Accepting the Indy Autonomous Challenge:
Purdue University – West Point Autonomous Race Team

Abstract:

This white paper serves as our submission for satisfaction of the Indy Autonomous Challenge's first Challenge Round. Here, we describe our team, our collective history with automation, and our technical and operational plans for competing in the competition.

1. **Our Team**: Our team consists of students and faculty from Purdue University and the United States Military Academy at West Point, as well as postdoctoral researchers and other partners.
    a. **Purdue University**: The Purdue Autonomous Vehicles Society consists of three joint student organizations from Purdue University, West Lafayette, Indiana, that focus on autonomous technology: Autonomous Motorsports Purdue (AMP), Electric Vehicle Club (EVC), and the Institute of Electrical and Electronic Engineers (IEEE Racing). Each team has its own history of automation and racing along with its own methodologies for developing competition software. Each team also has its own forms of project management and sponsorships. Our faculty advisor is Aly El Gamal, PhD, a professor in Purdue's Department of Electrical and Computer Engineering.
        i. **Autonomous Motorsports Purdue (AMP)**: AMP was founded as a club in the Spring of 2019 as a senior design project. The initial goal of the project was to build and design an autonomous go-kart to compete in the evGrandPrix Challenge at the Indianapolis Speedway.
        ii. **Electric Vehicle Club Autonomous Division (EVC-A):** Purdue's Electric Vehicle Club was founded in 2009 with the start of evGrandPrix (evGP). Its mission is to afford students practical experience with electric vehicle design concepts within a competitive motorsport setting.
        iii. **IEEE Racing:** Founded in 2011, IEEE Racing, a subordinate unit of the Purdue IEEE student branch, is part of one of the university's largest technical professional organizations. Its early focus was to give students the opportunity to develop advanced electric racing vehicles to compete in the first Electric Vehicle Grand Prix (EVGP) in 2011.
    b. **United States Military Academy at West Point:** The Robotics Research Center, directed by Colonel Christopher Korpela, Ph.D., is the lead for West Point's contribution to the team. The Robotics Research Center is the Academy's primary resource for expertise and academic scholarship in the field of robotics, enabling interdisciplinary cooperation and concentrating Academy-wide research efforts in robotic systems. The center supports margin-of-excellence research activities focused on artificial intelligence, machine learning, and autonomous systems to educate and inspire leaders of character prepared to think critically, innovate, and apply robotic systems in the United States Army.

        West Point's team members have experience with autonomous vehicles and associated subsystems, including Reinforcement Learning (RL), robot trust and teaming, swarms, human-machine interface, vehicle and path planning behaviors for small and medium-sized ground vehicles, and object classification, as well as the intersection of ethics and emerging technologies. The center has participated in the DARPA Swarm Challenge, the Intelligent Ground Vehicle Competition, and in multiple other initiatives in industry, government, and academia.

2. **Members of the Team**:

    a. **Nick Clark (Data Science Lead)**: Nick is a Lieutenant Colonel in the US Army with a BS from West Point, an MS from George Mason, and a PhD from Iowa State. His interests include spatio-temporal statistical modeling for discrete outcomes and high dimensional Bayesian inference.

