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AVIN Specialized Reports

Regional Technology Development Sites: Technology Focus Areas

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The Autonomous Vehicle Innovation Network (AVIN) is an initiative by the Government of Ontario

About AVIN

The **Autonomous Vehicle Innovation Network (AVIN)** initiative is funded by the Government of Ontario to support Ontario's competitive advantage in the automotive sector and to reinforce its position as a North American leader in advanced automotive and mobility technologies, including transportation and infrastructure systems.

This initiative capitalizes on the economic potential of connected and autonomous vehicle (C/AV) technologies by supporting the commercialization of best-in-class, made-in-Ontario solutions that create jobs and drive economic growth and global competitiveness. AVIN also helps Ontario's transportation systems and infrastructure adapt to these emerging technologies.

Areas of Focus

AVIN programs focus on supporting the development and demonstration of C/AV technologies in light vehicles (e.g., cars, trucks and vans), heavy-duty vehicles (commercial vehicles, trucks, buses and RVs), transportation infrastructure, intelligent transportation systems (ITS) and transit-supportive systems.

AVIN is administered on behalf of the Government of Ontario by Ontario Centres of Excellence (OCE). The initiative comprises four distinct programs and a central hub. The AVIN programs are:

- AV Research and Development Partnership Fund
- Talent Development
- Demonstration Zone
- Regional Technology Development Sites

The AVIN Central Hub is a dedicated team that supports delivery and administration of AVIN programming, and provides the following key functions:

- Connect & Coordinate - a focal point to help coordinate activities amongst industry, academia, research organizations and governments, and connect interested stakeholders and members of the public;
- Opportunity Identification - knowledge translation, research, data/information, trend analysis, and acting as a bridge between technology and policy; and
- Awareness & Education - promote AVIN programs and Ontario's AV testing pilot, and build awareness of Ontario's growing C/AV community.

AVIN has five Objectives:

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Introduction

Connected and autonomous vehicles (C/AV) have the potential to improve safety, optimize the performance of transportation networks, and free up valuable time for commuters to pursue other value-added activities.[1] To achieve these objectives, C/AVs rely on advanced computing capabilities that allow them to perceive and interact with the surrounding environment in a safe and robust way. Furthermore, C/AVs use advanced communication networks to notify other vehicles and infrastructure when they approach intersections, change lanes, and detect slow or stationary vehicles. Communicated messages are also used to report traffic jams, accidents and traffic signal violations; they provide better ways to analyze the performance of transportation systems and inform decision makers about required infrastructure improvements.[2]

The Province of Ontario has taken several steps to support C/AV developers and technology manufacturers. Examples include: a pilot project (Ontario regulation 306/15) [3] to allow testing and demonstration of automated driving systems, as well as the initiation of the Autonomous Vehicle Innovation Network (AVIN) [4] including the announcement of AVIN Demonstration Zone in Stratford, Ontario. These efforts build on Ontario's auto manufacturing and technology development base, which includes five global automakers; more than 20,000 information and communication technology (ICT) companies; an excellent supply of talent from more than 44 colleges and universities; and cutting-edge research facilities. On May 2nd, 2018, Ontario Centres of Excellence (OCE) announced, [5] on behalf of the Ontario government, six Regional Technology Development Sites (RTDS) across the province to accelerate the development of connected and autonomous vehicle technologies. These sites contribute to the ongoing efforts of Ontario researchers and developers and capitalize on the strengths of the automotive and technology sectors in Ontario.

In the previous AVIN specialized report, we presented some of the C/AV technologies that Ontario companies and researchers are working on, showcasing their activities and contributions. [6] In this report, we present the main C/AV technology development areas that RTDSs support, providing an overview of some of the emerging technologies in C/AVs. Technology development areas were identified using primary data collected from AVIN projects in addition to secondary research

[1] Talebpour, A., & Mahmassani, H. S. (2016). Influence of connected and autonomous vehicles on traffic flow stability and throughput. Transportation Research Part C: Emerging Technologies, 71, 143-163.

