RESEARCH AND EDUCATIONAL PROGRAMS FOR CONNECTED AND AUTONOMOUS VEHICLES AT THE UNIVERSITY OF WATERLOO

There are numerous challenges to overcome to advance from the current offering of automobiles with limited connectivity and partial automation, to a fully connected, highly automated vehicle that ultimately offers fully autonomous driving. University of Waterloo Centre for Automotive Research (WatCAR) faculty, staff and most importantly students are contributing to the development of in-vehicle systems education programs for connected and autonomous vehicles (CAVs) at Waterloo.

Waterloo's anechoic chamber, part of the Centre for Intelligent Antenna and Radio Systems (CIARS), offers both near-field and far-field testing capabilities, a world first.

The UWaterloo programs take advantage of geographical location in undertaking CAV research. Waterloo is uniquely positioned within clusters for both automotive and information technology. The school is at the centre of Canada's 260-mile (415 km) automotive industry running from Detroit to east of Toronto, with 16 OEM facilities and over 700 Tier-1, -2, -3 parts manufacturers and materials suppliers. Meanwhile, the Toronto-Waterloo innovation corridor covers 60 miles (110 km) and is home to over 15,000 information technology companies.

UWaterloo is Canada's largest engineering school, with 9,500 engineering students and 309 engineering faculty. Co-operative education, which is mandatory for all Waterloo engineering undergraduates, is differentiated from other co-op programs by its four-month study/four-month work sequence. As a result, it takes five years to complete a four-year degree with co-op at Waterloo. Graduate student workplace experience is also a priority at Waterloo, with numerous internships in place at CAV partner companies.

Over 130 Waterloo faculty, 110 from engineering, are engaged in WatCAR's automotive and transportation systems research programs. The school's CAV efforts leverage WatCAR research expertise from 5 areas: (i) Connected and Autonomous; (ii) Software and Data; (iii) Lightweighting and Fabrication; (iv) Structure and Safety; and (v) Advanced Powertrain and Emissions. Foundational and operational artificial intelligence (AI) expertise from the University of Waterloo Artificial Intelligence Institute complements the autonomous driving efforts, in disciplines that include neural networks, pattern analysis and machine learning.

Faculty researchers lead teams of graduate students, post-doctoral fellows, undergrads, engineers in training, research technicians and research engineers to enhance and integrate CAV technologies in facilities across the campus, notably at WatCAR's 10-bay autonomous vehicle garage. WatCAR research is further enabled by preferential all-season access to the Region of Waterloo test track, a 3/4-mile (1.2 km) loop with a 220-yard (200 m) skid pad, instrumented traffic intersection, and vehicle-to-infrastructure (V2I) sensors, all supporting Waterloo's CAV research. The University of Waterloo was the first organization in Canada approved to test and operate self-driving vehicles on public roadways.

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Industry partnerships are a strong, valued element of all automotive research projects at Waterloo. In connected vehicle projects, current partners include BlackBerry QNX, General Motors, Magna, Miovision and Toyota. Autonomous vehicle project work presently involves Applanix, Clearpath Robotics, Denso, Ford, General Motors, Maplesoft, NovAtel and Renesas Electronics. For example Renesas Electronics, the world's leading automotive semiconductor processor supplier, has engaged Waterloo to contribute key software elements to their Renesas autonomy vehicle in an ongoing capacity for the past two years.

DEMONSTRATOR AND TEST PLATFORMS

Connected Lexus Demonstrator

WatCAR researchers took their first deep dive with connectivity on a full-scale vehicle in 2013. As technology integrator for a demonstrator project, Waterloo's Real-time Embedded Software Group seamlessly connected 12 disparate technologies from 12 separate companies, making them fully functional on a Lexus SUV. Working through a QNX operating system, individual kernels were created for each installed technology.

