Cal Poly Indy Autonomous Challenge Round 1 Proposal

Charles Birdsong, Ph.D., Department of Mechanical Engineering, Cal Poly San Luis Obispo, CA 93407
Cbirdson@calpoly.edu, 805.756.1261

Team and History

Cal Poly has a strong tradition in hands-on learn-by-doing especially in the area of automotive engineering. Over the years, we have developed gas and electric formula cars, hybrid electric vehicles, solar cars, human powered vehicles and many more. Cal Poly participated in the first round of the DARPA Challenge in 2003 and the Future Truck competition in 2004. We have competed in the Formula SAE competition annually and won many top honors. We have been active in the area of automotive safety and automation competing in the DOE ESV Student Design Competition since 2010 and placing first or second three times. The hands-on tradition at Cal Poly drives our students and faculty to excel and these applied engineering challenges, which are perfectly aligned with our strengths and mission.

Cal Poly Future Truck 2004

Cal Poly Formula SAE, Formula SAE Electric, and Baja SAE

As an example of Cal Poly's recent achievements, in 2019 a multidisciplinary student team of four computer science and four mechanical engineering undergraduates developed a two-car platooning demonstration for the DOE ESV Student Design Competition in Eindhoven, Netherlands. The system consisted of two twelfth scale cars with stereo cameras, vehicle-to-vehicle communication, image-based lane detection, neural-network object detection and artificial intelligence. The team used the CarMaker software to design and test control algorithms in parallel with the platform hardware development. At the competition, the team demonstrated the ability to maintain a platoon in the face of disturbances and plan and execute lane changes when necessary and safe. The team was awarded first runner up. This project was a collaboration between Dr. Birdsong and DeBruhl with support from the Computer Science Capstone Project course and the Mechanical Engineering Senior Design Course. Students earned course credit and satisfied their capstone project requirements through participating in the project. Financial support was possible through private support from Daimler Trucks North America and other Cal Poly internal funding programs. This effort is a model for participating in the Indy Autonomous Challenge and a similar team and management structure will be used.

Our motivation to participate in the Indy Autonomous Challenge is to give our students the opportunity to apply their skills and knowledge in an exciting, real-world, technically challenging problem that requires multidisciplinary teamwork, careful planning and good management. This will be a student-centered project with faculty providing direction and support, but with primary tasks executed by Cal Poly students.

The team will include multidisciplinary faculty and students. The faculty team includes the following:

- Charles Birdsong, Ph.D. Mechanical Engineering, specialty in control systems, instrumentation, vehicle dynamics, autonomous vehicles, system modeling
- Bruce DeBruhl, Ph.D. Computer Science, Software Engineering, and Computer Engineering, specialty in privacy and security of automated vehicles and V2X communication
- John Seng, Ph.D. Computer Science, specialty on robotics, artificial intelligence and real time operating systems
- Jonathan Ventura, Ph.D. Computer Science, specialty on artificial intelligence and computer vision

- John Fabijanic, M.S., Mechanical Engineering, specialty in formula racecar design and modeling. Lead advisor for Cal Poly SAE Formula Car Team.
- Matt Haberland, Ph.D. Mechanical Engineering , specialty in robotics and computational dynamics and trajectory optimization

The student participants will be formed through the capstone courses and senior project courses in Computer Science, Computer Engineering and Mechanical Engineering programs. Ideally, students will earn course credit and advance in their degrees through participation in this project. Additional team members will be encouraged and both undergraduate and master's students will be welcome.

Plans for Developing Competition Software

Our software will be developed on top of a physics engine to allow for robust testing before connecting to dangerous hardware. We focus on the following features.

- Safety – Safety must be a prerequisite for performance. The kinetic energy of a formula car traveling at 120 mph is tremendous. In the field of autonomous vehicles, the business case is still a work in progress and acceptance of this new technology will depend on the perception by the public and legislators with safety as a high priority. High profile failures of autonomous vehicles have the potential to degrade the public perception and affect the future of this technology. The system must address safety-by-design, security-by-design, and privacy-by-design.
- Simulation – development of a robust simulator environment will add in testing and algorithmic development. We intend to use a vehicle simulator using with robust physical simulations. Dr. Birdsong has supervised projects using CarSim and CarMaker. Currently, Dr. DeBruhl is supervising a collaborative autonomous vehicle project built upon the AIRSIM vehicle simulator using the UNREAL Physics engine and Omnet++ network simulator. We will use the provided simulators and previous simulator experience for a robust development environment.
- Perception – The vehicle must be able to perceive the environment. This will include both the racetrack and competing vehicles. This challenge has the advantage that the track is well mapped and defined unlike many autonomous vehicle projects that must deal with undefined roadways and many random obstacles such as pedestrians and debris. High definition mapping and image

processing are the likely methods that will be used. Identifying and avoiding collision with competing cars will require additional tools to accurately estimate the location and plan a trajectory around them. Lidar or radar data is a likely solution here in connection with camera data.