[2] Mendez, V. M., Monje, C. A., & White, V. (2017). Beyond Traffic: Trends and Choices 2045—A National Dialogue About Future Transportation Opportunities and Challenges. In Disrupting Mobility (pp. 3-20). Springer, Cham.

[3] O. Reg. 306/15: Pilot Project - Automated Vehicles. (2016, January 1). Retrieved from https://www.ontario.ca/laws/regulation/150306

[4] Ontario Creating Opportunity with Cars of the Future. (2017, November 8). Retrieved from https://news.ontario.ca/opo/en/2017/11/ontario-creating-opportunity-with-cars-of-the-future.html

[5] Driving Regional Innovation for Vehicles of the Future. (2018, May 2). Retrieved from http://oce-ontario.org/news-events/news/2018/05/02/driving-regional-innovation-for-vehicles-of-the-future

[6] Autonomous Vehicle Innovation Network. (2018). Connected and Autonomous Vehicles in Ontario: Technology Highlights. Retrieved from http://bit.ly/avin-report1

conducted by the AVIN team. For each technology development area, we provide a brief description of associated challenges and key research and development activities in this area.

Autonomous Vehicles

Autonomous vehicles rely on complex sensing and computing systems to understand their surrounding environment and respond properly to different driving scenarios. These systems use several technologies in the fields of robotics, artificial intelligence and mechatronics. The key technology development areas in autonomous vehicles are described below.

1- Perception (Sensor Data Fusion)

Perception is a crucial functionality of autonomous vehicles (AVs) that allows them to operate safely and efficiently in all driving conditions. AVs perceive

AVIN Regional Technology Development Sites

Site	Focus Area	OCE Partners
Durham Region	Human-Machine Interface (HMI) and User Experience	Spark Centre in collaboration with the University of Ontario Institute of Technology (UOIT), UOIT's Automotive Centre of Excellence (ACE), Durham College and the Region of Durham.
Hamilton Region	Multimodal and Integrated Mobility	Innovation Factory in collaboration with McMaster University, Mohawk College and the City of Hamilton.
Ottawa Region	Vehicular Networks and Communications	Invest Ottawa in collaboration with Carleton University, University of Ottawa, Algonquin College and the City of Ottawa.
Southwestern Ontario Region (London and Windsor)	Vehicle Cybersecurity and Cross-border Technologies	Windsor Essex Economic Development Corporation (WEEDC) and London Economic Development Corporation (LEDC) in collaboration with University of Windsor, University of Western Ontario, Fanshawe College, St. Clair College, City of Windsor, City of London and WETech Alliance and Tech Alliance.
Toronto Region	Artificial Intelligence for Connected and Autonomous Vehicles	MaRS Discovery District in collaboration with the University of Toronto, Ryerson University and York University.
Waterloo Region	High-Definition (HD) Mapping and Localization	Communitech in collaboration with the University of Waterloo, Waterloo Region Economic Development Corporation and Canada's Open Data Exchange.

their surrounding environment by combining different sensor data into a unified and consistent model that represents all surrounding objects. Similar to the human brain, which combines inputs from vision and hearing to create a three-dimensional stereo picture of the surrounding environment, AVs fuse sensor data to create an underlying representation that can be used to perform the navigation and path planning functionalities required for driving.

AV developers experiment with different types of sensors to monitor surrounding environments. Examples include cameras, radar (radio detection and ranging), and LiDAR (light detection and ranging). These AV sensor types vary in their attributes and characteristics. Radar sensors, for instance, provide accurate distance estimation in bad weather conditions allowing vehicles to operate in adverse conditions such as snow, rain, fog and dust. Cameras offer strong object classification capabilities that allow vehicles to interact with surrounding entities such as vehicles, pedestrians, cyclists, and pets. LiDAR sensors have better performance in poor lighting conditions and they provide the ability to construct precise and highly accurate 3-D maps of surrounding environments.[7] The three types of sensors are typically mixed to achieve redundancy, which protect the system from a sensor failure, and ensure robust results.

