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Bumper-To-Bumper At High Speeds: A Vision-Based System For High Efficiency Vehicle Platoons In Metropolitan Areas

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Srinivasa Narasimhan (PI), Associate Professor

Robotics Institute, Carnegie Mellon University

https://orcid.org/0000-0003-0389-1921

James Hoe (Co-PI), Professor

Electrical and Computer Engineering, Carnegie Mellon University

https://orcid.org/0000-0002-9302-5287

Robert Tamburo (Co-PI), Project Scientist

Robotics Institute, Carnegie Mellon University

https://orcid.org/0000-0002-5636-9443

Subhagato Dutta, Graduate Student

Electrical and Computer Engineering, Carnegie Mellon University

https://orcid.org/0000-0003-3873-8679

Minh Vo, Graduate Student

Robotics Institute, Carnegie Mellon University

https://orcid.org/0000-0003-3873-8679

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1 Problem

Traffic congestion instantly became a problem when mass vehicle production and urbanization took hold in the early 1900s. Despite efforts to reduce congestion by constructing highways and urban expressways, and widening roads, congestion is still a significant source of headache in cities of all sizes [6]. Traffic has a profound negative impact on productivity, fuel expenses, regional economic health, quality of life, and the environment. In 2013, traffic cost the U.S. economy $124 billion, which is estimated to increase to $186 billion by 2030 [5]. Additionally, commuters lost 5.5 billion hours, wasted 2.9 billion gallons of fuel, and created 56 billion pounds of excess carbon dioxide. To put those numbers in perspective, commuters in a small city like Pittsburgh, PA lost $1 billion, 46 million hours, 21 million gallons of fuel, and created 431 million pounds of excess carbon dioxide [6].

An intelligent transportation system (ITS) approach to addressing these problems was proposed by General Motors at the 1939 New York World's Fair [11]. GM envisioned an automated highway system where vehicles could automatically drive on the road and follow other vehicles at safe distances in vehicle platoons.

Current prototype deployments of vehicle platoons utilize local sensors such as cameras, LIDAR, RADAR, and GPS, DSRC for vehicle-to-vehicle communications, and sensors/computers built into the infrastructure [1, 7, 2]. Such systems are able to achieve platoons traveling at 50 miles per hour with 6 to 10 meters between vehicles. With this gap, fuel waste can be reduced by as much as 10 - 20% [12] and fatalities can be reduced by 10% [9].

Data Source	Typical Acquisition Rate	Typical Accuracy
Camera	30 Hz (33 ms)	Algorithm dependent
RADAR	20 Hz (50 ms)	0.5 m, 0.12 m/s
LIDAR	100 Hz (10 ms)	60 mm
GPS	50 Hz (20 ms)	3 to 8 mm
DSRC	100 Hz (10 ms)	Distance dependent

Table 1: Typical parameters for data sources common in vehicle platoons.

Minimizing the inter-vehicle distance has the potential to double or even triple the efficiencies on both highways and city roads. Additionally, small gaps are necessary in metropolitan areas where, unlike highways, vehicles need to be densely packed between intersections and traffic lights. Achieving tighter gap spacing (e.g., 1 meter), however, is very challenging for control systems using typical local sensors because of their slow acquisition rates and low accuracy (Table 1). Some of these sensors, such as GPS and RADAR, are also unreliable in cities where tall buildings are present. Cameras, however, have proven robust in a variety of road environments for many computer-assisted transportation systems ranging from complex systems such as autonomous driving to simpler advanced driving systems such as lane detection. But their accuracies and precisions are unreliable in unconstrained environments. We propose a vision-based platform for vehicle tracking and inter-vehicle distance estimation that has the potential to overcome the issues of traditional sensors (Fig. 1).

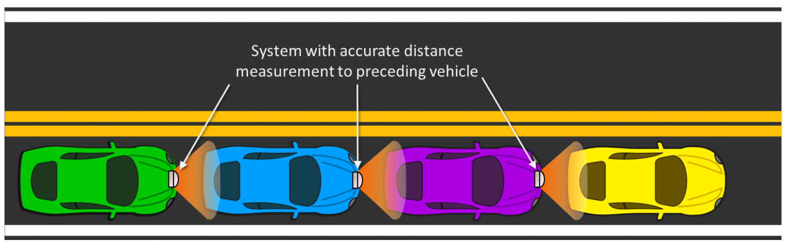

Figure 1: Vehicles equipped with a system that could quickly and accurately estimate the distance to preceding vehicles with low-latency and high bandwidth could enable very short, safe following distances in vehicle platoons. Densely packed vehicle platoons would benefit urban environments by increasing traffic throughput and reducing congestion, commute times, and vehicular emissions.

