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Using Quanser Platform to Introduce Engineering Technology Students to Autonomous Vehicles

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Abstract

The area of autonomous vehicles is not new, but the latest advances in various technologies gave it a new boost in the last decade and it keeps growing in interest. However, undergraduate curricula rarely include courses specific to this area, which is considered mostly an interdisciplinary graduate field. While numerous programs introduce students to the background needed to understand and approach the field, specific work on autonomous vehicle projects is left for extracurricular activities or student clubs, and eventually for senior design (capstone) projects. This paper presents the work of a team of electrical engineering technology (EET) students on an autonomous vehicle project using the QCar from Quanser, with mentorship from a graduate student in mechanical engineering. The paper discusses the teamwork collaboration, the learning curve, the motivation built by the availability of a Quanser student competition, and how the work was integrated into a senior design project for the engineering technology students.

Introduction

The area of autonomous vehicles has seen growing research interest in recent years, driven by advances in modern technologies, especially related to communication systems, sensors, and vehicular networks. This is a highly interdisciplinary field sitting at the crossroads between the traditional mechanical, electrical and civil engineering, with the modern sides of embedded systems, digital technology, robotics and mechatronics, sensors, wireless technology and networking, transportation and vehicular networks technology, cybernetics and artificial intelligence, and more [1-4]. The interdisciplinary nature of the field leads also to an interdisciplinary educational approach [5-6]. However, there are not many undergraduate or even graduate programs focused on autonomous vehicles and the specialization is most of the time left for extracurricular activities or student clubs [7], or capstone projects at the undergraduate level, with the field being mostly considered for graduate-level research work. In this context, Quanser [8] established itself as a leader in autonomous vehicle platforms for research and education. In particular, Quanser provides a self-driving car studio, specifically designed as a multidisciplinary laboratory for autonomous vehicle control and mobile robotics, to engage students in learning the basics of the field as well as pursuing research with hands-on experiences about self-driving vehicles. The Quanser platform provides an opportunity to explore camera-based vision programs and dynamic environments. To promote students' learning and engagement, Quanser also supports a highly competitive American Control Conference (ACC) Self-Driving Car Student Competition. The QCar from Quanser is highly used in autonomous vehicles research as shown in recent literature [9-12], including at the undergraduate level [13]. Other undergraduate level projects related to autonomous vehicles are also presented in literature [14-16]. Various programs started also to introduce courses specifically designed for autonomous vehicle education or to discuss the specific challenges of it [17-21].

Team Selection and Teamwork

The College of Engineering at Old Dominion University (ODU) acquired a set of two QCars from Quanser, Figure 1, to be used for autonomous vehicle training and education for students from different departments, both at the undergraduate and graduate levels. Access to the laboratory housing the QCar platform is opened to all students and the coordinating team includes faculty from different engineering departments, mainly Mechanical and Aerospace Engineering (MAE) and Engineering Technology (ET).

Figure 1. The QCar from Quanser and the Training Path.

Students selected for the training on the autonomous vehicle platform are expected to learn to operate and program the QCar, to test and characterize the QCar platform including the dynamics, sensors, and actuators. Students are expected to design motion planning and control algorithms to navigate an urban environment, considering the presence of stop signs, stop lights, as well as the addition of a second vehicle, and they are asked to prototype their algorithms in the Quanser Interactive Labs (QLabs) simulation environment.

As part of the initial efforts to train students on the autonomous vehicle platform and to stimulate engagement with the project, the investigators recruited a team of undergraduate students to work toward a self-driving car competition organized by Quanser at the ACC that takes place every year in July. The instructors team included two faculty from EET and two from MAE, combining expertise in electrical engineering, communication systems and IoT, and mechanical engineering, automation, controls and robotics. The first ODU team selected was set up to participate in the 2024 competition. The first milestone for the student team was to prepare and submit their results to the qualifying round of the competition in April of 2024. The first team that worked on the competition comprised a few undergraduate students from MAE, a few undergraduate students from EET, and one graduate student mentor from MAE. The graduate student had a strong background in programming and robotic systems, as he earned an undergraduate degree in Computer Science and had completed an Autonomous & Robotic Systems graduate course prior to joining this project. This background helped the graduate student familiarize himself quickly with the hardware and software installation of the QCar platform. As the team formed and the project got started, the graduate student assisted the team members in learning coding and hardware nuances. He served as a mentor for the undergraduate students, as most of them had no previous background with Python coding, and did not have prior experience with hardware similar to that used by the QCar.

Quanser Student Competition as a Platform for Student Training

To structure the students' meetings and focus their efforts on a concrete goal, the team registered for the 2024 Quanser Self Driving Car Student Competition at the ACC. The team had its first meeting at the end of January 2024, which gave them approximately three weeks to become familiar with the platform before the competition rules were released. The core team consisted of two EET undergraduate students, three MAE undergraduate students, and one MAE PhD student who was selected as the team captain. Having a graduate student dedicated to managing the team's code and meetings was a great asset to keep the team focused and on track, while also providing valuable team leadership training for the graduate student.