Researchers are working to improve C/AV perception using efficient and affordable methods. They are working to improve many functionalities such as detection and classification of moving and static objects, 3-D positioning and motion estimation of surrounding objects, and road shape estimations.[8] Developers use several techniques to construct a representation of the AV world such as occupancy grids.[9] Occupancy grids represent the world as a grid of cells, where each cell maintains an occupancy state that is estimated using input from all AV sensors. Several statistical methods, such as Bayesian and Kalman filtering[10], are used to provide accurate estimates of surrounding objects and their motion trajectories. All sensor fusion calculations are performed on real-time data and require a powerful processing unit to support the driving functionalities of AVs.

The area of perception and the application of artificial intelligence in C/AVs is one of the focus areas of the Toronto RTDS. The area is also supported by other regional sites such as Waterloo, Ottawa and Durham.

2- Localization and Mapping

Another fundamental challenge in the evolution of AVs, which can also be associated with perception, is localization. Localization techniques provide highly accurate vehicle position information that is used by many AV functionalities such as AV path planning and maneuvering decision-making modules. They rely on sensors such as GPS, odometry and inertial sensors to estimate a vehicle's position. They also employ advanced

[7] Ondrej Burkacky, J. D. (2018, February). Rethinking car software and electronics architecture. Retrieved from https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/rethinking-car-software-and-electronics-architecture

[8] Luettel, T., Himmelsbach, M., & Wuensche, H. J. (2012). Autonomous ground vehicles—Concepts and a path to the future. Proceedings of the IEEE, 100(Special Centennial Issue), 1831-1839.

[9] Elfes, A. (1989). Using occupancy grids for mobile robot perception and navigation. Computer, 22(6), 46-57.

[10] Estimation techniques that are used to improve the accuracy of noisy sensor data.

detection techniques that identify lane markings and road boundaries.

The quality of AV localization techniques depends on many factors such as the quality of the lane marking and the reflective characteristics of the road. Therefore, these techniques are combined with High Definition (HD) Maps to provide high precision at the centimeter-level. [11] HD maps provide lane-accurate information about roads including lane geometry and a detailed description of road furniture. The use of redundant sources of information, such as HD maps, increases the reliability and robustness of C/AV localization systems and helps the vehicle operate safely and efficiently in all driving situations.

The area of HD mapping and localization is a focus area of the Waterloo Regional Technology Development Site. This site will also support other related technology development areas such as perception and AV navigation and control.

3- Navigation and Control

Navigation systems are essential for human drivers to provide them with turn-by-turn instructions in unfamiliar places. In AVs, navigation systems play a dual role providing long-term planning and guiding functionality in addition to short-term local maneuvering instructions. In AVs, navigation systems allow vehicles to avoid obstacles, follow road marks, interact with bicycles and crossing pedestrians, and make safe turns. Meanwhile, they provide route instructions to guide the vehicle to its destination. AV navigation systems are typically combined with robust steering controllers to make safe and stable maneuvering decisions.

The area of AV navigation and control has attracted many researchers and developers. Activities include: local trajectory planning mechanisms, probabilistic trajectory predictions, modelling techniques for vehicles and their surrounding objects and advanced obstacle avoidance mechanisms. Techniques include building dynamic and kinematic models to predict the behaviour of surrounding objects and training vehicles to imitate human drivers using neural networks.

Navigation and control is one of the focus area of Waterloo RTDS. The area is also supported by the Toronto, Ottawa, and Durham regional sites.

4- Human Machine Interface

Another challenge that AVs face is how the vehicle interacts with drivers and passengers, or human-machine interface (HMI). HMI developers work to design efficient and user-friendly AV systems that use audio and visual instructions to construct two-way communication between cars and humans. Unlike traditional interfaces in which information flows in one direction from cars to drivers, modern systems allow users to apply their knowledge about the roads and provide their input in a simple and straightforward manner. Additionally, HMI plays a critical role in partially automated systems by reducing driver distractions and providing them with proper disengagement options to take control of their vehicles.