2 Approach and Methodology

The exact platform performance needed is unknown due to a lack of studies on gap distance impact on traffic throughput. We first performed a comprehensive study via computer simulations to evaluate the impact of gap distance on traffic throughput and energy efficiencies. We then developed a computer vision-based system for high-speed and high-precision estimation of inter-vehicle distances.

Computer simulations were conducted (VISSIM) using a traffic model for an 11-mile stretch of Route 51 between Crafton and Elizabeth (Fig. 2). This road section was used because it encompasses a variety of traffic patterns (Fig. 3). In the simulations, driver behavior was modeled to follow how we envision our system being used. Driving behavior was set to follow

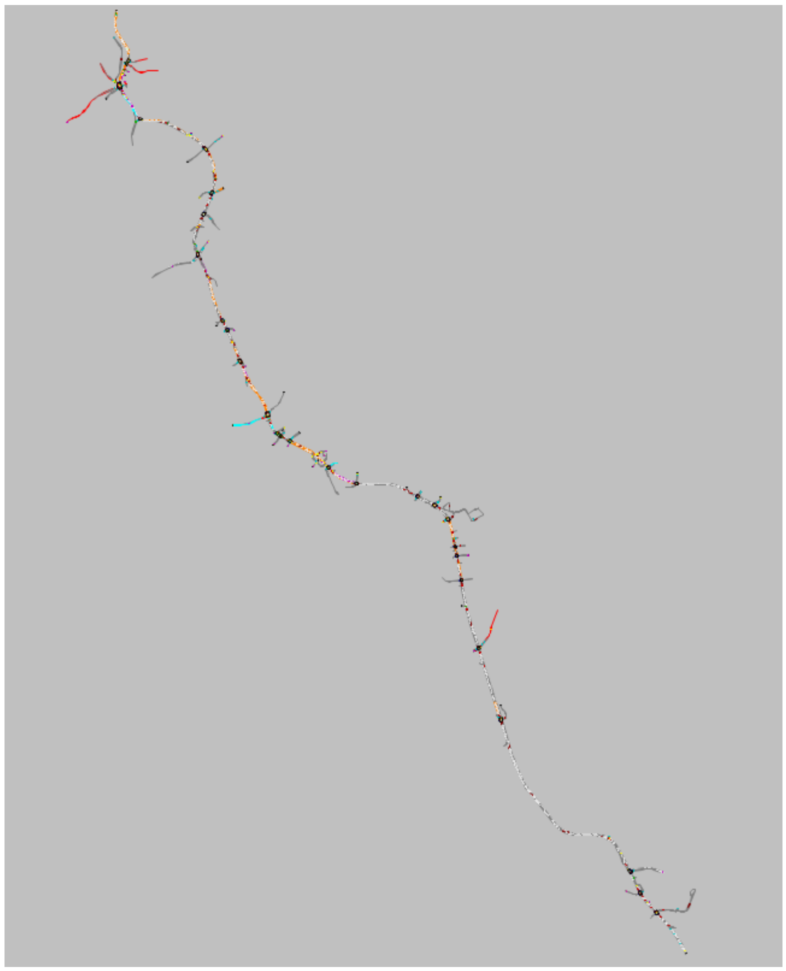

Figure 2: Road network used in traffic simulation study. The network is modeled after an 11-mile stretch of Route 51 between Crafton and Elizabeth in the Pittsburgh area.

closely to preceding vehicles (1 meter) and accelerate quickly when stopped at traffic lights. By modeling driving behavior in this way, we were able to simulate the overall effect that densely packed vehicles would have on traffic patterns.

