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FINAL REPORT
Research at the Intersection of Big Data and Connected and Autonomous Vehicles

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16. Abstract

This project aims to explore various issues related to research at the intersection of Connected and Automated Vehicle (CAV) research and Big Data research. The project is conducted in synergy with another project funded by New York State Energy and Research Development Authority (NYSERDA) and New York State Department of Transportation (NYSDOT), and which aims to design a suite of testing scenarios for evaluating the safety and reliability of CAVs. Two CAVs are considered in the current work. The first is a self-driving, low-speed shuttle, Olli, manufactured by Local Motors (LM), which seats eight passengers and drives at a maximum speed of 25 mph. The second vehicle is a Lincoln MKz outfitted for self-driving by AutonomouStuff. The tasks explored in the current project included: (1) Enabling Autonomous Driving with High-Definition Map Creation and the self-driving open source software, Autoware; (2) Lidar Simulation for Integrated Simulation based Safety Evaluation of CAVs; (3) Sensory Data Exchange Using V2V (Vehicular Ad Hoc Network); (4) Road Geometry Estimation for Advanced Driver Assistance Systems (ADAS) and CAVs; (5) Integrating Autonomous Shuttles with Public Transit; (6) Researching Fifth Generation (5G) Cellular Technology for CAVs; and (7) Acquiring LIDAR and Data Storage Equipment to support research at the intersection of CAV and Big Data.

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EXECUTIVE SUMMARY

This project aims to explore various issues related to research at the intersection of Connected and Automated Vehicle (CAV) research and Big Data research. The project is conducted in synergy with another project funded by New York State Energy and Research Development Authority (NYSERDA) and New York State Department of Transportation (NYSDOT), and which aims to design a suite of testing scenarios for evaluating the safety and reliability of CAVs.

Two CAVs are considered in the current work. The first is a self-driving, low-speed shuttle, Olli, manufactured by Local Motors (LM), which seats eight passengers and drives at a maximum speed of 25 mph. The shuttle is mostly 3D printed, fully electric and can be designated as a level 4/5 Autonomous Shuttle, capable of operating to the afore mentioned levels in a fixed route, fixed stop manner in a controlled environment. Olli is controlled by self-driving software developed by Robotics Research. The second vehicle is a Lincoln MKz outfitted for self-driving by AutonomouStuff. The vehicle is being integrated with the self-driving, open-source software, Autoware.

The tasks explored in the current project included: (1) Enabling Autonomous Driving with High-Definition Map Creation and the self-driving open source software, Autoware; (2) Lidar Simulation for Integrated Simulation based Safety Evaluation of CAVs; (3) Sensory Data Exchange Using V2V (Vehicular Ad Hoc Network); (4) Road Geometry Estimation for Advanced Driver Assistance Systems (ADAS) and CAVs; (5) Integrating Autonomous Shuttles with Public Transit; (6) Researching Fifth Generation (5G) Cellular Technology for CAVs; and (7) Acquiring LIDAR and Data Storage Equipment to support research at the intersection of CAV and Big Data.

INTRODUCTION

Recently, there has been an unprecedented interest in Connected and Automated Vehicles (CAVs) or self-driving vehicles. This is evidenced by the number of companies striving to develop automated and self-driving capabilities which include, major automotive companies (e.g., Ford, GM, Tesla, BMW, Nissan, and Volvo), major Tech companies (e.g., Google's Waymo, Uber, and Amazon), and several start-ups (e.g., Argo AI, Zoox, Drive.ai, Local Motors, Nuro and EasyMile). It is also evidenced by the number of research studies, scientific papers and conferences, pilots of the technology (e.g., the self-driving Uber in Pittsburgh), and even limited commercial deployments (e.g., Waymo One in AZ).

CAVs have the potential to revolutionize transportation, resulting in a major paradigm shift in the way we move and move our goods. Among the purported benefits of the technology are: (1) improved safety (by reducing crashes caused by driver error and/or incapacitation); (2) decreased traffic congestion and increased capacity (by reducing headways for example); (3) increased human productivity; (4) improved mobility for children and the elderly; (5) enabling innovative ideas for shared mobility; (6) solving the first- and last- mile problem associated with public transportation; and (7) reduced private car ownership.

While CAVs promise significant societal benefits, as outlined above, serious challenges still abound in the way to their wide-scale adoption and deployment. Chief among those challenges is the fact there is currently no established safety standards, nor safety certification process for CAV. There is also lack of effective and cost efficient evaluation methods and tools for design, verification and validation. Adding to the challenge is that, unlike traditional vehicles, the safety of CAVs is largely dependent on control software, and which is also much less understood.

