Improving Transportation Efficiency for Sustainable Society by Autonomous Traffic Management

Tsz-Chiu Au
Post-Doctoral Fellow
Dept. of Computer Science

Neda Shahidi
PhD student in Neurosciences
Univ of Texas Health Science Center at Houston

Peter Stone
Associate Professor
Dept. of Computer Science

Abstract

Recent robot car competitions and demonstrations have convincingly shown that fully autonomous vehicles are feasible with current or near-future intelligent vehicle technology. Our previous research on autonomous intersection management establishes that by leveraging the capacities of autonomous vehicles it is possible to dramatically reduce the time wasted in traffic, and therefore also fuel consumption and air pollution. We extend the scope of our system to a citywide network of intersections and theoretically analyze the conditions under which no vehicle gets stuck in traffic forever. This liveness property is essential for transportation systems in a sustainable society.

Introduction

Modern transportation is overly dependent on fossil fuel, which is not only a finite resource, but also a major source of greenhouse gas and air pollutants. Unfortunately, an ideal replacement for fossil fuel is not readily available. As demand for transport keeps increasing, an efficient transportation system is extremely important for the long-term sustainability of our society. Motivated by the recent advances in autonomous vehicle technology, Dresner and Stone proposed a novel intersection control mechanism called Autonomous Intersection Management (AIM) to direct autonomous vehicles through an intersection. They showed that by leveraging the capacity of computerized driving systems it is possible to devise a traffic control system that significantly outperforms traditional traffic signals and stop signs, resulting in fuel savings since vehicles are less likely to stop and wait to enter intersections.[1]

In 2007, the Department of Computer Science at UT Austin, in collaboration with Austin Robot Technology, designed a fully autonomous vehicle that can run in urban traffic without

Fig. 01 UT autonomous vehicle at Pickle Research Center.

human control (Fig. 01). It is an Isuzu VehiCross that has been upgraded to run autonomously for participating in the 2007 DARPA Urban Challenge. After the competition, our students have continued working on the vehicle to improve its capacities. Our department is one of the few computer science departments in the United States that offers courses on autonomous vehicles.

Based on our experience with autonomous vehicles, we believe that eventually most, if not all, vehicles on the road will be driven entirely by computer. The demand and potential for autonomous vehicles is already demonstrated by current research and practice. In addition to the remarkable success of the DARPA Urban Challenge, many manufacturers are working on autonomous cars—building on autonomous technologies already included in cars currently on the market, such as adaptive cruise control and automatic parking capabilities. Google has also been testing a fleet of autonomous cars on real roads, already logging thousands of miles of successful autonomous driving. Even laws are changing in response to these technological developments. For instance, Nevada recently passed a law making it legal to "drive" autonomous cars on the roads there.

We, therefore, think that it is time to consider transportation systems to support autonomous vehicles. The central question of our transportation research is: what is the best transportation infrastructure for traffic that consists of a mix of autonomous vehicles and human-controlled vehicles? To our knowledge, we are one of the first research groups to address the design issues of transportation systems for autonomous vehicles. In addition to the funding support by the Federal Highway Administration (FHWA), we have also collaborated with General Motors, whose research branch for autonomous vehicle research is located in Texas. We believe Austin is an ideal place for this research because it is a relatively small developing city (unlike cities in the east and west coast) with a special focus on technological industry.

The obvious benefit of autonomous vehicles is the convenience and safety brought by autonomous driving systems due to the elimination of human intervention from vehicle control. Furthermore, it opens up new opportunities for reducing fuel consumption through precise vehicle control and coordination. To test our hypothesis that the use of auton¬¬omous intersection systems can reduce fuel consumption tremendously, we designed an experiment to collect data regarding fuel consumption of vehicles under both the AIM protocol and with traditional traffic signals. That data was collected using Powertrain System Analysis Toolkit Software (PSAT), an industrial-strength simulation package for estimating fuel consumption of vehicles. We modified our traffic simulator to save all velocity profiles of the vehicles in simulation and then analyzed the overhead of the fuel consumption due to the traffic (the overhead is the total fuel consumption of all vehicles minus the sum of the fuel consumptions of the vehicles when there is no other traffic on the road). Our preliminary results show that the use of the AIM protocol reduces the overhead of fuel consumption by approximately two thirds when compared with an intersection controlled by traffic signals.