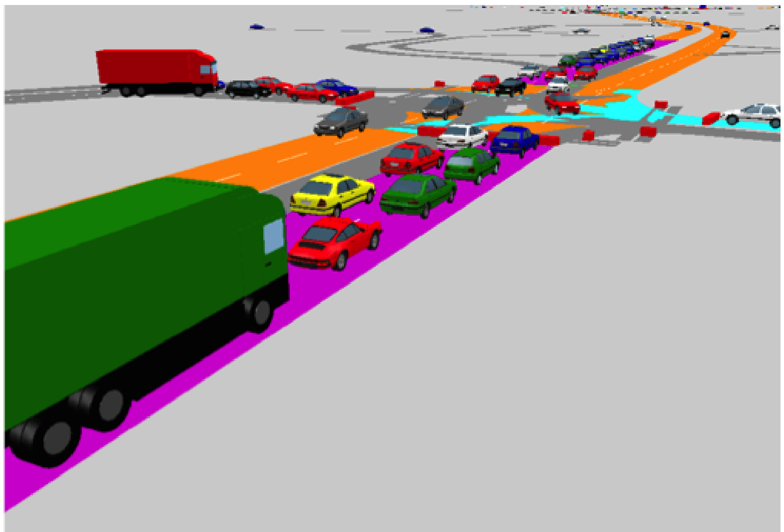

Figure 3: Example screenshot from computer simulations at a busy intersection.

The requirements of the vision-based platform are fast and accurate estimation of the speed and distance of a vehicle in front; information needed to automatically follow the vehicle. The method relies on projecting a fast modulating pattern or a set of patterns similar to bar codes on the rear of vehicles, which allows for the identification of vehicles and their distance. The patterns are projected at a high frequency to be imperceptible to the naked eye. Based on deviations from the expected parameters of the pattern, such as size, shape, and sharpness, speed and distance can be calculated. The platform consists of a pair rolling shutter CMOS cameras, micro-controller, and 30 lumen raster scanning projector. The camera captures images of the road environment. The micro-controller synchronizes the camera and projector. The projector displays patterns. Figure 4 shows a prototype of the system that was built.

The sensor's raster scanning projector illuminates the scene one scanline at a time. The cameras and projector are aligned so that by epipolar geometry, one projector scanline corresponds to a single row of pixels in each camera. The rolling shutter on the cameras are synchronized so that the exposed row moves in lockstep with the active projector scanline. The

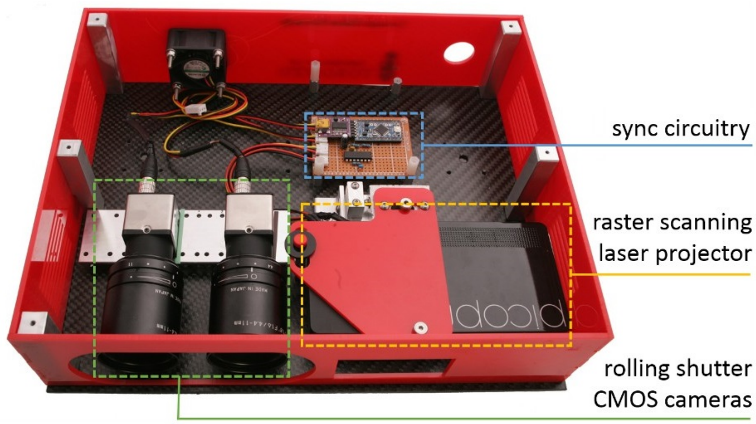

Figure 4: Prototype of vision-based platform for measuring distance to vehicles.

projector takes only 20 microseconds to draw a scanline, so the exposure for each camera row is also very short. This short exposure integrates very little ambient light while still collecting all the light from the projector, and, therefore, can be used in all lighting conditions including bright sunny days. Only light paths that follow the epipolar constraint between the projector to camera reach the camera sensor, this blocks almost all multi-path light, resulting in more accurate reconstructions of difficult scenes where global transport effects are pronounced.

3 Findings and Conclusions

Computer simulations were conducted using a network modeled after a road that connects suburbs to the City of Pittsburgh. The roadway has many signaled and un-signaled intersections and is prone to congestion. Our simulations showed that if vehicles quickly accelerated from complete stops and automatically followed preceding vehicles at a 1 meter distance would decrease commute time by 32% and decrease vehicle emissions by 22%.

