstacles and other vehicles, and with a limited resolution map.

The algorithm is a real life application of dynamic evolutionary algorithms, which optimize an objective under a changing fitness landscape. The operational scenario continuously changes as the vehicles move. At every instant the latest instance of scenario is given to the genetic algorithm for optimization. A single population pool of the genetic algorithm is maintained for a vehicle, which adapts to the changing scenario. This is an example of incremental learning where the learnt model (genetic algorithm population) has to be incrementally updated against the changing data (scenario). The changes may be gradual requiring the genetic algorithm to incrementally learn by small changes to the model (genetic algorithm population), or the changes may be large effectively requiring re-working of the complete model. Enabling optimization to be carried out in real time involves a variety of challenges, which are handled by various methods in this manuscript. As the solution is designed for a specific application, deterministically adaptive strategies can be framed for each of the challenges.

Traffic rules of everyday driving can in fact play a major role in coordinating the motion of multiple vehicles in general scenarios. Rules such as driving on the left (or right) hand side of the road, and overtaking on the right (or left) play a major role in enabling drivers to plan their motion amidst multiple vehicles. While tackling the complete problem of vehicle coordination would be extremely large, we observe that embedding these rules as heuristics can play a major role in realizing an overall efficient strategy. The use of other means, such as priority based planning [11,12], co-evolutionary genetic algorithms [13,14], or any other related technique (see e.g. [15,16]) would either lead to a sub-optimal solution or would require highly computational procedures which are presently not possible in a distributed environment.

In the domain of intelligent vehicles, while most works consider the notion of speed lanes, a few algorithms are capable of working in the absence of speed lanes. Kuwata et al. [17] used Rapidly-exploring Random Trees (RRT) for the planning of a single autonomous vehicle. The work considered other vehicles as obstacles and coordination was non-cooperative, which is a major limitation. Kala and Warwick [18] however used the RRT-Connect algorithm to solve the problem for planning multiple autonomous vehicles with communication. Priority based coordination was used which is non-cooperative. The algorithm can operate using low computational time, however due to the highly sub-optimal nature of the RRT algorithm it can be possible to miss out on a possibility to overtake a vehicle, and instead to follow it. The algorithm does not adapt the plans on-line which means that even if the overtake later becomes possible, it would not be performed. On the contrary, a poor control mechanism for an overtaking trajectory can lead to collisions. Not only is the proposed algorithm better in terms of optimality, online adaptations enable judicious decision making when situations change.

The algorithms used in robot motion planning may however be of use for planning vehicles in the absence of speed lanes, and hence a few related approaches are presented. Multi-layered planning is fundamentally used in the domain of robotics [19–21]. Kala et al. [22] fused probabilistic A* with the Fuzzy Inference System, realizing the mixed advantages of the constituent algorithms. Similarly Xiao et al. [23] used an offline planner for static obstacles and an online planner for dynamic obstacles, where preliminary offline planning can be a disadvantage. Due to their real time nature of operation, potential based approaches are extensively used for motion planning, and especially obstacle avoidance [24]. Fahimi et al. [25] used a harmonic potential field with concepts of fluid dynamics for the motion planning of multiple mobile robots. All these approaches cannot generate vehicle following and cooperative overtaking behaviours. They are either sub-optimal or computationally expensive. Unlike these approaches, segments of maps are taken in place of entire maps in our approach.