The 2024 Quanser competition challenge was for the QCar to drive though a course as fast as possible while respecting traffic rules. The car had to stop at stop signs and red stop lights while also remaining within the lanes of the road. The competition was split into three stages: Stage 1 was to control a virtual vehicle using the Quanser QLabs simulation software, Stage 2 was validating the control algorithm on the physical vehicle, and Stage 3 was the on-site demonstration and competition at the 2024 ACC. The competition was very strong, with numerous teams participating, and most probably more experienced teams. For our group this was the first attempt of this competition, and our team did not advance beyond Stage 1. However, the faculty team considered the competition mostly as a motivation and a training platform for our students, and we encouraged the undergraduate students to continue their work and implement their code on the physical QCar to complete the competition circuit as part of a senior design project.

To prepare for the virtual competition the team captain set up a GitHub repository and included Quanser's demo code that was released for the competition. The students then worked through the example to understand how the different parts work, identified changes they would need to make for the competition, and determined what module(s) they would need to write themselves for the competition. Ultimately, the students identified the vehicle desired speed, steering controller gains, and path waypoints as key variables to the competition. They also determined that they would need to write some kind of perception module to identify stop signs and stop lights and control the car to apply the brakes. The students settled on a computer vision solution using OpenCV, with the idea that this would be easier to design and debug than a machine learning-based perception algorithm.

While the majority of the students in the team had either a minor in computer science or some interest in programming, the major challenges faced by the team stemmed from the real-time nature of the task, aspects of which they had no prior experience. The students had primarily worked with scientific computation and databases, which can have runtimes from seconds to hours. However, for real-time control software, the physical system continues to move and the QCar could easily drive off the road if the code executes slowly. Even delays on the order of 1 second can cause the control system to become unstable, driving the car off the road and leading to a massive time penalty. This required the students to reconsider many programming patterns that they were more familiar with. For example, they could not use large *while* loops to calculate anything in the control code.

The students were successful to work around the strict requirements for real-time control by the completion date of the project. This is a critically important skill, especially for students with a background in software and an interest in control. The students were also able to implement the image recognition module, and they developed several clever shortcuts to minimize both i) how often the image recognition code needed to be run, and ii) how much processing the image recognition code had to do. This challenge took the greater part of February through April, and the students realized at the time of the Stage 1 submission that they needed to run the computer vision code in a separate thread for the control code to remain stable. Ultimately, this came down to a lack of institutionalized meta-knowledge within the team, which is a common challenge when creating a new student team with no prior experience with autonomous driving. For future iterations of the competition, we expect many of these challenges to be mitigated by veteran student team members and an established codebase. Since the ODU team did not qualify for the next stage of the competition, most of the team members moved away from the project. It was the EET student group that took over the challenge to continue the competition project into their EET senior design project. The first stage of the competition and working in a larger group, including the mentorship of the graduate student, helped the EET students to develop the background needed. At the same time, this larger team phase contributed to develop the interest in the project as well as the confidence needed for the students to assume the competition challenge as their senior design project. The part that the EET students were to complete for their senior design project was focused on completing Phase 2, implementing the student team code on a physical QCar, and Phase 3, completing and recording a video demonstration.

EET Curriculum Considerations

From the initial student team that started working with the QCar platform it ended up with a group of two EET students to continue the initial work into a senior design project. Because of this, some curriculum considerations of the EET program are included here. The College of Engineering at ODU is one of the few in the nation to include an Engineering Technology (ET) department along with the traditional engineering departments. The ET department includes programs in electrical, mechanical, and civil engineering technology and recently added a manufacturing technology program. Bachelor's Degrees are offered in each of these programs, but no graduate program in engineering technology is offered at this time, with students interested in graduate degrees usually continuing with either traditional electrical, mechanical, or civil engineering departments or more often with engineering management master's degrees. The EET curriculum includes core courses in electrical circuits, analog and digital electronics, microprocessor-based design, power systems and electrical machines, and frequency analysis along with analog and digital communication systems. At the upper level, elective courses expose students to wireless communication systems, computer networking, smart grids and advanced embedded systems design. Moreover, through senior design projects, students may dive deeper into specific topics and investigate areas of Internet of Things (IoT), smart systems, software defined radios, robotics and automation. While the curriculum prepares the students for basic programming skills, as well as electronics and hardware design, very often, for advanced senior design project topics as it was the case of this autonomous vehicle project, students had to go beyond course level and investigate specific software and hardware platforms.

