Autonomous Tiger Racing

Introduction

GAVLAB:

Autonomous Tiger Racing (ATR) is comprised of students from Auburn University's GPS and Vehicle Dynamics Laboratory (GAVLAB). The GAVLAB, directed by Dr. David Bevly and Dr. Scott Martin, has approximately 40 total students (35 graduate) with research focused on Navigation, Vehicle Dynamics and Controls, and Signal Processing. The navigation group studies GPS, inertial navigation, perception, sensor fusion, machine learning, and sensor modeling. The vehicle group has experience in automation related research including truck platooning, passenger vehicle automation, off-road vehicle automation, vehicle dynamics, and state estimation. The signal processing group works primarily to develop algorithms for navigation in degraded and contested environments.

The lab has extensive experience with real-time implementation and fusion of sensors, such as GPS receivers, IMUs, cameras, LiDARs, radars, magnetometers, barometers, and DSRC radios. The lab has a variety of test platforms including DBW passenger cars, class-8 tractor-trailers, ATVs, indoor robots, and drones. Other university resources include a two lane 1.7 mile test track with banked turns, a large skid pad, and a surveyed RTK station.

Team Members:

Matt Boler is a 2nd year Master's student in the GAVLAB and the simultaneous localization and mapping (SLAM) lead for ATR. He studies computer vision and GPS-denied navigation with a focus on multispectral imaging and visual SLAM. Prior to his graduate studies, Matt was a member of FRC Robotics team 2974 and participated in undergraduate research on computer vision for navigation. He enjoys long walks on the beach and not cleaning his dishes.

Will Bryan is a 2nd year Master's student in the GAVLAB and the Controls lead for ATR. His research focus is vehicle dynamics and controls, particularly adaptive control. His additional research interests include estimation and deep learning. As an undergrad at Auburn, Will performed research in GPS signal processing and played lacrosse. His hobbies include skiing, mountaineering, camping, and playing tug-of-war with his dog, Naomi.

Brendan Schretter is a 2nd year Master's Student in the GAVLAB and the Estimation lead for ATR. His research focuses on the estimation of vehicles states using integration of various sensors, including inertial and GNSS systems. He has also studied the fields of GPS, software, and optimal estimation. He has gotten much of the lab to enjoy playing Chess (and losing to him) and for those who want something faster paced, Melee.

Jake Ward is a 2nd year Master's student in the GAVLAB and the Path Planning lead for ATR. His research focus is optimal control. Jake is highly involved in Auburn's truck automation work. He is experienced in writing controls software in C++ and Python using the ROS interface. Outside of work, Jake enjoys listening to music through a quality pair of headphones and Friday night trivia at a local cafe.

History with Automation

Truck Convoying:

Auburn has been involved with class-8 vehicle automation since 2013 when Auburn began its truck platooning project. Platooning describes a multi-vehicle system where the front vehicle is manually driven and the following vehicles autonomously follow at a set distance. The objective of the project was to implement a system that allowed trucks to follow one another at distances as close as 35 feet, which requires a longitudinal controller on each vehicle in the platoon as well as communication between vehicles. This research utilizes two Auburn owned Peterbilt 579's and two M-915's on loan from US Army GVSC-CCDC. Auburn requires no additional actuators on the vehicles to enable level 1 control because of their unique control implementation. The vehicle's existing Adaptive Cruise Control (ACC) is "spoofed" to execute control commands. Auburn was able to maintain a precise distance, or headway, behind the leading vehicle of the platoon utilizing information from the DSRC network and Cooperative Adaptive Cruise Control (CACC).

This project was then followed by level 2 leader-follower lateral control. For this work, a precision ranging technique called Dynamic-Base Real Time Kinematic (DRTK) positioning is used in conjunction with Time Differenced Carrier Phase (TDCP) measurements to generate precise positions of the lead vehicle. These positions are stored and used as "waypoints" to create a reference path for the following vehicle. Results from a level 2 run can be seen below in Figure 1. There is currently ongoing work to implement optimal control over the vehicles propulsion system using methods such as Non-linear Model Predictive Control (NMPC).