HMI technologies use several techniques to interact effectively with car users including heads-up displays, steering wheel controls, rear seat systems, and e-mirrors. Researchers and

[11] Newcomb, D. (2018, July 17). New Data Platform Helps Autonomous Vehicles Learn Rules Of The Road Directly From Cities. Retrieved from https://www.forbes.com/sites/dougnewcomb/2018/07/17/new-data-platform-helps-autonomous-vehicles-learn-rules-of-the-road-directly-from-cities/

developers use these tools to present relevant vehicle data including speed, acceleration, safety alerts, road information and weather conditions. Techniques include advanced augmented reality solutions that use voice, facial and hand gesture recognition techniques to create a safe and comfortable driving experience. HMI research activities are typically implemented using a team of engineers and psychologists who use a wide range of sensors to interact with users.

Human-Machine Interface and User Experience are the main focus areas of the Durham RTDS. They are supported by other sites including Waterloo and Toronto.

Connected Vehicles

Vehicle-to-Vehicles (V2V) and Vehicle-to-Infrastructures (V2I) communications have a great potential to improve traffic safety and efficiency. Connected Vehicles (CVs) can play a critical role in optimizing traffic, alleviating congestion and reducing the number of collisions. The key technology development areas in autonomous vehicles are:

1- Vehicular Networking and Communications

Reliable communication channels and network architecture are essential to realize many of the benefits of CVs. CVs rely on these networks to ensure that applications are safe, secure and reliable. Requirements are diverse and depend on the nature of the application. While some CV applications, such as map downloads, accept a latency (the delay between information travelling from source to destination) of 500 milliseconds, safety applications, such as intersection collision warnings, require a maximum latency of 100 milliseconds. [12] As a result, the design of a reliable, efficient and universal networking solution for connected vehicles is a challenging task.

CV applications require special latency, communication range and message routing protocols. These requirements are addressed using advanced communication technologies such as dedicated short-range communications (DSRC) and 5G cellular networks. Developers are currently working to improve CV communications technologies using different techniques such as advanced cybersecurity mechanisms, advanced delay-aware communication protocols and advanced mobility management mechanisms.

Vehicular Networks and Communications is the focus area of the Ottawa RTDS, Southwestern Ontario RTDS (with a focus on cybersecurity and cross-border technologies), and the Hamilton RTDS (with a particular focus on V2I and integrated mobility applications).

2- Infotainment

Another area that has interested many CV researchers and developers is the design of in-vehicle infotainment systems. Infotainment systems include a set of hardware and software components that offer audio and video entertainment options in an interactive and user-friendly manner. Examples include a dashboard and rear seat systems that provide rich user experiences and allow vehicle occupants to interact with their vehicles while

[12] Papadimitratos, P., De La Fortelle, A., Evenssen, K., Brignolo, R., & Cosenza, S. (2009). Vehicular communication systems: Enabling technologies, applications, and future outlook on intelligent transportation. IEEE communications magazine, 47(11).

watching a movie or listening to music or an audiobook.

Infotainment systems are typically integrated with in-vehicle navigation systems and smartphones to allow passengers to give hands-free instructions to cars, make phone calls, search their contact list and update their calendars. They may also turn the car into a Wi-Fi hotspot, enabling users to browse the Internet, send social media updates and access other location-based services including weather, news and roadside services. The design of safe and user-friendly infotainment systems is a challenging task and requires a collaboration among multi-disciplinary teams to coordinate simultaneous running of multiple applications. Coordination requires functions such as timing, memory allocation, networking and managing input/output devices.

In addition to infotainment applications, CVs can provide many other capabilities. For example, a car can be connected to a smart home, allowing passengers to access their home systems or make online purchases securely using their personal clouds. Users may also use infotainment systems to monitor their front door camera or order groceries. They can also be connected to user wearable devices to provide real-time driver health monitoring services capabilities.

Infotainment is one of the focus areas of the Ottawa RTDS . This focus area is also supported by other regional sites such as Waterloo, Toronto and Durham.