EET Senior Design Project Delivery

In recent years, the field of autonomous vehicles has gained significant popularity, often with substantial support from the industry. In academia, this trend has directly influenced research interests and student capstone/senior design projects. Following these current interests the ODU College of Engineering is currently developing an Autonomous Vehicle research group, including faculty and students from all engineering departments. The first work of this group is presented here and involved a student team preparing for the Quanser competition, with a senior design project on autonomous vehicles using Quanser's QCar platform following this submission. To ensure proper delivery in terms of academic requirements and project objectives, the senior design project work was divided into several phases: (1) Literature Review, (2) Project Planning, (3) Project Development and Implementation, (4) Project Testing, and (5) Project Final Report and Presentation.

A team of two EET students worked on the autonomous vehicle senior design project, which was delivered at the end of the Fall 2024 semester, one semester after the competition application. The project utilized camera-based programs to scan the environment, leveraging the Robot Operating System 2 (ROS2) and Python programming language. To achieve autonomy, the QCar operated independently, making decisions and navigating based on inputs from its cameras. Path planning, cameras, and algorithms developed or refined by the students worked together to enable the QCar to complete its course while adhering to traffic rules. The project goals included several specific tasks for the QCar:

- Stop at red traffic lights and pause for three seconds at stop signs before resuming its path.
- Start at a known location and complete a full revolution around the track while staying within the lanes.

The students began by working with a virtual simulation tool, QLabs, to test the basic functionality of the QCar, such as path planning, camera activation, traffic light detection, and stop sign detection. Transitioning from QLabs to the physical QCar platform required a deeper understanding of Python programming and of the algorithms developed by the larger student team of the Phase 1 of the competition. According to experimental results and demonstrations, the QCar had successfully completed the following tasks:

- Drive through its given path correctly.
- Detect stop signs and then stop for three seconds.
- Stop at a red traffic light and then continue its path when it turns green.

Figure 2 illustrates the demonstration of traffic light and stop sign detection, showcasing how the QCar identifies these features using regions of interest (ROIs). This project utilized the 2D Camera Serial Interface (CSI) located at the front of the QCar for camera-based vision programs. Traffic light and stop sign detection relied on live camera feeds. ROIs were defined to narrow the focus of the program to specific areas. These ROIs were created using x and y coordinate systems, with rectangular areas determined by the proportions of the camera feed's width and height.

Figure 3 displays the integration of software and hardware in following the desired waypoints set in the Vehicle Control program. The intended path of the course is shown in orange, while the actual path taken by the QCar is shown in blue. The close alignment of these paths demonstrates the successful collaboration between software and hardware components.

