Technical Overview and Plan for the Indy Autonomous Challenge (IAC)

Michigan State University – The CANVAS Initiative

Introduction

The Indy Autonomous Challenge (IAC) represents a unique and arguably historic opportunity for Michigan State University (MSU) and other academic institutions to advance autonomous system research in unprecedented way[1]. The impact of IAC could be far reaching many years or even decades beyond the anticipated initial years, 2020 – 2021, of the competition. In this document, we highlight MSU's capabilities and level of readiness in the area of autonomous vehicles. We also provide a high-level description of our technical approach for participating in IAC.

MSU's Research Capabilities in Autonomous-Vehicle Research

The College of Engineering at Michigan State University is among the largest engineering colleges nationwide with enrollment of more than 7000 students in the 2019-2020 academic year[2]. With nine departments, including Electrical and Computer Engineering, Computer Science and Engineering, Mechanical Engineering, Civil and Environmental Engineering, Chemical Engineering, and the newly formed Computational Mathematics, Science, and Engineering (CMSE), the college is well positioned as a leader in the education, training, and preparation of engineers for the future of the automotive industry and mobility. Equally important is MSU's world-renowned faculty members and research programs that at the core of autonomous driving technology areas. The areas where MSU developed international reputation and strong pedigree over the past five decades include computer vision, pattern recognition, machine learning, deep learning, image processing, signal processing, radar, antenna, sensor networks, and software engineering.

Due to its strong expertise and knowledge base in autonomous-driving related disciplines, MSU established a world-class initiative: CANVAS – Connected and Autonomous Networked-Vehicles for Active Safety. CANVAS includes more than 20 faculty members engaged in different research areas of autonomous and connected vehicles, three members of the National Academy of Engineering (NAE) and nine Fellows of the SAE/IEEE/ACM. Equally important, the CANVAS initiative has attracted talented undergraduate and graduate engineering students toward the

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[1] https://www.indyautonomouschallenge.com/history

[2] https://www.egr.msu.edu/news/2019/08/26/welcome-2019-20

area of autonomous driving. This led to the formation of a CANVAS student club, where undergraduate students are volunteering and enthusiastically collaborating to explore technical challenges and solutions for autonomous driving under the mentorship of MSU engineering faculty.

In addition to being located within the state of Michigan, which is the nation's center for R&D in automotive engineering, the College of Engineering at MSU has many centers of excellence, national centers, and laboratories that students and faculty working in the area of autonomous driving can draw expertise from. This includes the Composite Vehicle Research Center (CVPR), Energy and Automotive Research Lab (EARL), the US Department of Transportation Center for Highway Pavement Preservation (CHPP), National Science Foundation Center for Evolutionary Computing (BEACON), and many others.

The CANVAS Research Program

CANVAS is built on decades of MSU faculty expertise and world-renowned research in key areas for autonomous vehicles, including electromagnetics, computer vision, machine learning, deep learning, image and signal processing, pattern recognition, and sensor fusion. Moreover, CANVAS is a comprehensive initiative integrating broad research areas in autonomy, connectivity and mobility as shown in Figure 1.

In the context of autonomous research, an important focus of the CANVAS initiative is on the development and integration of advanced solutions for high-precision sensing of autonomous vehicles' environments. In particular, our focus has been on three sensing modalities: Radar/mm-wave based sensing, visual sensing, and LiDAR sensing. Both external and internal/human sensing are being pursued. A crucial aspect of our research is the fusion of these sensing modalities in conjunction with advanced artificial intelligence solutions based on machine learning and novel deep learning architectures and models. Below, we provide a brief overview of selected research activities as an example.

(a) **Radar and Electromagnetics**: Electromagnetic waves-based sensing in the form of radar signals with a variety of short- medium, and long-range scanning and comprehensive 360-degree coverage around autonomous vehicles represents a cornerstone research area of the CANVAS initiative. Besides exploiting state-of-the-art in autonomous radar sensing solutions, the EM Research Group (EMRG) at MSU, and with more than 100 years of combined expertise of current research-active faculty, have established solid foundations in many EM areas that are crucial for autonomous and connected vehicle research. These areas include antenna design and integration over frequency spectrum up to the terahertz (THz) range, EM Interference and Compatibility (EMI/EMC), high-frequency silicon electronics, and materials characterization. While the early stages of the CANVAS effort is exploiting current state-of-the-art radar sensing solutions (e.g., over the 77 GHz frequency spectrum) to develop an early prototype for an autonomous vehicle, the CANVAS EM group is pursuing advanced research that will perfect current solutions, increase radar signal resolutions in time and space, achieve reliable sensing under extreme conditions, and integrate various autonomous and connected vehicle EM technologies. More importantly, a crucial objective of this research is to reduce cost, power consumption, interference, and the hardware footprint that these advanced EM solutions require while perfecting the active-safety performance of autonomous vehicles.