- Vehicle State Estimation – The system must be able to estimate state variables such as position, speed, bearing, yaw rate, slip angles, etc., in order to optimize the speed within the stability limits of the vehicle. Not every important state is measurable and may require state estimation techniques to compute them and address inherent noise and uncertainty.
- Localization – the system must estimate where it is in a lane and where it is on the track to maintain stability, lane position and optimize speed. We will use localization techniques based on GPS, perception, and state estimation to give the most accurate estimate.
- Trajectory Planning – to meet the high-speed requirements of the challenge trajectory planning will be a fine balance between optimizing speed and maintaining stability, lane position and safety.
- Trajectory Control – after an ideal trajectory is established the system must follow this trajectory in the face of random disturbances and uncertainties. Controller design will again be a balance between performance and margin of safety and stability.
- Data Management - Our testing dataset will be based on free and open-sourced data, simulated data, and real-world sensor data. Many open source data sets for autonomous vehicles are available [Hang and Berger] and we have developed interfaces to use this data in our testing. Any developed algorithms will be made open-source and published via github after the competition and subsequent relevant publications.
- Data Storage - All data will be stored on premise in local servers or on team shared cloud drives in OneDrive, Github, or google docs.
- Code Optimization – Driving at 120 mph creates unique challenges for autonomous vehicles because the time to measure the environment, estimate states, plan a trajectory and generate driving commands is much less than at public road speeds. Sacrifices will be required to achieve the necessary update rate at high car speeds. Since all teams will be using the same sensors and computers the advantage will go to the team that optimizes their code to deliver fast response time for a fixed computer operating speed. We will work

to leverage parallel computing platforms, FPGAs, and hardware optimizations as available on the final car.

Testing and Validation

Software will be tested through a combination of simulation and prototype platform hardware testing.

Our team has experience using commercial car simulation software platforms including CarMaker, CarSim, and AirSim for software development. Simulation environments allow early developing and testing of algorithms in parallel with other development tasks. We understand that the program will provide the ANSYS simulation platform , which we will use for the project.

At Cal Poly, we know very well that simulations are not sufficient to test and develop a vehicle. Real world testing is a must. We will consider different options for developing a prototype platform for testing. We currently have a two-person golf cart vehicle that has been developed over several years as an autonomous vehicle platform. This platform may be useful for testing localization and vehicle control algorithms. We will also consider developing a new platform that is more suitable for the Indy Autonomous Challenge such as the Top Kart EV Kart platform. A hardware platform will allow the team to generate sensor data, validate sensor integration and control strategies and learn more about optimizing the performance of a high-speed racecar.

Project Management

The lead faculty team members are Birdsong and DeBruhl with support from the additional team members in their areas of specialty. The leads will develop an overall software architecture and select algorithms required for each task. They will form sub teams to focus on individual processes and one team for overall system engineering and integration. Sub teams will include a faculty lead and student members. Faculty team members will take the lead on specific tasks but be available to all team members to advise in their area of specialization. Faculty will provide direction and support, but the main task of code development will be performed by students. Common industry tools will be used for project management, which may include Slack, Trello, GitHub, and Gira.

References

Cal Poly, "*Team Cal Poly (DARPA Grand Challenge 2005)" - Home*, web.archive.org/web/20070314031341/www.ee.calpoly.edu/telab/gc2005/.

"Advanced Vehicle Technology Competitions (AVTC)." *Wikipedia*, Wikimedia Foundation, 17 Sept. 2019, en.wikipedia.org/wiki/Advanced_Vehicle_Technology_Competitions_(AVTC)#2002-2004_FutureTruck.

ESV Conference, "Student Safety Technology Design Competition (SSTDC)." *NHTSA 26th ESV 2019 | Home*, www-esv.nhtsa.dot.gov/SSTDC.html?view=10.

Yin Hang, and Christian Berger. "When to use what data set for your self-driving car algorithm: An overview of publicly available driving datasets." *2017 IEEE 20th International Conference on Intelligent Transportation Systems (ITSC)*. IEEE, 2017.