Infrastructure-Based Sensors Augmenting Efficient Autonomous Vehicle Operations

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INFRASTRUCTURE-BASED SENSORS AUGMENTING EFFICIENT AUTONOMOUS VEHICLE OPERATIONS

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ABSTRACT

Autonomous vehicle technology development relies on an on-board network of fused sensor inputs for safe and efficient operation. The fused sensors offer multiple perspectives of similar information aiding in system decision robustness. The high cost of full systems on individual vehicles is seen as a potential barrier to broad adoption and achieving system energy efficiency gains. Since traffic intersections pose the greatest probability of accident leading to congestion and energy waste, this paper proposes the use of infrastructure-based sensors providing bird's-eye intersection visibility to all vehicles within the vicinity. This data sharing strategy would enhance the robustness of autonomous vehicle decisions and provide connected vehicles and their operators with augmented visibility enhancing the opportunity to reduce accidents, congestion and in the end improve traffic flow and system energy efficiency.

KEY WORDS

Autonomous vehicle, LIDAR, traffic flow control, fuel economy, crossroad safety

INTRODUCTION AND BACKGROUND

Autonomous vehicles, or self-driving cars, are increasingly gaining interest from automobile industry, government agencies, and media thanks to recent successes in field deployment of unmanned aerial vehicles (UAVs), accomplishments in DARPA Grand Challenge/Urban Challenge, real-world demonstrations of self-driving cars by Google, Audi, etc. However, focusing on autonomous vehicle technology alone seems to limit the potential safety and energy benefits with respect to a systems-integrated approach that includes infrastructure enhancement (1). Integrated transportation systems knowledge development leveraging collaborative sensor systems both vehicle-based and infrastructure-based provides a pathway with rapid returns in both safety enhancement and energy benefits. The U.S. Department of Energy is focused on reducing transportation fuel consumption and connected automation offers an opportunity for achieving these goals.

Transportation system energy demands are significantly affected by driver behavior, system design, and environmental conditions. For example, aggressive driving such as speeding, rapid acceleration and braking could lower fuel economy by more than 30% (2). Traffic flow and congestion also affect vehicle fuel economy. Congested traffic flow results in more time required to reach a destination and vehicles then consume more fuel for the same trip distance. Traffic congestion can be induced by car accidents as well as the volume of cars on the roads. Therefore, optimized driving profile in conjunction with optimized traffic control leading to reduced accident rates can significantly increase transportation system energy efficiency.

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Autonomous vehicles are operated by computers evaluating the environment based on complex sensor inputs. The sensor systems are composed of arrays of cameras, ultrasonic sensors, and laser range detectors (LIDAR) (3). The individual sensors provide a complimentary perspective of the environment. LIDAR provides an environmental lighting condition independent option for physical feature and object detection. On the contrary, a camera-based imaging system can provide a more granular view including color and textures aiding in accurate object detection. BRAiVE autonomous vehicle built by VisLabs, Inc. has ten cameras and five LIDAR sensors in various locations of the vehicle (3). While blind spots can be reduced by distributing many sensor units in different locations of the vehicle, it increases the costs. Sensor units installed in the bumper area of a vehicle provide obstacle detection but also put them in a high-risk area for damage during collisions.

The opportunity for information flow to a vehicle from external sensors and the use of that information for driving control can be referred to as connected vehicle automation. It is expected that connected vehicle automation will bring convenience and a reduction in traffic accidents using the most cost effective combination of sensors, algorithms, and controls. Advanced computational algorithms are required to define a vehicle's safe and efficient operation. It has been also shown that autonomous vehicles can avoid collisions using sensor systems and algorithms. However, the cost of the sensors used for autonomous vehicles, especially the LIDAR units, is very high and will be a significant barrier to broad adoption of autonomous vehicle technology. Even with 50% cost reduction, a single LIDAR unit might be 25% of the cost of a typical sedan today. At these costs, it is challenging to foresee all vehicles having LIDAR at some future date. The theory of this paper is that an infrastructure-based LIDAR system focused on critical intersections can serve the information needs of many vehicles and thus be a much more cost effective systems strategy.

Traffic flow can be controlled to reduce congestion by utilizing traffic monitoring and flow control equipment such as adjusting light timings to reduce stop and go events. The U.S. Department of Transportation (DOT) is aggressively working with industry and state DOTs to develop and deploy Intelligent Transportation Systems technology that disseminates traffic state information to improve network operations. Bayless, *et al.* (4) showed a reduction of up to 29% in crashes with speed harmonization by applications of radars in road operations. Other advanced efforts focus on connected vehicles in which vehicles share information with each other and with infrastructure to enhance system safety. Challenges for technology deployment include communication network structures interconnecting vehicles, sensors, and traffic controllers, and the information integration strategies and control algorithms that optimize the traffic system as a whole.

SENSOR SYSTEM DESCRIPTION

Given the barriers identified in the previous section, a traffic system is envisioned in which the most expensive autonomous vehicle component, the LIDAR, is moved from the vehicle to the infrastructure to be used as a shared sensor augmenting the decision making process of both autonomous and human driven vehicles. With intersection monitoring the strategy will be to communicate a birds-eye view of the environment to all vehicles in the area in such a way that either the on-board autonomous control or even the human driver will have greater visibility and capability to avoid accidents at intersections and thus improve traffic flow. A 360-degree view of a crossroad area seen from LIDAR is illustrated in Figure 1.