b. **Sean Cleveland, PhD (Director of Communications)**: Sean is a career US Army officer and combat veteran, with a BS from West Point, MA from Arizona State University, and PhD from Texas Tech University. Sean served as a Professor of English at West Point and was a co-creator of the Mounger Writing Center. He currently serves as the Founding Partner of nxtU Academic Consulting and Coaching Services.
c. **Eric Dietz, PhD (Senior Advisor, Resourcing)**: Eric is a career US Army officer with a BS and MS from Rose-Hulman Institute of Technology and PhD from Purdue University. As a Director in Purdue's Discovery Park, Eric serves as the catalyst for Purdue's homeland security research, increasing the impact of Purdue research on society, and organizing interdisciplinary projects within the university.
d. **Aly El Gamal, PhD (Lead Developer/Purdue Scrum Master)**: Aly is our lead developer and scrum master for Purdue team members. He is an Assistant Professor of Electrical and Computer Engineering at Purdue University and his research interests include information theory and wireless communications, learning theory and big data analytics, and graph theory.
e. **John Graham, PhD (Senior Advisor, Resourcing)**: John is a career US Army officer and combat veteran, with a BS from West Point, MS from The Ohio State University, and PhD from Carnegie Mellon University. John is a Managing Director at Campfire Capital and previously served as the Founder and Director, Network Science Center, and as the Chief Scientist for West Point.
f. **Shyam Sundar Kannan (Graduate Student, Purdue University)**: Shyam is a Ph.D. student at Purdue University specializing in Robotics. Prior to his Ph.D., he completed his masters at Purdue University and his bachelors from Anna University, India. His current research focuses on localization and path planning for mobile robots. He has prior experience in using geometric and computer vision-based techniques for localization and planning. He has worked at Bell Labs, developing new localization methods for ground and aerial vehicles, and also been involved in 1/10 autonomous racing at Purdue. He anticipates developing new localization and planning methods that can function robustly in the high speeds of autonomous racing vehicles.
g. **Christopher Korpela, PhD (Supporting Developer / West Point Scrum Master)**: Christopher is our supporting developer and scrum master for West Point team members. He is an Associate Professor of Electrical Engineering and the Director of the Robotics Research Center at West Point. An active duty Army officer, Christopher has deployed to both Iraq and Afghanistan. He has coordinated research projects and grants across the U.S. Department of Defense, academia, and industry in the field of robotics, control, and autonomy and has authored and coauthored over 35 scientific and professional papers and book chapters.
h. **Daniel J. Gonzalez (Postdoctoral Fellow, Robotics Research Center, West Point)**: Dr. Daniel J. Gonzalez is a Postdoctoral Fellow at the Robotics Research Center in the Department of Electrical Engineering and Computer Science at USMA West Point. He earned an S.B., S.M., and Ph.D. in Mechanical Engineering from the Massachusetts Institute of Technology. Daniel is currently working on Bio-Inspired Kinodynamic Motion Planning for Wheeled, Tracked, and Legged Robots and integrating this work into the navigation stack of the Ground Vehicle Systems Center (GVSC) Robot Technology Kernel (RTK), which is a certified set of autonomy libraries for use by the armed forces of the United States of America. Additionally, Daniel works on analyzing the internal dynamics of quadrupedal locomotion as it relates to giving humans a pair of Extra Robotic Legs that bear the weight of a backpack payload as it walks in sync with a human operator.
i. **Dominic Larkin (Deputy Director, Robotics Research Center, West Point)**: A retired Army officer, Dominic Larkin is the Deputy Director for the Robotics Research Center and an Assistant Professor at the United States Military Academy at West Point. In 2008, he earned a Master of Science in Computer Science from Georgia Institute of Technology and joined the junior faculty at the United States Military Academy at West Point. An Assistant Professor, he has served as a Research Scientist for the Cyber Research Center and the Robotics Research Center. His academic interests include robotics, cyber warfare and computer science education.

j. **Tyler Mahlmann (Purdue Undergraduate Leader)**: Tyler is the project lead of Electric Vehicle Club Autonomous, a student organization at Purdue. His work focuses primarily upon steering controller design, telemetry software development, and safety condition management. Projected BS AAE '21, MS AAE '22.

k. **Rohan Kumar Manna (Graduate Student, Purdue University)**: Rohan is currently a Master's student in the Electrical and Computer Engineering department and a Graduate Teaching Assistant in the Computer Science department at Purdue University. He serves as a lab lead and has taught object-oriented programming to over 200 students over the past two years. His master's thesis focuses on the topic of hardware security, proving artificial neural networks give better accuracy than traditional digital signal processing algorithms. He will continue to pursue a Ph.D. degree from Purdue University, where he will continue his work on Machine/Deep Learning algorithms. Before coming to Purdue, he completed his Bachelor's degree from KIIT University, India. During his undergraduate studies, he worked on image processing and software cost estimation using a modified particle swamp optimization algorithm. He anticipates developing robust machine learning algorithms for autonomous racing vehicles.

l. **Manuel Mar (Graduate Student, Purdue University)**: Manuel is currently a Master's student pursuing his degree in Computer & Information Technology. He holds a B.S. in Electrical Energy Engineering from UTEC University in Lima, Peru. Focusing on the cybersecurity of electric vehicles and powerplants, he has worked with General Motors to research electric vehicles. He strives to make an impact and learn more about electric and autonomous vehicles in support of industry innovation.

m. **Robert Megennis (Technical Advisor)**: Robert Megennis is an American race car driver who has been active since 2015, starting his career in the F1600, later moving up to the F2000 series, Pro Mazda, and Indy Lights. He currently races with Andretti Autosport in the Indy Lights series.

n. **Byung-Cheol Min, PhD (Technical Advisor, Purdue University)**: Byung-Cheol is an Assistant Professor of Computer and Information Technology at Purdue University. He completed his postdoctoral training at the Field Robotics Center at Carnegie Mellon University. His current research interests include multi-robot systems, sensor networks, human-robot interaction, robot design and control, with applications in field robotics and assistive technology and robotics.

o. **Joe Pekny, PhD (Senior Advisor, Resourcing)**: Joe is responsible for applying Purdue University resources to the team. A Professor of Chemical Engineering at Purdue University, Professor Pekny and his students work at the interface between engineering, computer science, mathematics, management science, and information technology to develop improved methods for the scheduling, planning, design, and optimization of manufacturing, business, and research pipeline processes.

p. **Trevor Powers (West Point Undergraduate Leader)**: Trevor is pursuing a BS in Computer Science at West Point.