Liveness in Autonomous Traffic Management

In designing such autonomous traffic control systems, we need to make sure that no vehicle would be stuck in the traffic for too long. *Unbalanced traffic*—when the traffic on a main road is much heavier than the traffic on a crossing road—can prevent vehicles on the crossing road from entering the intersection. In Fig. 02, vehicles from the side road (the vertical direction) have difficulty in getting reservations to enter the intersection due to the heavy traffic

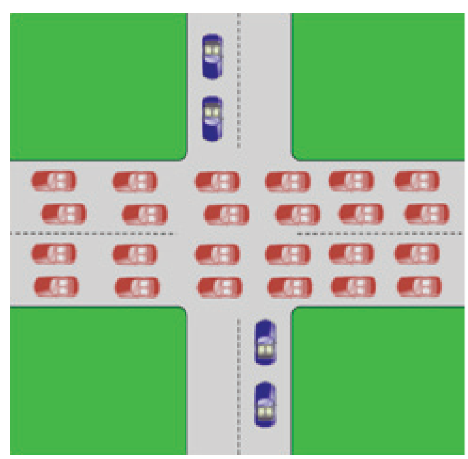

Fig. 02 Unbalanced traffic.

Fig. 03 Gridlock.

on the main street (the horizontal direction). In the worst case, the vehicles from the side road will be denied from entering the intersection indefinitely, causing *starvation*. Unbalanced traffic is common as many intersections in cities are junctions connecting alleys or side roads to main streets. For example, the intersection at Lamar Boulevard and 38th Street is one of the worst intersections in Austin; traffic on the Lamar Boulevard is usually much heavier and faster than traffic on 38th Street, causing a long delay for the vehicles on 38th Street due to the prolonged red signals. While traffic signals can smoothly and fairly handle this type of traffic, they are an order of magnitude less efficient than AIM.[2]

We recently introduced a new intersection control policy called the *batch policy*, which is not only as efficient as AIM but also able to prevent inequalities in granting reservations in unbalanced traffic. We further showed that a modified version of the batch policy can enforce the *liveness* property of an intersection—every vehicle waiting at the intersection is guaranteed to enter and leave the intersection eventually.

Starvation at one intersection may potentially develop into a network blockage called *gridlock*, like the one in Fig. 03. When gridlock occurs, the impact is no longer limited to one intersection, as many vehicles at different parts of the traffic network are involved. Gridlock occurs in all parts of the world. For instance, the "Great Chinese gridlock of 2010" in Hebei province, China, is considered the worst traffic jam in the history—the 60-mile jam lasted for 10 days. Thus it is very important that transportation systems guarantee that no vehicle gets stuck in traffic and every vehicle eventually reaches its destination (the liveness property of the transportation systems). Although the liveness of individual intersection controllers, as guaranteed by policies such as our batch policy, is necessary for preventing gridlock in a network, it is not by itself sufficient. We therefore analyze liveness properties in a road network and present the sufficient conditions for liveness of a simplified version of a road network.[3] This analysis can shed light on what is needed to prevent starvation and keep traffic flowing in a transportation network.

Conclusions

Autonomous vehicles may seem like a future technology in scientific novels. In fact, the day when people can own a personal vehicle that can drive by itself will come much sooner than most people would expect. In the future, people will simply "tell" the vehicle the destination and then the vehicle will bring them to that destination along the most efficient route. Apart from convenience, autonomous driving systems will also make our journey safer by eliminating human errors in the control loop of the vehicles. Based on our experiences, we anticipate that most, if not all, vehicles in the future will be autonomous. By leveraging the advanced capacities of autonomous vehicles, we set out to design a transportation system with a focus on fuel and time efficiency. We believe that the autonomous vehicle research at UT Austin has a great potential to make our world greener for our future generations.

1. Kurt Dresner and Peter Stone, "A Multiagent Approach to Autonomous Intersection Management," *Journal of Artificial Intelligence Research* 31, (2008): 591-656.

2. Ibid.

3. Tsz-Chiu Au, Neda Shahidi, and Peter Stone, "Enforcing Liveness in Autonomous Traffic Management," Proceedings of the Twenty-Fifth Conference on Artificial Intelligence, (2011).