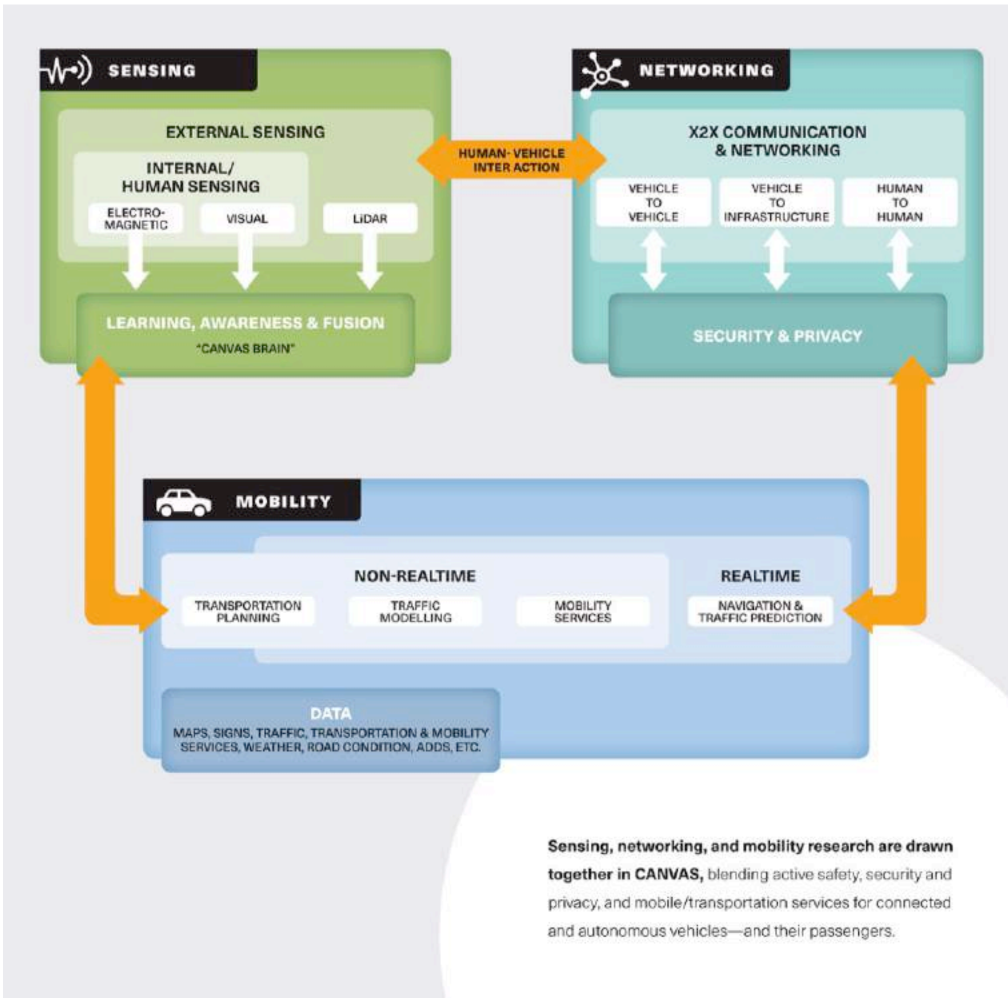

Figure 1: The CANVAS Architecture

(b) **Visual Sensing**: Visual sensing represents another cornerstone component of the CANVAS initiative. With world-renowned faculty and labs in the areas of computer vision, pattern recognition, machine learning, video scene analysis, video communications, and image processing, the CANVAS team has been developing high-precision solutions for a variety of object recognition, detection, and tracking applications. These solutions are pivotal for detecting and tracking pedestrians, animals, cyclists, and other vehicles, assessing weather and road conditions, and issuing lane departure warning for semi-autonomous driving. It is crucial to highlight that under CANVAS, visual sensing related research is being pursued in synergy with research activities in the radar area to achieve robust, smooth, and highly precise operation of autonomous vehicles. Additionally, the CANVAS visual research group is building on state-of-the-art in automated driver monitoring applications such as drowsiness detection, age and gender estimation from face images for customized analysis and response, gesture and posture analysis, cognitive and emotion assessment, and driver personalization. Furthermore, the group has experience in processing images and videos acquired either in the visible spectrum or infrared spectrum, including thermal images. We are also fully cognizant about the necessity for developing solutions targeted at the transition period toward full autonomous driving. For this transition period, it is pivotal to integrate solutions that are mindful of the driver's needs and conditions. In that regard, we have developed an array of algorithms for facial landmark tracking, head pose estimation, facial expression analysis, hand tracking, and body gesture analysis. Given a camera pointing at the driver, these algorithms can be applied to analyze the behavior and emotional state of the driver for customized response to road conditions.

(c) **Lidar Sensing**: In the lidar area, we are developing robust solutions for maintaining a 3D, dynamically varying, local environment map surrounding a vehicle. In addition to employing Lidar sensing for navigating the vehicle around different obstacles, we have developed Lidar-based approaches for localization[3] and mapping[4]. Achieving this requires robustly detecting nearby vehicles, estimating and tracking their poses, and making predictions of their future trajectories. In addition, novel solutions for employing advanced lidar models of a variety of objects are being pursed for robust classification. Fusion of lidar data with other sensing modalities for more robust detection and classification of objects is also being pursued.