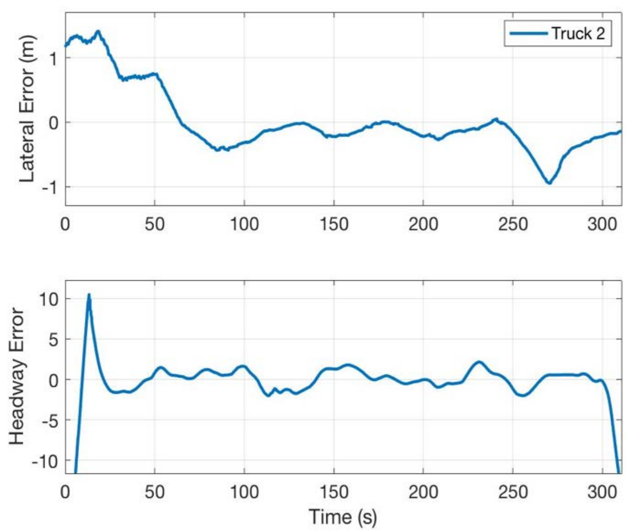


Figure 1: Experimental Level 2 Platooning Results

Passenger Car Automation:

The GAVLAB also researches single vehicle automation, particularly in the fields of path following and obstacle avoidance. A Dataspeed Lincoln MKZ, shown in Figure 2, is used by the lab to test control and path planning algorithms such as MPC and adaptive control. All testing and implementation is done through the vehicle's CAN interface, utilizing the drive-by-wire system for steering, brake, throttle, and shifting, as standard from the OEM.

Figure 2: Dataspeed Lincoln MKZ

DARPA Grand Challenge:

Dr. Bevly and his students participated in the 2004 and 2005 DARPA Grand Challenge, a driverless vehicle race in the Mojave Desert. In 2004, Auburn teamed with SciAutonics, LLC and finished 7th out of 45 initial competitors. Only nine made it out of the starting gate. In 2005, Auburn again teamed with SciAutonics as well as participating with the Terramax team. The SciAutoincs-Auburn team was one of 10 selected early for competition (from the 7th place standing at the qualification), and finished 16th out of 195 initial competitors, while the Terramax team was one of the 5 vehicles to complete the Grand Challenge Course. The fact that the number of entrants increased more than fourfold indicates the response from the first Grand Challenge. The figures below depict the SciAutonics-Auburn and Terramax teams' vehicles.

Figure 3: SciAutonics-Auburn Engineering Team

Figure 4: Team Terramax at the Finish Line

Plans for Competing

Approach to automated vehicle software architecture:

A diagram of the team's planned software architecture is shown below in Figure 5. Incoming sensor measurements, loosely divided into vehicle state sensors and environmental sensors, will be passed into vehicle state and environmental monitoring systems. The high-level information from these systems will be used by the path planning and safety monitoring scheme to determine a safe and optimal path. This will be sent to the vehicle controller to determine the control outputs required to follow the path. These outputs will be directed to the appropriate actuators by the vehicle control system.