The current project is conducted in synergy with another project at UB, funded by New York State Energy and Research Development Authority (NYSERDA) and New York State Department of Transportation (NYSDOT). That project is evaluating the technical feasibility, safety and reliability of using CAV technology, and in particular the self-driving shuttle, Olli, manufactured by Local Motors (Figure 1).

Figure 1. UB's Self-Driving Shuttle, Olli

Olli seats eight passengers and drives at a maximum speed of 25 mph. The shuttle is mostly 3D printed, fully electric and can be designated as a level 4/5 Autonomous Shuttle, capable of operating to the afore mentioned levels in a fixed route, fixed stop manner in a controlled environment. It is controlled by self-driving software developed by Robotics Research. The NYSERDA/NYSDOT project is also researching the public policy changes needed to allow for AVs to be driven on NYS public roads, and will be conducting an evaluation***, using simulation***, of the costs and benefits of using AV technology on a realistic case study involving the Buffalo-Niagara Medical Campus (BNMC).

In the current work, in addition to utilizing Olli, the project is utilizing another Autonomous Vehicle (AV) platform we are developing here at UB. That second vehicle is a Lincoln MKz outfitted for self-driving by AutonomouStuff (Figure 2).

Figure 2. UB's Automated Vehicle Platform – the Lincoln MKz

The vehicle is being integrated with the self-driving software, Autoware, an open source software for self-driving cars in urban areas on pre-defined paths. Autoware 2.0 mainly consists of ROS 1 based modules for doing localization, object detection, prediction and planning. It output basic velocity control for the by-wire controller of the vehicle. Autoware can be run on many vehicles equipped with Lidar, radar, IMU, GPS, cameras but requires a High Definition (HD) map which consists of point cloud information and annotations of specific objects such as stop signs, traffic lights and road lines. Autoware 3.0 is still being developed. It is based on ROS 2 and improves over Autoware 2.0 with support for autonomous Valet Parking and autonomous Depot Maneuvering while using more radars and cameras.

While utilizing both Olli and the Lincoln MKz, the current project explored the following seven research tasks: (1) Enabling Autonomous Driving with High-Definition Map Creation and the self-driving open source software, Autoware; (2) Lidar Simulation for Integrated Simulation based Safety Evaluation of CAVs; (3) Sensory Data Exchange Using V2V (Vehicular Ad Hoc Network); (4) Road Geometry Estimation for Advanced Driver Assistance Systems (ADAS) and CAVs; (5) Integrating Autonomous Shuttles with Public Transit; (6) Researching Fifth Generation (5G) Cellular Technology for CAVs; and (7) Acquiring LIDAR and Data Storage Equipment to support research at the intersection of CAV and Big Data. Each of these tasks will be briefly discussed in the next sections of this report.

TASK 1: ENABLING AUTONOMOUS DRIVING WITH HIGH-DEFINITION MAP CREATION AND THE OPEN-SOURCE SOFTWARE, AUTOWARE

Autonomous driving will have a significant impact on future transportation systems. The data collected in the process of enabling autonomous vehicles will provide a valuable set of information for future research and simulated autonomous driving scenarios. The wide range of data and sheer volume of which can be collected can also have further use in improving autonomous driving algorithms for mapping, localization, computer vision and vehicle control. In this task, we used our Lincoln MKZ, which had been retrofitted with a computer, and sensors that are used in the autonomous vehicle industry including LIDAR, GPS, camera and CAN based vehicle control. We setup Tier IV's Autoware, an open source self-driving software platform and ROS which is the backbone that Autoware runs on. We then configured the vehicles main sensors to work with the platform (each sensor had its own unique challenges which we had to address in order to enable its use and integration). The end goal was to create a basic High Definition (HD) map to enable the autonomous drive mode. The HD map consisted of two main parts: (1) a point cloud map; and (2) a vector map; both provide the vehicle with needed information.