(d) **Deep Learning and Sensor Fusion**: Under deep learning and sensor fusion, a critical module of the CANVAS initiative is the "CANVAS Brain" engine, where a broad range of advanced algorithms are being realized[5]. This engine represents both the training aspects of autonomous vehicles in addition to realtime decision-making algorithms. Each sensing modality (radar, visual, and lidar) has its own optimized algorithms for recognizing and tracking a

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[3] S. Pang, D. Kent, X. Cai, H. Al-Qassab, D. Morris and H. Radha, "3D Scan Registration Based Localization for Autonomous Vehicles - A Comparison of NDT and ICP under Realistic Conditions," *2018 IEEE 88th Vehicular Technology Conference (VTC-Fall)*, Chicago, IL, USA, 2018, pp. 1-5. doi: 10.1109/VTCFall.2018.8690819

[4] S. Pang, D. Kent, D. Morris and H. Radha, "FLAME: Feature-Likelihood Based Mapping and Localization for Autonomous Vehicles," *2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, Macau, China, 2019, pp. 5312-5319.doi: 10.1109/IROS40897.2019.8968082

[5] M. Al-Qizwini, I. Barjasteh, H. Al-Qassab and H. Radha, "Deep learning algorithm for autonomous driving using GoogLeNet," *2017 IEEE Intelligent Vehicles Symposium (IV)*, Los Angeles, CA, 2017, pp. 89-96. doi: 10.1109/IVS.2017.7995703

variety of objects surrounding the vehicle. A crucial aspect of the CANVAS initiative is the acquisition of an extensive and massive amount of data, on a continuous basis, for each sensing modality under a wide range of traffic and weather conditions. This massive data will be continuously collected and used to train and tune advanced machine-learning algorithms, deep, and popular convolutional learning neural networks. The CANVAS Brian engine also uses data from the Mobility component of CANVAS, which includes highly-accurate positioning data, maps, and related navigation information. Collectively, all of the sensed and navigation data are optimally diffused to guide the autonomous vehicle and determines its realtime action.

(e) **Planning and Control:** Under this area, CANVAS faculty and students are exploring advanced approaches for global and local path planning and novel control algorithms for guiding autonomous vehicles toward following the planned paths. In particular, one area of research focus is on developing robust path following control frameworks for of self-driving vehicles operating under mismatched perturbations due to the effect of parametric uncertainties, vehicle side-slip angle, and road banking. This form of research could be pivotal for a autonomous racing scenarios such as the ones envisioned for the IAC competition.

