CLOUD-INTEGRATED INFRASTRUCTURE FOR AUTOMOTIVE CYBER-PHYSICAL NETWORKS (ACPN)

Shahyar Taheri*   Saied Taheri   Corina Sandu
Center for Tire Research at Virginia Tech (CenTiRe), Blacksburg, VA, USA
*Corresponding author: Taheri@vt.edu

1 INTRODUCTION

The automotive systems have evolved from purely mechanical to electromechanical, and, more recently, to software controlled platforms. These systems share the same planar transportation infrastructure, and, consequently, can be considered as a distributed network. For achieving the higher safety and efficiency within this network, new transportation systems can take advantage of the control algorithms and informational services within the vehicle (V) and the surrounding infrastructure (I), in addition to the interactions between vehicles (V2V) and between vehicle and infrastructure (V2I). As a V2I service, cloud computational resources can be used to virtually represent the automotive systems for monitoring, actuating, and navigation purposes in an efficient and reliable manner. By adding this new dimension, vehicles will become service-based mobile cyber-physical platforms that can be informative about their surroundings, and can be optimally controlled via the available models and data-bases in the cloud service.

2 BACKROUND/MOTIVATION

Cloud computing servers are powerful online computational resources that can be used to aggregate the road and vehicle data over large spatial regions over time, in order to manage the intelligent transportation networks. Platform-as-a-Service (PaaS) is proposed as a viable cloud framework option. In this case, a platform hosts multiple instances of an application (e.g., vehicle models or road databases), and handles infrastructure (hardware), security, and scalability of the application. In this study, the areas in which cloud computing will be beneficial are proposed, and the anticipated challenges in the development stage are discussed.

3 PROPOSED RESEARCH (INCLUDING POTENTIAL IMPACT IN/TO CPS)

The following research areas are suggested for benchmarking the ACPN concept:

Road health monitoring: High density of roads and highways makes it difficult for corresponding authorities to assess the roads safety shortcomings with conventional inspection routines. The powerful cloud computational resources may analyze the vehicle sensor readings and GPS data in order to identify and locate road hazards. For example, by passing the car suspension acceleration data through a wavelet feature extraction filter and by classifying the results, the location of potholes can be identified. Moreover, it is possible to incorporate cameras behind the rearview mirror and process the images to find unclear road signs and markings.

Road features database: Road parameters, such as local friction coefficient and bank/grade angles, have significant impact on vehicle safety and performance. To evaluate these parameters, the measurements from the vehicles sensors (e.g., 3-axis accelerometer and gyroscope), in addition to the readings from the intelligent tire sensors (e.g., accelerometer, passive SAW sensor, and pressure sensors), are processed with proper estimation methodologies (e.g., sliding mode observer, Kalman filtering, and recursive least squares). Then, an informational map of these parameters at different local points is generated and constantly updated in the cloud database to be utilized by vehicle control algorithms. The resulted maps can be further enhanced by the data from the long-term pavement performance program (LTPP).

Remote vehicular diagnosis and programming: Modern premium vehicles run on more than 100 million lines of codes which are executed on 70 to 100 microprocessor-based electronic control units (ECUs). The cloud-integrated architecture will enable the automakers to remotely diagnose the vehicle's software and hardware issues in real-time and manage the vehicle recalls more effective. Furthermore, a diagnosis center, using a model based design, can develop a fault-tolerant controller, and remotely reprogram the vehicle to address the faulty modules or sensors.

Connected vehicle platform for efficiency and safety: The road information from the cloud database is incorporated into the vehicle automated systems in order to increase the level of efficiency and safety. The road inclination is used in the adaptive cruise control systems to adjust the vehicle speed and gear before encountering the high gradient road profiles, which, in turn, helps avoiding unnecessary gear changes. This will ultimately reduce the fuel consumption to a great extent. Additional road information, such as local friction coefficient, local speed limit, road curvature, and road banking are used in the vehicle stability program as a-priori to help the associated controller converge faster. Moreover, instead of using simplified models (e.g., bicycle model) in these adaptive control systems, full vehicle models can be incorporated into the cloud system, and the realistic results are generated promptly via the parallel computational resources.

Environmental analysis: Weather forecasting requires high density observation networks as well as many radar and satellite estimations. The available sensors in a modern vehicle can be exploited for improving the estimations in the environmental studies; measurements from the optical sensors used in the automatic windshield wipers can be used to construct a model that correlates the wiper's frequency and vehicle speed (at multiple network nodes) to the rainfall patterns. Additionally, readings from other sensors, such as temperature, oxygen, and carbon oxide sensors are useful for evaluating the weather conditions, as well the urban air quality.

4 CHALLENGES

In development phase of an intelligent ACPN, subsequent challenges should be addressed:

Data communication and timing: Vehicle communication with cloud for uploading the sensor data and receiving the control inputs can be established by cellular or wireless communication links. The mobile nodes of this wireless network can reach the edge of connectivity. This can be avoided by improving infrastructure connectivity, using inner-vehicular sub-wireless connections (e.g., IEEE 802.11p/Wave protocol), and applying loss anticipation rules (e.g., slowing down the vehicles in case of a connectivity problem). Additionally, the timing requirements should be considered to avoid real-time faults such as jitter, delay, and incorrect sampling rate.

Security and failure semantic: Despite the physical systems that usually inherit a fail-stop failure theme, the CPS suffer from partial failures that can stem from the aleatory uncertainties in sensors and actuators data. In addition, there are failure modes that cannot be anticipated due to their epistemic nature. Constructing an intricate paradigm for estimating the probability of the failures is essential for risk analysis, and helps mitigate system faults efficiently. Furthermore, in case of cyber-attack scenarios in the network, such as incorrect information propagation and information holes, appropriate prevention, detection and mitigation strategies are essential.

Verification and validation (V&V): Testing the intelligent ACPN with the human subjects in the loop, requires prototyping the initial design. Development of the complex human interaction models using neural network and fuzzy logic algorithms is suggested to optimize the V&V process. Furthermore, considering the fact that number of the vehicles in a CPS network changes with time will in turn alter the dimension of the system state-space. The V&V architectures should be scalable both in dimension and complexity to handle this system dynamic behavior. Furthermore, integrating multiple motion based vehicle simulators in a V2X framework would be advantageous for realistic real-time model based controller design verification.