Initiated by the Canadian Automotive Parts Manufacturers' Association (APMA), with lead partners BlackBerry QNX and Toyota, the Connected Lexus Demonstrator was taken directly to company offices and exhibited at select conferences, including ASME's 2014 Advanced Design and Manufacturing Impact Forum in Buffalo, simultaneously showcasing each company's technologies on the enhanced, fully functional SUV. The vehicle travelled throughout Michigan and Ontario as well as to California, New York, Kentucky and Quebec, completing demonstrations extensively for three years, while also profiling the collaborative result of a collective effort from all project partners.

WATonomous

In April 2017, Waterloo was selected as one of just eight schools from across North America to participate in AutoDrive, a newly established three-year autonomous driving competition. The team, named WATonomous, will use a Chevrolet Bolt provided by General Motors as their autonomous vehicle platform. Faculty supervisors for the team come from Engineering's Computer and Mechatronics programs, who will work with the team to identify and facilitate Capstone Design projects from elements of the AutoDrive competition. Graduate students serve as mentors and project managers, furthering the educational connection between the real world (competition) and academics.

The WATonomous team is based in the Sedra Student Design Centre, a 20,000 sq. ft. (1,860 sq. m) space that is home to 20 student competition teams and a hub for engineering experiential learning labs. Undergraduates, who may initially join a team based on personal interest, have the option to pursue a tie-in to their academic studies, which academic programming and the Student Design Centre both facilitate.

Autonomoose

Waterloo's first autonomous vehicle, Autonomoose, uses a Lincoln MKZ hybrid sedan as the platform. Currently in year two of a three-year research program, Autonomoose, named by graduate students working with the vehicle, is being modified to autonomous drive-by-wire operation. The program involves seven academic researchers from six Engineering programs (Computer, Electrical, Mechanical, Mechatronics, Software, and Systems Design) as well as two academic researchers from the Cheriton School of Computer Science, which is based in the world's largest faculty of Mathematics.

When completed, the Autonomoose research platform will feature a full suite of radar, sonar, lidar, inertial and vision sensors. Additional feature sets involve GPS, wireless vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication, machine learning, mobile security, vehicle control and power management.

Throughout every phase of the Autonomoose platform's development, safety is paramount. The use of real-time embedded software provides security and safety monitoring of the vehicle while in operation, contributing to the operating system

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ABOUT THE AUTHORS

John McPhee is the Canada Research Chair in System Dynamics at the University of Waterloo. He has pioneered the use of linear graph theory and symbolic computing to create dynamic system models and model-based controllers, with applications ranging from autonomous vehicles to rehabilitation robots. He has won 5 best paper awards and his research algorithms are a core component of the MapleSim modeling software.

Dr. McPhee is a Fellow of the ASME, where he has served on a technical committee, a journal board, and conference committees. In 2014, he received the prestigious NSERC Synergy Award from the Governor-General of Canada.

Ross McKenzie is the Managing Director of WatCAR at the University of Waterloo. He is responsible for facilitating collaborative research between industry partners and faculty. Ross has served on the board of ITS Canada since 2011 and as chair of Electric Mobility Canada's annual student competition since its inception in 2013.

In 2016 Ross addressed the G7 Transport Ministers in Japan, summarizing Canada's activities and initiatives in connected and autonomous vehicles. In 2017 he was presented with the Ontario Ministry of Transportation Partnership Award, recognizing significant contributions to road safety.

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(ROS) that runs the on-board autonomy stack. Powerful computers have been installed to run a complete autonomous driving system, integrating sensor fusion, path planning, and motion control software. To support the required integration, a custom autonomy software stack is being developed at Waterloo.

RESEARCH AND EDUCATIONAL DIRECTIONS

WatCAR researchers are focusing on specific open problems essential for Level 5 autonomy, namely: (i) robust perception, (ii) integrated planning and control, and (iii) safety assurance. Advances in deep learning, multi-sensor fusion, and onboard 3D geometric scene modeling are being used to improve driving perception reliability in the presence of adverse weather conditions, degraded road surfaces and highly dynamic environments [1,2]. Tightly integrated planning and control algorithms have been created using a combination of machine learning and model-based techniques [3,4]. These algorithms exploit the enriched sensor and environment data to enable the AV to operate efficiently and safely throughout their operating envelope [5]. The researchers are establishing minimal hierarchical safety requirements for autonomous functions, fidelity-aware simulations that can rapidly evaluate large numbers of challenging driving scenarios, and safety assurance methods for systems that rely on machine learning [6,7].