q. **Mike Saxon, PhD (Team Principal)**: Mike is responsible for all aspects of our team's performance, including planning and strategy, operations, and fundraising. Mike is a career US Army officer and combat veteran, with a BS from West Point and MA and PhD from Indiana University. He previously directed the core philosophy and ethics education program at West Point. Mike operates Storm King Group, a business growth consultancy headquartered in Zionsville, Indiana, and is an Assistant Professor, Adjunct Faculty, at the University of Indianapolis, teaching ethics and business ethics, and a research fellow at the Robotics Research Center, West Point.

r. **Jeremy Tang (Purdue Undergraduate Leader)**: Jeremy is the president of Autonomous Motorsports at Purdue, having joined the club in Fall 2018. Jeremy has worked on project management and transitioning the team from a senior design project to a lasting student organization. Projected BS EE '22.

s. **Tim Vander Woude (Purdue Undergraduate Leader)**: Tim is the vice president of Autonomous Motorsports at Purdue, a student organization focused on developing an autonomous go-kart. As mechanical team lead, Tim designed and manufactured new structural components for the kart. Projected BS ME with ECE Minor '22.

t. **Tony Vespa (Software Development Environment and Infrastructure)**: Tony is the founder of Vespa Group, a security and technology consulting firm headquartered in Indianapolis, Indiana. He holds a BS in Computer Science, is a distinguished graduate of the U.S. Naval Academy, and has completed six overseas deployments. He is an expert in intelligence collection, exploitation, and fusion and has extensive experience in U.S. interagency and foreign government collaboration. He is actively engaged with key Indiana stakeholders such as the Indiana Office of Technology, Indiana Economic Development Corporation, National Center for Complex Operations, and the Cyber Leadership Alliance.

u. **Shakti Wadekar (Graduate Student, Purdue University)**: Shakti is a PhD student at Purdue University working on Deep/Machine learning algorithms and architecture. He has been selected as a Machine Learning Teaching Assistant for Purdue's Study Abroad program in Prague, Czech Republic (May-2020) after serving in a similar capacity in Dublin, Ireland (May-2019). He completed his master's degree at Purdue in 2019. Before coming to Purdue, he worked for 2 years in Tata Consultancy Services Ltd., where he received the 'On-the-spot' Award 2017 for resolving a major production challenge. He received his B.Tech degree in Electronics and telecommunication from Shri Guru Gobind Singhji Institute of Engineering and Technology, Nanded, India in 2015. During his under-graduate studies, he received 'Popular Student Project Award' from Tata Consultancy Services Ltd. for his project on 'Hand Gesture Recognition Using Artificial Neural Networks' (2015).

v. **Purdue University Undergraduates**: August Abt, Sayed Alaali, Logan Anderson, Mitchell Arndt, Shibi Balamurugan, Ryan Bobber, Ethan Campbell, Yupei Cao, Rudranshu Datta, Susan Evans, Aidan Fisher, Gautam Fotedar, Zach Ghera, Ethan Grinnip, Isaac Hagedorn, Lucy Han, Connor Hansen, Mohamed Ibrahim, Justin Lee, Daniel Moon, Noah Pictor, Alex Quivelli, Tessa Quivelli, Jack Roy, Nishay Shah, Sam Smith, Dhruv Swarup, Jason Toberman, and Will Young.

w. **West Point Undergraduates**: Will Anderson, Reed Burton.

3. **History with Automation**:

a. **Autonomous Motorsports Purdue (AMP):** After the 2019 evGrandPrix Challenge, many seniors graduated and a new group of leads assumed responsibility. Autonomous Motorsports Purdue has grown into an engineering club with members of various academic disciplines at different levels of their education. Currently, the team is working on perfecting the go-kart that competed in last year's evGrandPrix by improving path planning algorithms, cleaning up wiring, making sure the emergency brake is fully functional, and other critical tasks that improve operability. Many graduated seniors remain active in helping the club achieve its goals to build a fully autonomous go-kart and have helped the club's new members make major progress in algorithms and electronics design over the past semester. The team is passionate about autonomous technologies and shares similar goals with the other Purdue Autonomous Teams united to compete in this competition.

b. **Electric Vehicle Club Autonomous Division (EVC-A)**: The team has built a wide range of electric vehicles, including electric go-karts to compete in the evGP, electric motorcycles, skateboards, and scooters. In the Fall of 2017, evGP announced the founding of an autonomous division, allowing for the design, manufacture, and testing of self-driving go-karts University teams. Mechanical Engineering senior, Steven Padilla, headed Purdue's efforts in this competition. In May 2018, the IMS showcased Purdue's kart and its demonstrated remote-control capability. Throughout the Summer of 2018, the team's Mechanical Engineering seniors added a number of autonomous features as a senior design project, culminating in a kart that could autonomously navigate the historic Purdue Grand Prix track. Since then, EVC's Autonomous Division has made many improvements and feature additions to the kart, with the primary goal of increasing its speed and durability. The team placed 1st in the evGP Autonomous race in 2018 and 2nd in 2019. Only 2 years old, the club's membership has increased every year as general interest in autonomous vehicles increases. Our team members look forward to the opportunity to compete in the Indy Autonomous Challenge, bringing our experience of the past two years to bear upon our collaboration with West Point and Purdue's other autonomous teams.