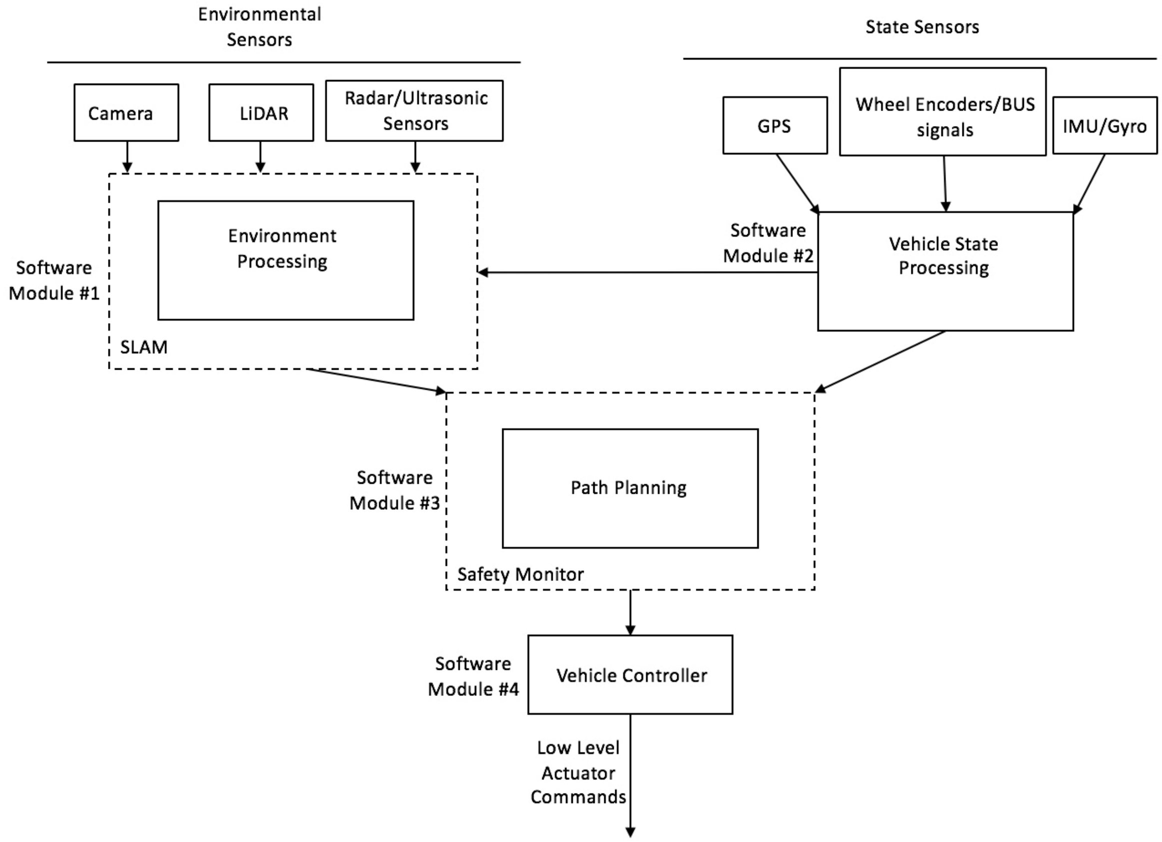


Figure 5: Software Stack Architecture

Vehicle State Estimation:

The group's goal for the vehicle state estimation module is to integrate sensors to correct for each sensors inherent errors (noise, drift, biases) while leveraging their strengths (the accuracy of GPS, the update rate of an IMU). The estimation suite will provide the vehicle's current position, velocity, and orientation to the path planning software module. Further estimation of critical safety parameters such as vehicle and tire sideslip will be performed as well. A fast update rate will be essential to track the dynamics of a racing Indy Car, so the fusion of high update rate sensors (such as IMUs) with stable but slower update rate sensors (such as GPS) will be imperative.

Simultaneous localization and mapping (SLAM):

SLAM will aid in path planning and general semantic awareness of the vehicle. An accurate time-evolving map of the race environment will be created to define not only racing lines but also safety hazards. Our initial approach for SLAM leans on building an accurate map of the racetrack through iteratively combining LiDAR scans with positioning from our state estimation software suite. The map will be augmented with semantic information through object detection and tracking to include the other vehicles into the map.

While current work has shown great success in combining LiDAR with GPS/INS navigation solutions for map building, testing is needed to validate these methods in the extreme dynamic environment of the competition. If needed, visual methods can be incorporated into the SLAM system to increase performance and robustness. SLAM can be approached with either filtering or nonlinear optimization methods, both of which will be investigated during the simulation phase for performance and potential integration into the state estimation system.

Path Planning:

A critical aspect of vehicle automation is the ability to detect both static and dynamic objects and plan a path of travel that assures no collisions will occur. GAVLAB has extensive experience working with safe path planning. One previous method GAVLAB has implemented for safe path planning is tracking a "ghost" vehicle and using Proportional Navigation (Pro-Nav) in conjunction with non-linear model predictive control to successfully evade oncoming vehicles, as shown in Figure 6 [3]. New path planning techniques will also be investigated.

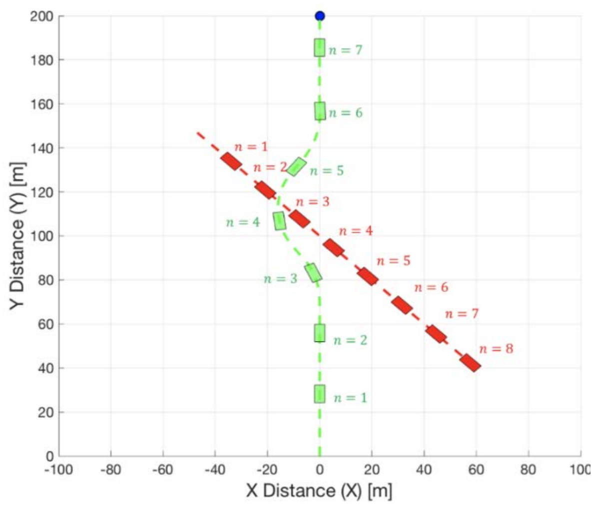


Figure 6: Collision Avoidance

One potential new methodology to be explored originates from The University of Michigan's study of reachability-based trajectory design for high dynamic platforms. Their research showed that even in randomly generated environments, a quadcopter can navigate the environment using accelerations up to 5 m/s with zero collisions [2].