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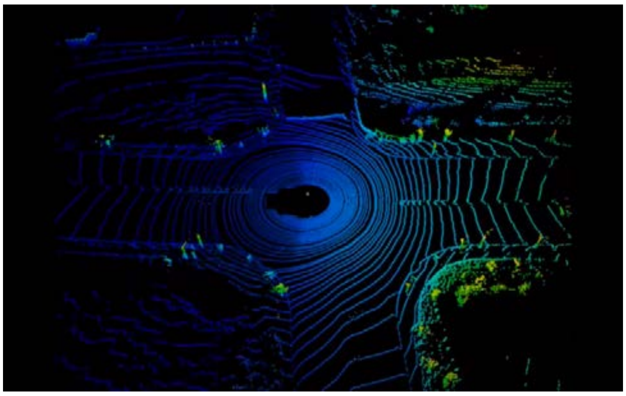

Figure 1: A 360-degree view of a crossroad area seen from LIDAR (Source: http://velodynelidar.com/lidar/lidar.aspx)

Another design for LIDAR installation in a crossroad area is to install multiple LIDAR's with less than 360° horizontal field of view. A good candidate of the locations would be on or under the traffic lights. Ibeo LUX LIDAR's have 110° horizontal FOV (5). Four units can cover 360° FOV with some overlapped areas as illustrated in Figure 2 and a 360° view can be obtained by fusing the data from four LIDAR units.

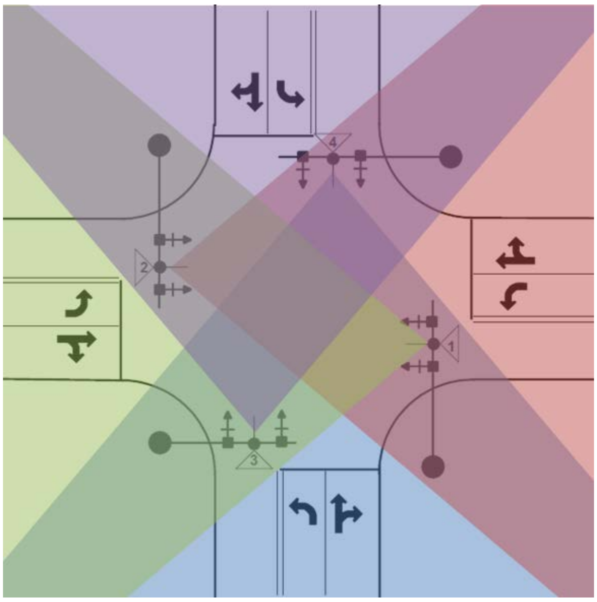

Figure 2 : Area covered by four LIDAR units installed on the traffic lights on each way

VEHICLE CONTROL

Further research should investigate the opportunity of combining fuel-efficient driving profiles and traffic flow control with infrastructure-based LIDAR in comparison to individual vehicles with complete standalone systems. An infrastructure-based strategy will reduce the cost of automobiles and can accelerate the introduction of vehicles that have capability to adopt to intelligent roadway and even autonomous driving. Available LIDAR technology can provide 360-degree bird's-eye view of a crossroad area such as in Figure 1 or a combined view by multiple units as in Figure 2. Those views can provide information about obstacles that cannot be detected by vehicle-mounted sensors and thereby can improve intersection collision avoidance.

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A computer in a traffic flow controller will be directly connected to LIDAR, receive raw LIDAR data, and process the LIDAR data. Processed data can be disseminated to local vehicles and dash-mounted displays much the way drivers today use GPS turn-by-turn directions. This structure can relieve computing loads from in-vehicle computer and reduce implementation costs compared to one that processes LIDAR data or sensor data onboard. Another advantage of the proposed structure is an easy integration of autonomous and non-autonomous vehicles. With this structure, even vehicles without autonomous driving capability can utilize the information and nearby vehicles and drivers would then have the benefit of a new perspective of the intersection risks not currently available in the vehicle or in a vehicle with a stand-alone autonomous sensor network. Information about distances between vehicles/pedestrians, hidden objects, traffic amounts, etc. would be available to all regardless they are autonomous or not.

CONCLUSION

A new application of LIDAR sensors for smart infrastructure is proposed in this paper providing data integration for both autonomous and non-autonomous vehicles that as part of a smart transportation system should rapidly improve safety and energy efficiency in a cost effective strategy. With infrastructure-based LIDAR, automobiles, autonomous or not, can utilize the processed LIDAR data for collision avoidance reducing intersection risk and improving traffic flow.

The U.S. Department of Energy is working to reduce fuel consumption in transportation systems. Connected vehicle automation is a potentially significant pathway to more energy efficiency. In conclusion, the proposed infrastructure-based sensor systems leverages future broad vehicle connectivity to reduce the costs of autonomous vehicles promoting their early introduction to the market in addition to improved accident avoidance capability of non-autonomous vehicles.

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