c. **IEEE Racing**: IEEE Racing focused its efforts over the last 7 years on building driver-controlled electric karts. Projects in the past included dual-motor kart, battery pack design, and torque vectoring. IEEE Racing competes at the annual evGP at IMS and against dozens of other racing teams in head-to-head competition. In addition to the traditional race, evGP introduced an autonomous category for teams to build an autonomous kart. IEEE turned its focus to meet this challenge and has subsequently completed the remote-control subsystem for the autonomous kart and has begun working on autonomy algorithms on a Nvidia Jetson TX2 Development Kit and TI Microcontroller

d. **Robotics Research Center at West Point**: The RRC participates each year in the Intelligent Ground Vehicle Competition (IGVC) held in Detroit, Michigan. Sponsored by the Ground Vehicles Systems Center (Combat Capabilities Development Command - Army Futures Command), the competition hosts two tracks: auto-nav involving a smaller robot carrying a 25lb payload and self-drive, consisting on a Polaris GEMe2 electric car. Both tracks in the competition involve a series of tasks such as lane following, trajectory generation, localization with and without GPS, obstacle and collision avoidance, and mapping. The RRC has competed for the last 15 years.

4. **Plans for competing:** Our plans for competing in the Indy Autonomous Challenge draw inspiration from our participation in the previous EV Grand Prix competitions. Currently, our karts use Robot Operating System (ROS) for processing the sensory inputs, controls, and visualizing the data. We are looking forward to extending our current setup to satisfy the unique challenges of the Indy Autonomous Challenge and our will serve as a test platform to develop methods for the race in October, 2021. Our current software architecture consists of the following key components and our first and primary task is to customize it to handle the challenges of racing at high speeds.

   a. **Global and Local Planner:** Our current setup fuses GPS, IMU, and LiDAR data to localize globally on the track as well as locally. We look forward to analyzing the specific setup and layout of Indianapolis Motor Speedway and using that information to enable us to localize precisely on that track.

   b. **Dynamic Obstacle Avoidance:** In our current setup, LiDAR has been our primary resource for detecting and avoiding obstacles, including debris and other cars. We plan to extend this module by increasing its capabilities for detecting objects at high speed and estimating object trajectories.

   c. **Trajectory Control**: We currently use two levels of trajectory generation: global and local planner. For the Indy Autonomous Challenge, we plan to generate global paths for the car to follow the IMS oval by studying the racing lines used by professional racers, including the insights we glean from our partner Indy Lights race team, RKM Racing. For the local planner, we intend to develop new methods based on geometry or reinforcement learning that will enable us to stay as close as possible to the global path and at the same time avoid other cars.

   d. **Lateral and Longitudinal Control**: We use PID to control our go-karts and we plan to execute a similar strategy with the Dallara IL-15, unless we discover that extending our current methods are not viable.

   e. **Testing:** Our current testing platform is based on an actual go-kart with a TI Microcontroller that assesses speed and turning angles from a Nvidia Jetson and sends corresponding signals to the kart's driving and steering motors. Both the Nvidia Jetson and TI Microcontroller have programmed timers that continuously check the state of the host computer and other processors. If either timer triggers or something fails during the run, the go-kart automatically brakes fully and disengages both motors. Our current software relies upon a Nvidia Jetson TX2 Development Kit. Moreover, the current implementation uses the Robot Operating System (ROS) Navigation Stack to organize and process inputs (sensor streams, odometry, map, goal setting) to ensure safe velocity and turn command. ROS also supports a 3D visualization tool called RViz, which provides a view of a simulated robot and can capture/display other sensor information, as well. In total, these systems allow us to test our software safely on simulated 2D tracks prior to real-world testing on the track. We currently rely on a Velodyne VLP 16 LIDAR to receive depth data and to build a 2D cost map by taking a single slice of the point cloud. The LIDAR sensor is our go-kart's main way of

getting important SLAM data. The kart uses this data for its path planning algorithm using Potential Field Avoidance. More specifically, 3D depth data builds a 2D "laser scan" by taking a single slice of the point cloud. From these laser scans, we use a SLAM library called Hector Mapping to produce odometry information based on the change in scans over time. Absent an extant map, these scans also set the next target location (goal) relative to the current position and pose of the robot by computing a resultant vector in the direction of the most "free space" in front of the robot. While ROS ensures the robot does not crash into a wall, we must also integrate additional verifications and error handling measures.