Vehicle Control:

The objective of the control team is to ensure following of the path determined by the path planning module at the highest speed possible, while still maintaining stability. To accomplish this, the vehicle must be able to be held right at the edge of tire adhesion, which introduces complex dynamics. To combat this problem, advanced control architectures, such as NMPC or adaptive control, will be employed to ensure that the vehicle follows the commanded path. With the speeds and extremely dynamic environment present in racing, maintaining precise control of the vehicle is imperative to avoid scenarios of high consequence, whether collision or time lost.

Testing

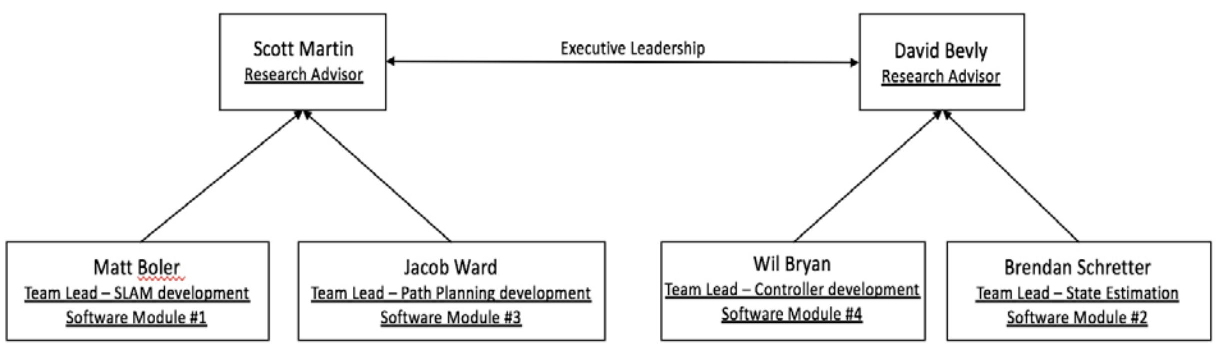
The GAVLAB does a substantial amount of work in vehicle automation and algorithm development, as discussed in prior sections. GAVLAB often works with real-time implementation of these algorithms on various vehicle platforms, which has driven the development of many different test environments.

One of the most critical aspects of algorithm development is ensuring expected performance on non-linear systems before any physical implementation of the algorithms occurs. CarSim and Gazebo are commonly used for this purpose within the lab. CarSim is a high fidelity vehicle simulation environment that is commonly used as truth when comparing simulation results from other environments. CarSim allows the user to build a vehicle from the ground up, specifying hundreds of vehicle parameters. Furthermore, CarSim allows the user to define non-linear tire models and import various sensor models for use in testing control algorithms. Gazebo is a slightly lower fidelity simulation environment, but is more suitable for testing real-time code. Gazebo interfaces with the Robot Operating Software (ROS), which encompasses Python/C++ algorithm classes. This makes Gazebo the ideal platform for testing real-time code before applying it to a physical vehicle. For more information regarding these environments, please reference [1].

The state of Alabama has laws that allow for the testing of autonomous vehicles on public roads. While it is unlikely the GAVLAB will soon run a car fully autonomously on public roads, the ability to test various partial automation functions on passenger vehicles is employed regularly. The GAVLAB leverages a large number of high-quality sensors that can be mounted to one of the lab's test vehicles in order to test algorithms such as SLAM, controls, and estimation on our test track and public streets.

Overall Approach to Project Management

Autonomous Tiger Racing will be led by the GAVLAB directors, Dr. David Bevly and Dr. Scott Martin. The team members listed above will lead subgroups for SLAM, controls, estimation, and path planning comprised of other engineering students at Auburn.



Fundraising

Auburn's Samuel Ginn College of Engineering plans to solicit sponsorship and corporate donors utilizing the professional fundraising staff in the college's Engineering Development Office.

References

[1] R. Brothers, D. Bevly, "A Comparison of Vehicle Handling Fidelity Between the Gazebo and ANVEL Simulators", In *Proceedings of the Ground Vehicle Systems Engineering and Technology Symposium* (GVSETS), NDIA, Novi, MI, Aug. 13-15, 2019.

[2] S. Kousik, P. Holmes, and R. Vasudevan, "Technical Report: Safe, Aggressive Quadrotor Flight via Reachability-based Trajectory Design," *arXiv:1904.05728 [cs]*, Jun. 2019.

[3] R. Shaw, D. Bevly, "Obstacle Avoidance of an Unmanned Ground Vehicle using a Combined Approach of Model Predictive Control and Proportional Navigation", M.S. thesis, College of Eng., Auburn University, Auburn, Al., 2018