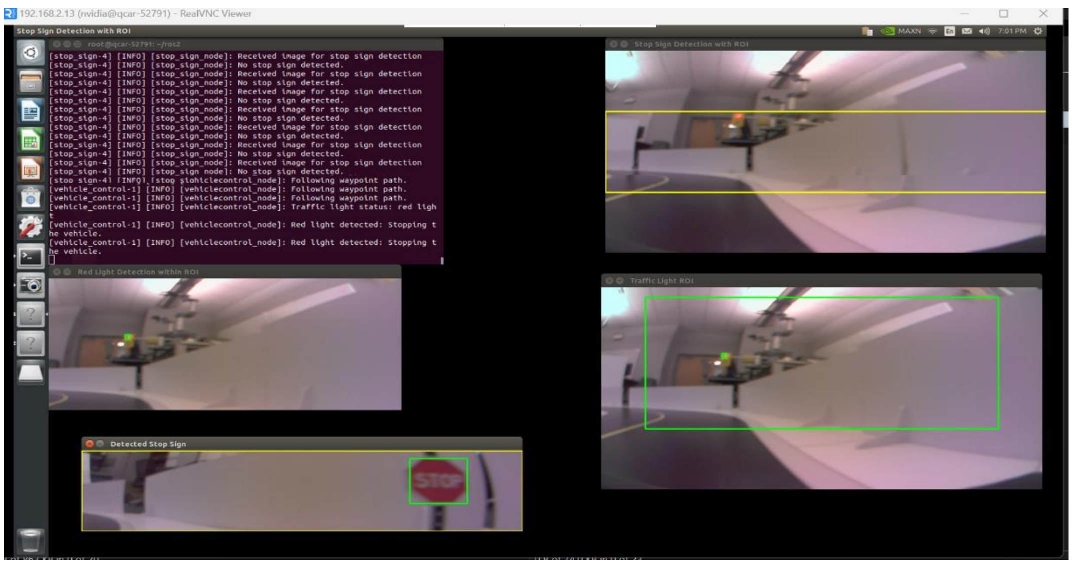

Figure 2. Traffic light and stop sign detection

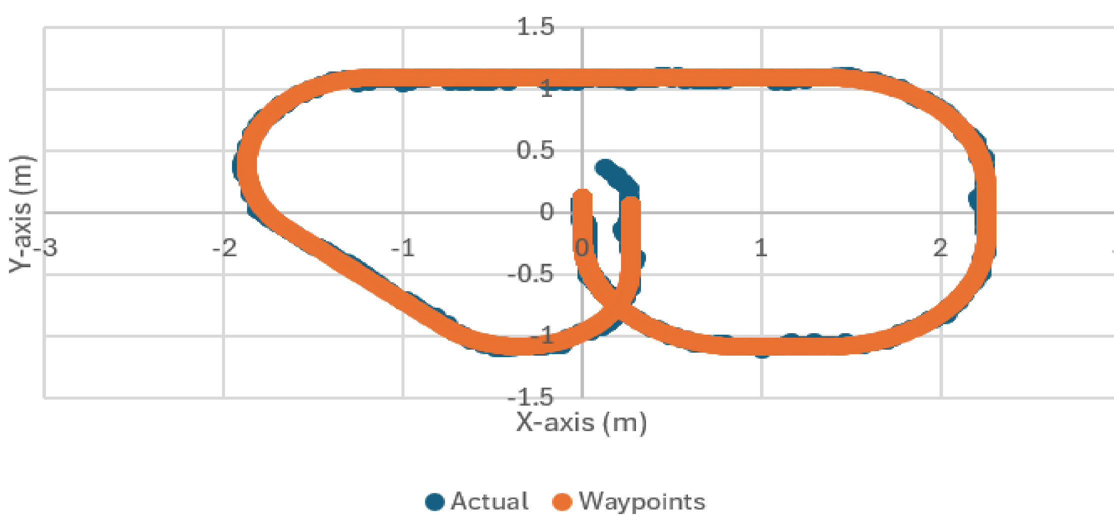

Figure 3. Actual and desired waypoint route

The EET students completed the project, as was originally proposed by the competition's challenge, and Figure 4 shows them presenting the project at the end of the semester senior design project expo organized by the college. The delivery process ensured that the project met its academic requirements and project objectives while also preparing students for future careers, and engaging them in interdisciplinary teamwork collaboration, advanced programming, algorithm development, and autonomous vehicle systems.

While for this first time of working with the Quanser platform and participating in the self-driven car student competition the authors did not complete any assessment or surveys with the student group, it is still to note that participating students were very excited about the work and found the training very valuable for their future careers. The faculty recognize that allocating more time would have made a big difference in preparing for the competition, and for future iterations of the project an earlier starting point would be very important, with team recruiting being better done in the fall semester. However, with only few months to work on the project and very basic background to start with, the first student team accomplished the most important challenge of submitting for the stage 1 of the competition. It was also notable that the EET student group took over the task of completing the competition challenge, even though outside of it, and formalized their work in their senior design project. Based on the feedback they provided to the faculty, they were excited to see how what they thought as a limited background from their undergraduate engineering technology program was in fact a very good starting point to become proficient in using the software and hardware of the QCar. They also mentioned how the training they got through this project opened for them a broader range of employment opportunities.

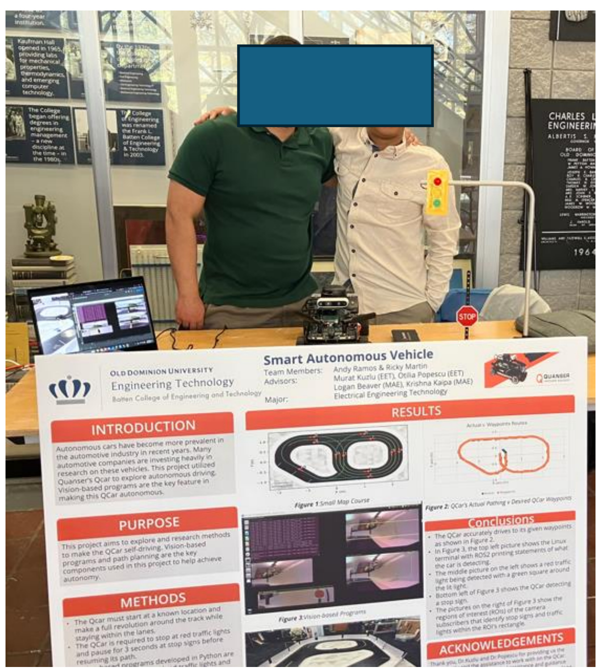

Figure 4. Students Presenting their Autonomous Vehicle Senior Design Project

Conclusions and Future Work

This paper presented the first work done with the QCar platform from Quanser by the newly developed Autonomous Vehicle cluster at ODU. A first student team was formed and the Quanser student competition was used as a guide in training the initial team. The work was continued into a senior design project by a small team of EET students. The work was notable especially because the background of the EET students was limited and they had to put a lot of effort in building up the needed skills. Moving forward, the faculty team will focus on recruiting a larger interdisciplinary student team and use the experience gathered with this first round in future projects.

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