f. Given the unique environment at Indianapolis Motor Speedway, we expect to consider other methods for this competition. Given the scenario presented by the Indy Autonomous Challenge, where we need to maintain high speeds over distance, we know that our existing solutions and setup from the EV Grand Prix will need significant modification and improvement to satisfy the conditions of the challenge. Extracting a 2D Map from the 3D Velodyne LiDAR is insufficient for racing in high-speed conditions. We must use the entirety of our 3D data to simultaneously analyze the trajectories of other vehicles and to plan the path for ours. Hector mapping might not be a viable option as it requires features to localize, which might not be sufficiently present in the IMS oval. In contrast, the kart race has walls on the side which provide features for the algorithm to localize. Given the differences at Indianapolis Motor Speedway, we intend to investigate using the curvature of the track's sidewalls to localize. The curvature can be estimated using data from the LiDAR. Clearly, we need to develop new SLAM strategies since current state of the art methods have not proven reliable at very high speeds. We anticipate developing new tracking methods based on existing methods like YOLO real-time object detection. We also have concerns that Hector Mapping will not function properly at high speeds. Given our focus on high-speed racing, the use of vision-based methods like tracking the curvature of the roads and fusing GPS and IMU readings might afford a viable solution. Collision avoidance methods from the ROS Navigation Stack will also likely prove problematic and we might well have to rely upon integrated vision and LiDAR data.

g. Because of these significant challenges, we expect to invest significant effort in research and development of new localization and navigation techniques that are robust enough to satisfy the demands of the high speeds and cornering capabilities of these autonomous Dallara cars. We continue to add new resources and members to our already diverse and experienced team.

5. **Approach to project management**:

   a. **Software Development**: Our architecture team is currently developing the software development and infrastructure framework and assessing best practices using the Microsoft Azure cloud computing platform. We will use agile methodology, including stakeholder analysis, multidisciplinary teams distributed over time and space, and internal and external quality assurance measures. We will rely upon engineers and analysts to assist in the development of databases and back-end systems, including a robust data science and analytics efforts in collaboration with RKM Racing. Our delivery cadence will include sprints by software and engineering focus areas / teams, planning / prioritization, commitments, and updates and demos integrated into our team's meeting rhythm.
   b. **Business and Other Operations**: We will integrate business operations into our overall agile methodology, including internal systems and processes for operations, planning and strategy, fundraising, and communications. These processes are consistent with those developed and utilized in other contexts by our team principal.

6. **Fundraising**: We currently have multiple interested parties who have expressed willingness to provide funding or in-kind contributions to our race team. We have a fundraising campaign plan, which began with an event in Indianapolis on February 18, 2020 and then at West Point on February 21, 2020, in conjunction with our race team partners, RKM Racing / Andretti Autosport.

Both Purdue University and West Point have provided funding for multiple faculty, postdoctoral researchers, and full-time graduate students to concentrate on our team's entry in the challenge, in addition to the undergraduate student members of our team. Additionally, our team has already secured help from multiple partners in industry with software development expertise and resources, project management, planning and strategy, leadership, communications, and marketing. As we successfully raise money, we will look to increase our stable of full-time graduate students, faculty, and postdoctoral researchers. In addition, we have integrated our fundraising operations with tax exempt organizations at both Purdue University and West Point to support sponsor donations.

Premier sponsors will have the opportunity to purchase locations on the livery for our race car, which we plan to purchase, race, and then put on permanent display at the West Point Visitor's Center, as well as rotate to various STEM and automobile and motorsports events and venues around the country.

Last, we have a partner with extensive experience in automotive documentaries who intends to create a documentary film that tells the story of our team and its effort to race and win at the Indianapolis Motor Speedway in October 2021.

Indy Autonomous Challenge
Indiana University-Purdue University Indianapolis
IUPUI Team

Round 1

The IUPUI Team

Indiana University-Purdue University (IUPUI) is a research public university located in Indianapolis, Indiana. IUPUI was founded in 1969 and today has over 21,000 undergraduate students and 8,000 graduate students. IUPUI is one of the seven campuses of Indiana University. It has sixteen Indiana University schools and two Purdue University schools, namely, Purdue School of Science and Purdue School of Engineering and Technology—the first one in the United States to offer a bachelor's degree in motorsports engineering.

The Purdue School of Engineering and Technology hosts various research centers, institutes, laboratories, and initiatives, including the Transportation & Autonomous Systems Institute (TASI), the Engineering Design Research Laboratory (EDRL), the Mechatronics & Automotive Research Laboratory (MARL), and the Autonomous Vehicle Initiative. The IUPUI Team for the Indy Autonomous Challenge is formed by researchers such institutes, laboratories, and initiatives.