3- Telematics

Telematics applications provide several functionalities that help owners and fleet operators monitor, manage and control their cars.[13] Example applications include:

- remote vehicle diagnostics that monitor vehicles' systems and offer predictive maintenance capabilities;
- vehicle tracking and monitoring applications that provide real-time information about expected arrival times;
- driver behaviour monitoring applications that analyze driving patterns and offer recommendations to reduce fuel consumption and improve safety;
- geofencing applications that limit vehicles' use to certain geographic areas; and
- vehicle remote operations that control the start/stop and lock/unlock functionalities.

Traditionally, telematics systems have been used extensively in trucking companies. Today, and with the proliferation of ride-sharing and car-sharing services, telematics applications are expected to have a greater impact on the way people move around cities. Researchers and developers are working to improve telematics technologies including better visualization methods to present fleet monitoring data, better fleet management functionalities to improve vehicle utilization, and advanced usage-based insurance applications that determine insurance premiums based on the driver behaviour and the places vehicles are driven.

The area of telematics is identified as one of the focus areas of the Southwestern Ontario RTDS (with a focus on cross-border technologies and vehicle cybersecurity). It is also supported by other regional sites such as Hamilton and Ottawa.

[13] The BC Freedom of Information and Privacy Association. (2015). The Connected Car: Who is in the driver's seat? Retrieved from https://fipa.bc.ca/connected-car-download/

4- Safety and Integrated Mobility Applications

Vehicle-to-Vehicles (V2V) and Vehicle-to-Infrastructures (V2I) communications are used in many intelligent transportation solutions to improve safety and efficiency of transportation systems. Connected vehicles can communicate safety messages and notifications to improve their awareness of potentially dangerous situations. Additionally, V2I communications can be used in smart mobility applications allowing integrated and coordinated mobility options. V2I are also used in advanced traffic and transit management solutions to optimize phase intervals and maximize the efficiency of resource utilization.

Researchers and CV developers are investigating several techniques to improve the coordination among vehicles and provide seamless integration among transportation modes.[14] Examples include integrated mobility applications that use the information from different service providers to recommend itineraries and reduce travel costs, cooperative and decentralized traffic control algorithms to improve the coordination among smart traffic signals, smart tolling algorithms that use CVs to alleviate congestion, and smart parking systems that provide real-time information about parking spots and their availability.

Multimodal and integrated mobility is a focus area of the Hamilton RTDS. It is also supported by other regional sites such Southwestern Ontario and Ottawa.

[14] Karim, D. M. (2017). Creating an Innovative Mobility Ecosystem for Urban Planning Areas. In Disrupting Mobility (pp. 21-47). Springer, Cham.

Conclusions

The introduction and mass adoption of connected and autonomous vehicles is expected to have an overall positive impact on future transportation systems by providing more convenient, safe and affordable mobility options.[15] These emerging technologies provide a glimpse of what future vehicles will look like and the main components and systems that will support their operation. In addition, future cars will be equipped with advanced environmental perception and analysis modules that monitor all surrounding objects and predict their behaviour. They will also have advanced entertainment systems that allow user to interact with their cars while working, watching movies or performing other tasks. Researchers and developers are working on several technologies that will accelerate the arrival of this new wave of vehicles, including: efficient and affordable methods to detect and classify moving and static objects; advanced communication mechanisms to improve vehicle connectivity; and advanced infotainment and telematics to improve the interaction with vehicle occupants and offer predictive maintenance capabilities.

Many of today's cars are already equipped with C/AV technologies. Examples include auto emergency braking, adaptive cruise control, lane-keeping assist, reversing cameras and collision warning systems. These systems are rapidly evolving to support fully autonomous driving functionalities which present an unprecedented opportunity for job growth and economic

[15] Milakis, D., Van Arem, B., & Van Wee, B. (2017). Policy and society related implications of automated driving: A review of literature and directions for future research. *Journal of Intelligent Transportation Systems*, *21*(4), 324-348.

development in the automotive and technology sectors. Most importantly, connected and autonomous vehicles will free up time for consumers to devote to other value-added pursuits, with a potential for increasing productivity. The technology is also poised to improve safety and make commuting experiences more affordable and convenient.

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