(f) **Connectivity:** Vehicle-to-vehicle connectivity represents another area where CANVAS faculty and students have made some key contributions. This includes developing some of the fundamental technologies and protocols in the early areas of vehicle networks[6] (VANETs). More recently, we have been exploring advanced sensor fusion among connected vehicles for improved safety[7]. This includes a novel framework for sharing visual data between connected vehicles in scenarios where certain objects are not in the field-of-view of a given vehicle, while the same objects could be viewed and detected by other vehicles within the same network[8].

High-Level Technical Plan for IAC

The Indy Autonomous Challenge will require unprecedented solutions for autonomous driving at ultra-high-speed (UHS) that could exceed 200 mph, and at a minimum speed of 100 mph as stipulated by the competition rules. At such UHS, many of the conventional

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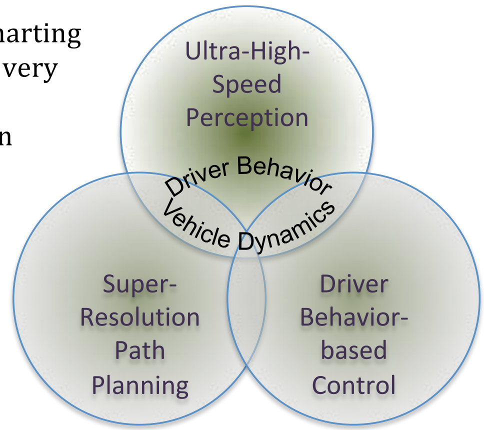
[6] S. Biswas, R. Tatchikou and F. Dion, "Vehicle-to-vehicle wireless communication protocols for enhancing highway traffic safety," in *IEEE Communications Magazine*, vol. 44, no. 1, pp. 74-82, Jan. 2006. doi: 10.1109/MCOM.2006.1580935

[7] Al-Qassab, H., Pang, S., Al-Qizwini, M., Kent, D. et al., "Active Safety System for Connected Vehicles," *SAE Intl. J CAV* 2(3):191-200, 2019, https://doi.org/10.4271/12-02-03-0013.

[8] Al-Qassab, H., Pang, S., Al-Qizwini, M., and Radha, H., "Visual Sensor Fusion and Data Sharing across Connected Vehicles for Active Safety," SAE Technical Paper 2018-01-0026, 2018, https://doi.org/10.4271/2018-01-0026.

technologies will either be obsolete or incapable of handling the environment in terms of perception, planning and control. Consequently, new design frameworks and corresponding algorithms will be needed for IAC. Key aspects of these new solutions include:

(1) Ultra-High-Speed Perception that enables the vehicle to detect static and dynamic objects, most notably other racing vehicles in the environment. This will require development of novel sensor-data processing and fusion techniques that must operate in real-time at UHS.
(2) Super-resolution Path Planning that is capable of charting multi-scale and multi-resolution paths that require very rapid updates in real-time.
(3) Driver-Behavior-based Control that will be based on thorough analysis of professional racecar drivers' comprehension, planning and control of the vehicle.
(4) Vehicle Dynamics analysis and simulation will be of paramount importance. This will be accomplished utilizing an industrial-grade vehicle simulation environment that will be provided by ANSYS[9]. The vehicle simulation will capture the full dynamics of the actual Dallara IL-15 Indy Lights that have been redesigned for the competition to accommodate a set of sensors to be mounted on the vehicle.
(5) Professional Racecar Driver Behavior analysis represents another pivotal area for a successful completion of the competition. In essence, the vehicle must learn from a professional racecar driver and not from an average vehicle driver. There have been many studies showing clear differences between professional racecar and novice drivers in terms of reaction time, cognitive aspects of perceiving the environment, planning the next move, and controlling the vehicle.



Conclusion

The CANVAS initiative at MSU has been developing advanced frameworks and solutions for autonomous vehicles for many years. This program positions MSU as a leading contender for participating in the Indy Autonomous Challenge. MSU's readiness is also evident due to the invaluable experience that MSU's students and faculty have gained through their participation in the SAE/GM AutoDrive Challenge. MSU's readiness is also evident when considering the availability of two autonomous-vehicle platforms equipped with state-of-the-art sensing devices and computers capable of performing complex deep learning and related algorithms in real-time. Consequently, the MSU team is looking forward to participating in the IAC historic competition.

[9] https://www.ansys.com/products/systems/adas