We started working with the LIDAR sensor first as that is what can generate a point cloud. We configured it to work with ROS/Autoware, built a basic point cloud map using the NDT mapping/matching algorithm, and iterated on this process to create a higher fidelity map. To also help us generate a better point cloud map we wanted to include GPS in hopes that we could match point cloud in a better way. This required us to improve our GPS accuracy so we had to setup our GPS receiver to use NTRIP corrections from a local base station network. With the improved accuracy we were able to better use the LIDAR data and improve our point cloud map. Afterwards, the last step in creating the HD map was to build an initial vector map which includes roadside-related information such as information on stop signs, traffic lights and cross walks. For our initial vector map build, we turned to the help of Autoware's online vector map tools which allowed us to manually build a vector map based on an uploaded point cloud. With the initial HD map created, and after configuring the vehicle control interface which allowed us to drive the vehicle by sending control messages, we were able to test the vehicle in autonomous mode. We used LIDAR localization, using the point cloud map to locate the vehicle in the world, we were able to run the vehicle in autonomous mode, following the waypoints we defined in the vector map.

TASK 2 - LIDAR SIMULATION FOR INTEGRATED SIMULATION BASED SAFETY EVALUATION OF CAV

LIDAR constitutes a critical component that supports autonomous driving, and therefore any safety evaluation of CAV, whether in the real-world or in simulation, needs to assess the functionality of the LIDAR sensors. At UB, in addition to physical testing, we have been developing an integrated simulator to allow for the safe and efficient testing of CAVs. Therefore, in order to evaluate the safety and efficiency of CAVs via simulation using an integrated simulator, one needs to be able to simulate the LIDAR output. The focus of this second task was therefore on simulating LIDAR in the Unity simulation environment.

In this project, we isolated LIDAR simulation in the LGSVL simulator, from other functionalities and other code architecture of LGSVL to develop the simplest possible Unity project with only LIDAR Simulation. This Unity project makes use of a camera with a custom shader to report depth, and a script to read that depth and transform it into real-world distances just like the distances reported by a real-world Lidar sensor. The Unity project also reports the distances in ROS PointCloud2 message format and transmits to ROS over a ROS bridge server. We used a simpler ROS bridge server implementation as compared to the one used by LGSVL. Finally, we integrated the LIDAR sensor simulation as a part of our integrated simulator for CAVs.

TASK 3 - SENSORY DATA EXCHANGE USING V2V (VEHICULAR AD HOC NETWORK)

Information dissemination plays a crucial role in enabling autonomous driving by overcoming the limitation of perception and stand-alone decision-making of a single autonomous vehicle (AV). An AV always has a limited scope of perception and blind spots which can result in potential hazards. These blind spots might be due to the presence of large obstacles like buildings, trucks or other vehicles. Enabled by IEEE 802.11p DSRC communications, sharing the sensory data among vehicles and roadside sensors in proximity will significantly enhance the anticipation of unseen events and rapid reactions to potential accidents. In this project we investigated DSRC-based AV blind spot discovery and dissemination. We particularly focused on 3D point cloud as a faithful representation of raw data captured by AV's light detection and ranging (LIDAR) sensor and studied the feasibility, challenges and solutions for the problem of AV data exchanges.

The aforementioned problem is thereby tackled using LIDAR sensor data fusion from an AV or roadside unit with the ego AV unit to help increase the sensor range of the vehicle and to get more data for blind spots. It involves scene matching from two sensor data followed by merging 3D points from roadside unit with the ego vehicle. The focus here is to fuse data and to get as close to real time computation as possible. One of the most important use cases is in the traffic intersection area where occlusions occur very often due to variety of reasons. By sending important sensory data from a roadside unit or another AV, an ego AV can make more informed decision.

TASK 4. ROAD GEOMETRY ESTIMATION FOR ADAS AND CAVS.

Accurate information of road geometry features such as grade, cross-slope, super-elevation and curvature, is the enabler of a variety of ADAS applications. For e.g. a) Predictive Powertrain Control System, which can result in significant fuel savings by switching to optimum vehicle speed and transmission based on the geometry of the road ahead. In the future, fully autonomous operation of vehicles would require highly accurate information about the road network, which is provided by a High-Definition Map (or HD Map for short). Accurate information about road geometry features is an essential component of a HD map. Thus, an effective solution for estimation and collection of road geometry features will directly impact the autonomous industry by scaling the creation of HD maps of world road networks.

The task of estimating road geometry features, however, is a challenging one. Firstly, the scale of the current road networks is huge. Secondly, road networks are dynamic in nature. The properties of road networks are ever changing due to construction of new roads and maintenance of the existing ones (e.g., resurfacing). Therefore, an ideal sensing framework for the task of road geometry estimation should be scalable, cost-efficient, and capable of providing frequent data updates.