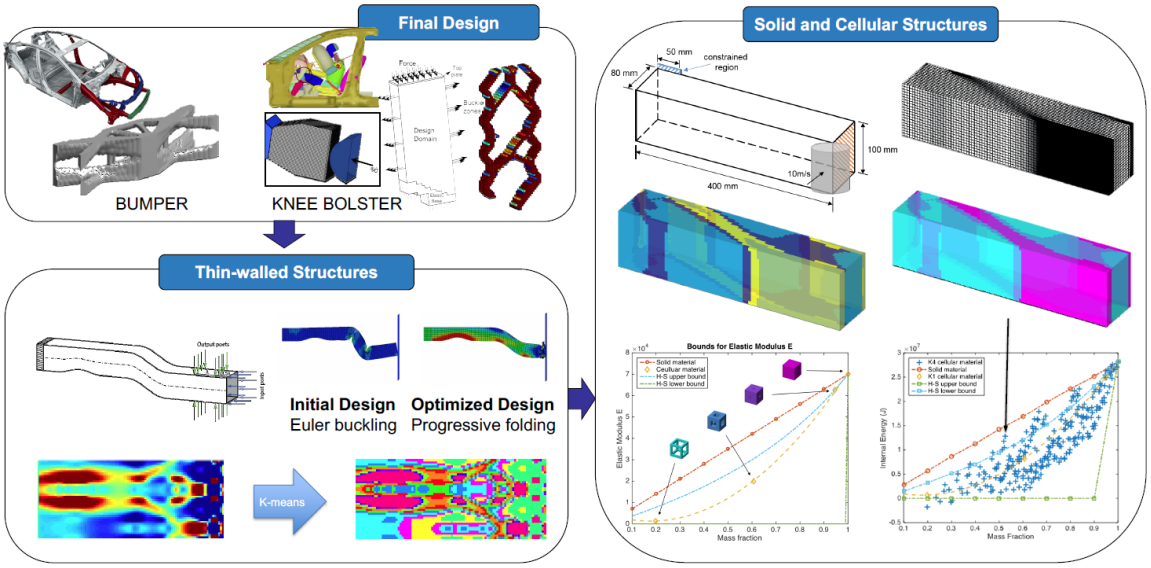
Transportation & Autonomous Systems Institute (TASI) (tasi.iupui.edu)—TASI is a collaborative University, Industry, and Government consortium to facilitate research, development, evaluation and assessment of transportation active safety and autonomous systems. As a cross-campus research center, faculty members from more than 10 departments and schools at IUPUI, Indiana University Bloomington, and Purdue University West Lafayette are involved in TASI's research activities. TASI's main activities include vehicle testing and evaluation, human factors in active safety systems, crash data analysis and risk benefit analysis, scientific research on automation of selected driving functions, crash prevention technologies, and connected vehicles.

TASI research areas include modeling and simulation, pedestrian/bicyclist safety, and vehicle dynamics and control

TASI faculty team has the expertise and technical skills to address research needs for these enabling technologies for connected vehicles and automated driving systems by collaborating with its academic and industry partners. Research

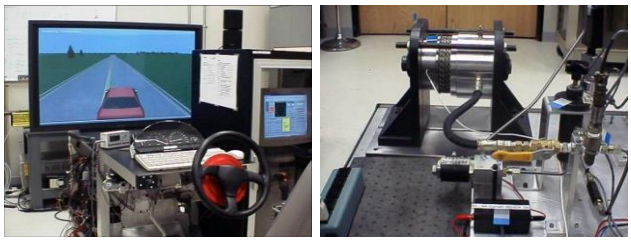
areas include pedestrian and bicyclist safety, human factors/HMI in automated driving, driver state sensing and performance evaluation, ADAS system performance test and evaluation, V2X communications for traffic safety, impaired and fatigue driving, NDD and crash data analytics, SAE/IEEE standards development for automated driving, modeling and simulation, and vehicle dynamics and control.

Engineering Design Research Laboratory (EDRL) (edrl.et.iupui.edu)—EDRL research focuses on engineering systems, structures, and material design optimization algorithms. Their work exploits and develops synergies among structural vehicle engineering, engineering mechanics, material science, and manufacturing to introduce new insights and capabilities to vehicle engineering design. Research topics include machine learning-assisted design (Bayesian optimization), topology optimization (mechanical and thermal-fluid structural optimization), and generative design (bio-inspired design). Applications include vehicle structural optimization (e.g., crashworthiness, ballistic penetration, and blast mitigation), materials for energy storage, and composite material optimization, and their integration in a multiscale material and structure design methodology



EDRL research includes vehicle lightweighting through multimaterial topology optimization and machine learning-assisted design.

Mechatronics & Automotive Research Laboratory (MARL) (www.iupui.edu/~meengr/mrl/)—MARL was established in 2005 to facilitate teaching and research in the areas of Mechatronics and Intelligent Systems, Diagnostics/Prognostics, Advanced Control Systems, Modeling and Simulation, Drive-By-Wire and Autonomous Systems, and Sensors & Algorithms. MARL is aimed at creating high-tech workforce in the area of automotive mechatronics and intelligent systems by providing appropriate training to the students in order to meet the needs of these rapidly changing technologies and provide services to industry for promoting new technologies.



MRL is equipped with state of the art rapid control prototyping hardware and software which are used to conduct fundamental research.