Two specific projects currently underway highlight the intertwining of these facets as well as the need for simultaneous engagement on both the research and development fronts.

Improve self-driving in all-weather conditions that are specific to Canada

Improvements to self-driving in all-weather conditions is utilizing simultaneous localization and mapping (SLAM) as well as undergoing autonomous maneuvers under extreme conditions. During initial winter driving tests in 2016, the lidar unit interpreted glare ice on the roadway as a pothole.

The varied refraction level of the ice was 'viewed' by the lidar's laser beams to be six inches lower than the adjacent roadway of bare asphalt. Researchers subsequently enhanced the on-board software of Autonomoose to scrutinize and evaluate lidar data, factoring in variables such as external temperature, recent weather conditions and time of year on the calendar.

Safe, robust computer-based controls for self-driving vehicles.

Methods to design safe, robust computer-based controls for self-driving vehicles are being provided with the introduction of: (i) Feature-oriented engineering (FOE); (ii) Runtime monitoring and reconfiguration infrastructure for autonomous driving; (iii) Fault-tolerant electric/electronic (E/E) architectures for autonomous vehicles; and (iv) Functional safety for software and components of autonomous vehicle systems.

Autonomoose in the GAIA Vehicle Test Cell strapped down and ready to drive-by-wire on the 4-wheel chassis dynamometer. Autonomoose, a Lincoln MKZ hybrid, is Canada's first autonomous vehicle.

In autonomous driving, feature-oriented engineering (FOE) refers to a required multitude of distinct behaviors, called features (such as lane changing and self-parking). FOE promotes independent development of the features, ultimately leading to feature interactions. Feature interactions are a fundamental challenge in FOE.

RESEARCH INFRASTRUCTURE ENABLERS

Waterloo has unique labs and equipment utilized in their CAV research, three of which are outlined in this section. These are in addition to the 10-bay autonomous vehicle garage and 3/4-mile (1.2 km) test track discussed previously.

GAIA vehicle test cell: The Green and Intelligent Automotive (GAIA) facility, has the capacity to simultaneously validate advanced driver assistance systems (ADAS), V2I communications and next-generation powertrain systems in a full vehicle test cell. A full 4-wheel chassis dynamometer is the cell's main component alongside a millimeter-wave signal generator combined with a traffic simulator to allow for ADAS validation activity. In 2018, a 270° screen wrap-around driving simulator will be added, integrated with sensor and traffic simulation software to support safe CAV testing prior to deployment on a test track.

Anechoic chamber: As part of the Centre for Intelligent Antenna and Radio Systems (CIARS), the anechoic chamber is capable of holding a full-size pick-up truck. Looking like a gigantic isolation booth, the chamber is part of the Centre for Intelligent Antenna and Radio Systems (CIARS). The chamber is used for many aspects of vehicular connectivity testing, including signal validation and antenna placement.

RoboHub: Waterloo will open an advanced robotics testing facility in 2018. A two-story glass cube, the RoboHub, will serve as a development lab and demonstration zone for robots, scaled autonomous passenger vehicles, autonomous delivery vehicles and unmanned aerial vehicles. The facility will bridge the laboratory and the real world, where researchers and students will simulate complex real-world environments and explore the potential of combined robotic technologies, many of which are targeted for CAV application.

CONCLUSION

The parallel pursuit of research and education programs for CAV activity at the University of Waterloo is succeeding. Industry partners are engaged, with several already integrating Waterloo advancements into their product portfolios. As discoveries continue to unfold, the next generation of engineers is learning about tomorrow's technologies in an experiential environment. Waterloo graduate and undergraduate students alike are receiving real-world training to become highly qualified personnel and will graduate equipped to further technological discoveries and their integration into connected and autonomous vehicles. ■

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