The prototype has been demonstrated in static, sunny environments with a vehicle moving 0.5 to 3 meters in front of the system (Fig. 5). As the vehicle moved from the system, a second camera on the system captured the projected pattern (not visible to naked eye) (left side of Fig. 6). The right side of Fig. 6 shows a depth map captured from the sensor with computed distance to the license plate as the vehicle moves away from the system.

Figure 5: The position of the system relative to a vehicle during an experimental run. The vehicle was in direct sunlight and 0.5 to 3 meters in front of the system.

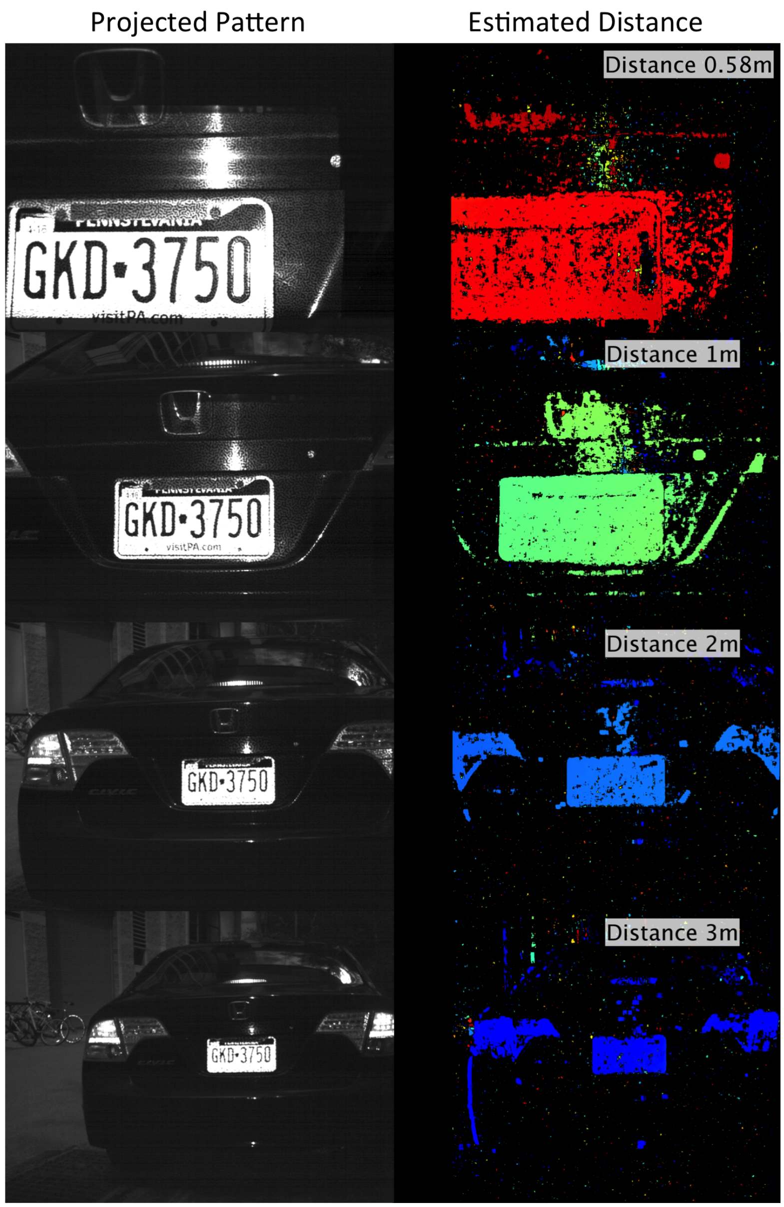

Figure 6: The patterns projected by the system are shown on the left side. Example distance maps to a vehicle?s license plate are shown on the right.

4 Recommendations

Computer simulations demonstrate that vehicle platooning in metropolitan is a worthwhile endeavor for reducing traffic congestion, improving commute times, improving work productivity and the economy, and decrease vehicle emissions. The proof-of-concept sensor that was developed demonstrates that a vision-based platform can be accurate and fast enough to provide distance estimates suitable for urban platooning. Further investment in urban platooning can lay the groundwork for new research, development, and deployment of technology in related areas. For example, how do traffic signals need to be controlled for tightly packed vehicle platoons? Can roadways be more efficient designed if urban platoons improve traffic throughput? How will urban platoons affect humans (drivers, bicyclist, pedestrians)?

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