Team members

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Andres Tovar is an Associate Professor of Mechanical and Energy Engineering and an Adjunct Assistant Professor of Biomedical Engineering at Indiana University-Purdue University Indianapolis (IUPUI). He received his B.S. in Mechanical Engineering and M.S. in Industrial Automation from the National University of Colombia in 1995 and 2000, respectively. He earned his M.S. and Ph.D. in Mechanical Engineering from the University of Notre Dame in 2004 and 2005, respectively. At IUPUI, he has been the recipient of the 2015 Wisner-Stoelk Outstanding Faculty Award and the 2016 IU Trustees Teaching Award. He also received the 2014 SAE Ralph R. Teetor Educational Award, the First Place in the 2015 ARPA-E LITECAR Challenge, and the 2018 SHPE STAR Educator of the Year Award. At IUPUI, he teaches courses in design engineering including topology optimization, Bayesian optimization, and additive manufacturing. He is the director of the Engineering Design Research Laboratory (EDRL) and the Center for Additive Manufacturing Research at IUPUI. His research areas include machine learning-assisted design for of lightweight vehicle structures.

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Sohel Anwar is an Associate Professor in the department of Mechanical Engineering at Purdue School of Engineering and Technology, IUPUI. He is also the graduate program chair of the department and the director of Mechatronics and Automotive Research Lab (MARL). He has over 24 years of combined academic and industry R & D experience in the general area of mechatronics and controls. He received his Ph.D. from University of Arizona, Tucson, AZ in 1995. He worked as an R&D engineer at Caterpillar, Inc. between 1995 and 1999 where he focused on X-By-Wire systems design for Wheeled Loaders. He then joined Ford Motor Company / Visteon Corporation in 1999 as a Senior R&D engineer where he led the fault tolerant design of Drive-By-Wire systems. He joined Purdue School of Engineering and Technology at Indiana University Purdue University at Indianapolis (IUPUI) in 2004. Dr. Anwar has published over 135 papers in peer-reviewed journal and conference proceedings. He is also an inventor or co-inventor on 14 US patents. He is a member of ASME, IEEE, and a faculty advisor for SAE student chapter at IUPUI. He is on the editorial board of four international journals.

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History with automation

The IUPUI team has been involved in many automation projects including the design and fabrication of autonomous vehicles for applications in precision agriculture since 2015. These vehicles are referred to as agricultural robots (agBOTs). The first agricultural robots was a small electric vehicle that participated in the agBOT Challenge in 2016. A second and a third robots have participated in the agBOT Challenges of 2017, 2018, and 2019. The IUPUI team placed in the top three for two consecutive years (2018 and 2019).

All agricultural robots have been capable of remote controlled and autonomous navigation. These last two robots (one electric and one powered by internal combustion engine) have been equipped with RGB depth cameras, 2D LIDAR or ultrasonic proximity sensors, GPS enhanced with a real-time kinematic (RTK) positioning system, and wifi antenna and router with a range of 10 miles. In addition, a deep neural network has been implemented to identify different weeds and crops and spray with precision either a specific weed agent or fertilizer. This technology can be utilized to detect obstacles and other objects and improve autonomy in environments other than agriculture.

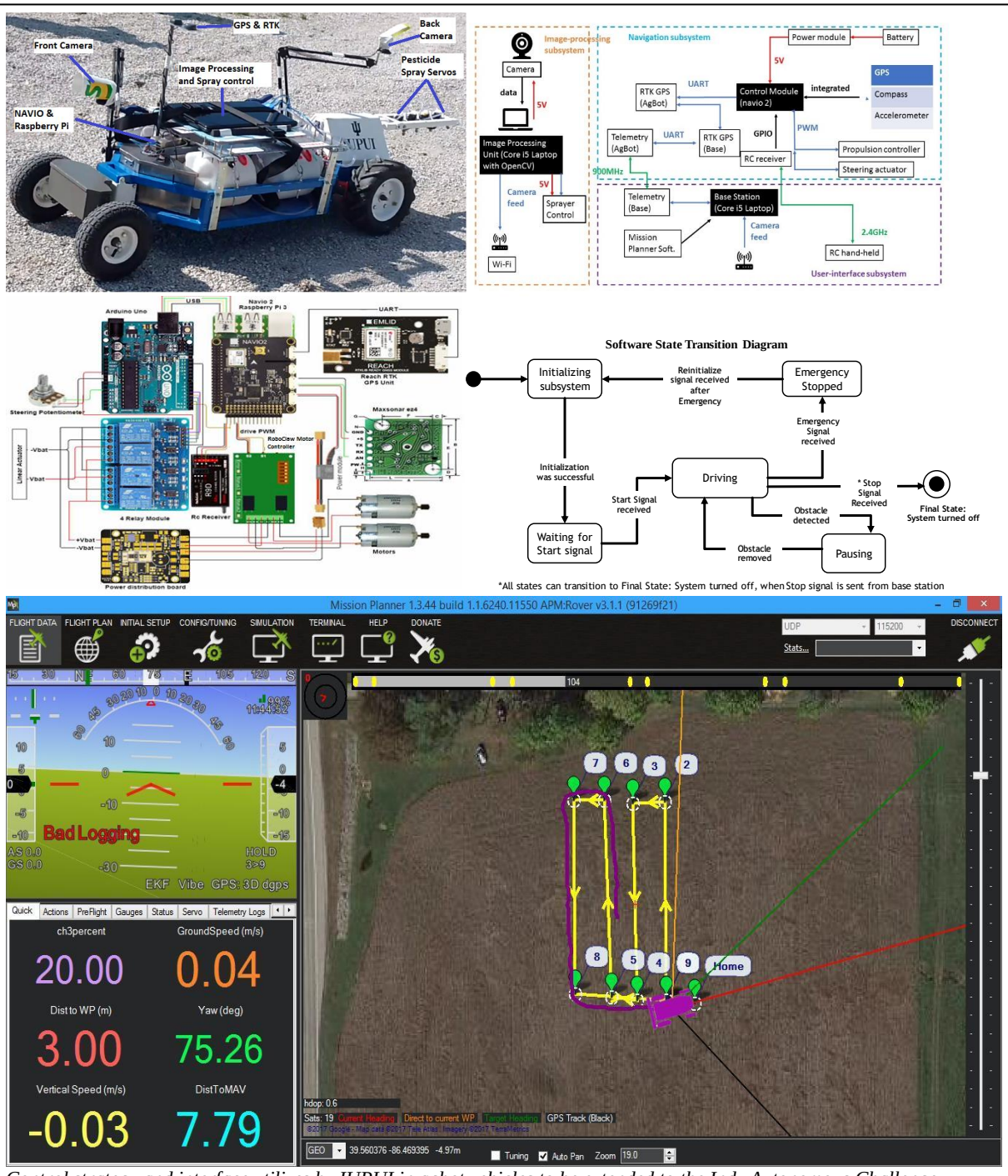
IUPUI agBOT ver 1.0 (2016): Seeding Competition (4th place)