In order to address the above challenges, in this project, we studied a crowdsourced road geometry features estimation framework using smartphones as the sensing platform. Due to its ubiquity and inclusion of all the necessary sensors (IMU, GPS and Magnetometer), smartphone provides a unique opportunity to develop a cost-efficient and scalable solution for road geometry estimation. However, the use of smartphones introduces new challenges, including a) Unknown Smartphone Orientation and Placement; b) Low and Varied Data Quality; c) Heterogenous smartphone/sensor; c) Varied vehicle suspension properties; and d) Varied driver behavior on profiled road segment.

In this project, we fuse the readings from accelerometers and gyroscopes to obtain better estimation of the grade than any existing methods including Google's elevation data. The basic idea is to detect (short) periods of time during which the vehicle has little acceleration or deceleration, and thus the accelerator based readings are pretty accurate, and then estimate the "drift" in the gyroscope-based readings throughout the trip (i.e., not just during the above mentioned periods). The results are then derived according to the gyroscope-based readings (which can be much more accurate, after the drift is adjusted, than the accelerator based readings during vehicle acceleration and deceleration). We also employed crowd sourcing to further improve the estimation.

TASK 5. INTEGRATING AUTONOMOUS SHUTTLES WITH PUBLIC TRANSIT

The need for accessibility to public transit is well-documented in transportation theory and network literature, and is known as the first/last mile problem. Autonomous shuttles are capable of providing on-demand services at a low cost and thus a promising solution to the first/last mile problem.

In this task, we conducted a case study to investigate autonomous shuttle deployment strategies when the ridership demand is unknown. As a result, we first estimate the demands (both hourly and peak) by using the employee data along with public transit data in a given area. Then we use the estimated demands, along with the autonomous shuttle's data to calculate the route plan, dispatch time, shuttle schedule frequency, decisions to serve demands or return to parking lots and etc. As a next step, we plan to develop and run a simulation model of the case study, by feeding in our data and customized autonomous shuttle model to test and tweak the parameters.

TASK 6. INVESTIGATING 5G TECHNOLOGY FOR CAVS

5G technology promises a much higher throughput and smaller delay than DSRC and the current 4G systems, and is thus considered an enabler for CAVs. In particular, despite the long-time push for DSRC to support V2X communications, it seems that cellular based V2X (or C-V2X) is winning the battle thanks to the 5G technology.

In this project, we exploited the throughput and delay performance of 5G technology using simulation based on the 5G toolbox in Matlab (see these two websites for information on the 5G technology and the Matlab simulation tool resp.: http://www.sharetechnote.com/ and https://www.mathworks.com/products/5g.html).

Both the throughput of uplink (PUSCH) and downlink (PDSCH) channels are tested.
In 5G, numerology/ subcarrier spacing, radio frame structure, signal channel which influences the Bit Error Rate and modulation scheme could change the throughput dramatically.
For the signal channel, Clustered Delay Line (CDL) and Tapped Delay Line (TDL) could be employed. For different Signal-to-Noise Ratio (SNR), the throughput varies greatly from 12Mbps to 60 Mbps with subcarrier spacing of 30kHz and with CDL channel, the delay spread could be 300e-9 (delay spread is caused by the multipath propagation of radio waves. In reality one radio sent at one time may arrive in the same antenna not at one point but in a time period. The delay spread is the root-mean-square value of this time window.

The desired delay spread could be found in the ETSI TR 38.901 7.7.3 (see tables 7.7.3-1 and 7.7.3-2). The maximum latency of this scenario according to this simulation would be 87ms. Further work is still needed to evaluate the feasibility of 5G in supporting demanding V2X applications such as exchange of HD Map information.

LIDAR AND DATA STORAGE ACQUISITION

As a part of the project related to the study of the intersection of big data and autonomous vehicles (AVs), we conducted many experiments with AVs. AVs rely on many sensors including LIDARs, radars and cameras to operate. Among them, LIDARs, which are essential for AV experiments, generate the largest amount and often the most useful/detailed sensor data. In order to conduct the research described in Tasks 2 and 3 above, we purchased an Ouster LIDAT to conduct the necessary research experiments. In addition, since research and testing of AVs require storing huge amounts of data - hundreds of gigabytes per hour of testing. Fast and efficient storage is a necessary element of the test system. To ensure adequate space for data collected from our two autonomous cars, roadside sensors and the integrated simulation platform, a 150 terabyte NAS server was purchased and installed. To achieve a fast data transfer between a server and research workstations, the NAS is equipped with two 10GbE network cards.