IUPUI agBOT ver 2.0 (2017): Weed and Feed Competition (4th place)

IUPUI agBOT ver 3.0 (2018) and IUPUI agBOT ver 3.1 (2019): Weed and Feed Competition (2nd place in both years).

Plans for the competition

Proposed approach—This project will be executed in three phases: (1) Simulation Model and control software for an autonomous vehicle, (2) Autonomous electric go kart, (3) Autonomous control and communication software for Indy Light racecar. The simulation model and control software will be developed based on existing codes and expertise on our AgBot vehicles. A suitable simulation will be selected for modeling the vehicle, road, and implementing the control software. The hardware / software architecture of our AgBot 2.0 is shown in the following figure. The autonomous electric go cart will be equipped with RGB depth cameras, infrared cameras, 3D LIDAR, long range RADAR (77 GHz), and ultrasonic proximity sensors, GPS enhanced with a real-time kinematic (RTK) positioning system, and Wi-Fi antenna and router. The top speed reached by the go-cart is about 80 mph. Finally, the developed software technology will be transferred to the Indy Light racecar.



Control strategy and interface utilizes by IUPUI in agbot vehicles to be extended to the Indy Autonomous Challenge.

Testing— The autonomous control software will first be tested on the simulation model proposed above. Testing includes both virtual tests (simulation) and physical tests (lab and track). Virtual tests will be performed at IUPUI utilizing state-of-the-art models and software infrastructure from

EDRL. Lab physical tests will be done at IUPUI at TASI and MARL. Track physical tests will be done at the Indianapolis Motor speedway.

Project management— The leadership team will provide project management oversight, maintaining control over the scope, schedule and costs associated with the project. By making sure the strategy and goals of the project are visible and aligned, the true and valid outcomes of this project will be realized, that is the advancement of knowledge and understanding in the field of autonomous driving. Project management provides the framework and guidance that allows an effort such as this to maintain focus on these goals and to deliver value that transcends the end of the race, and the project. For this effort to have lasting value to the school and community, there must be residual benefit, which is the ultimate responsibility of project management.

Fundraising—The goal of the fundraiser is to tell the story in an engaging manner to companies that identify with the challenge. With a heavy regional presence of automotive, racing and automation related industry and the long and storied history of the Indianapolis Motor Speedway engrained in Indiana's very being, the story almost writes itself. Its an easy pitch to make our signature institute, TASI the hero in a story like this, with our very labs residing in the building where the Stutz Bearcat, that raced in the very first Indianapolis 500, was built. The story of the local team and the local track competing for Indiana pride is compelling and will be told well.

Plans for collaboration—While winning the race would be nice, if that is the end of the adventure, we haven't gained much. The true prize in this challenge is the advancement of the collective knowledge gained by more than twenty universities from around the word focusing on a shared task. The IUPUI team welcomes collaboration with industry and academic partners. With our close proximity to the track, our signature institute centered on autonomous systems (TASI), and the presence of the first Motorsports Engineering program in the United States to offer both Bachelor's and Master's degrees, we believe our school has a unique offering to teams wishing to collaborate.