Final report: Control & Semi-autonomous Driving as Challenge-based Education

Date: Friday 8 October
Main applicant: S.Haesaert, W.H.A. Hendrix.
Co-application: M.C.F Donkers, Siep Weiland, M. Schoukens
Capacity group: Control systems group

Table of Contents

1. Background and justification of the project

Preparing future engineers for real-life challenges.

With new technological advances, the market for high-tech products incorporating advanced computer electronics is growing. Pushed by the downscaling of sensors and processors, a ubiquitous embedding of digital components has been observed. These advances allow for new and anticipated smart systems that can operate autonomously and interactively with their environment. In control engineering, this has caused a shift from classical control engineering, which mostly focused on stabilization, disturbance attenuation, and reference tracking of dynamical systems, to a new era of engineering systems where control, computation, and communication are tightly integrated into so-called cyber-physical systems [1]. Additionally, with the increasing embedding of autonomy in the daily lives of people, adaptability to new scenarios and the interaction with humans is becoming a new challenging element in control engineering. Consider as an example an autonomous car (Figure 1) in which the control structure includes aspects of control and planning but also sensing and perception. Moreover, the structure is built up in a networked-based way and build by a multidisciplinary team of people.

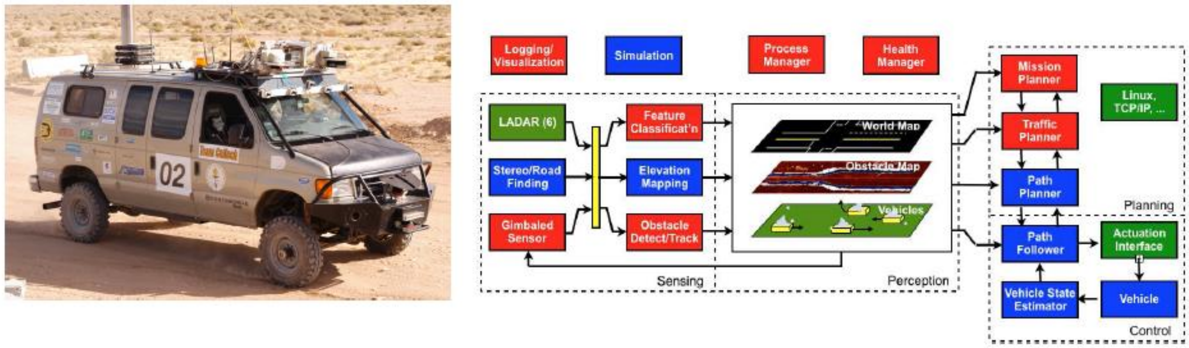


Figure 1: DARPA Grand Challenge "Alice" Caltech's entry in 2005 & 2007 and its networked control architecture Figure 1.23 in Feedback systems: An introduction for Scientists and Engineers By K.J. Astrom and R.M. Murray.

TU/e promises to educate future-proof academic engineers [2]. To follow and anticipate the new technological advances in control engineering and the requirements this imposes on future engineers, we would like to pilot a small-scale challenge-based education project. As pointed out in [3], challenge-based education takes a prominent role in the educational vision of the university. By 2030, challenge-based education will be a core part of the student's portfolio [3].

Original project goals

With this educational project initiated in 2019, we want to explore challenged-based learning for control. We wanted to enable students to learn about real-life challenging control problems present in semi-autonomous driving and to get hands-on experience.

Therefore, the goal was to embed a challenge-based learning course as a pilot into the curriculum of students graduating at the control systems group that are doing their master's in either the *Electrical engineering, Automotive Technology* or the *Systems and Control* masters program. For this group of students, working in a team on a complex control problem that interfaces with real societal issues will be a valuable addition to their curriculum.

Goals

- Give the staff of the control systems group the opportunity to gain experience in challenge-based learning and to investigate the following questions:
  - whether challenge-based education has a positive effect on the maturity of graduate students?
  - How to teach control systems as an interdisciplinary field?
  - How much time per student do we need?
  - How much time & money does it take to maintain complex enough lab setups that offer a real challenge?
- Support the development of a long-term strategy for incorporating challenge-based education within the MSc education of the Control Systems group.

Boundary conditions

- A course and challenge that can serve for challenge-based learning for a long enough time to make it worth the investment
- setups that are safe, affordable, and dummy proof so that students can learn how to solve open problems in engineering without injuries and without costing us a lot of money when they break something.

The topic "semi-autonomous driving" for challenged-based education has been accompanied by a small-scale setup for semi-autonomous driving. This setup represents the increasing complexity in control design, the multidisciplinary aspects, and the human-in-the-loop and data-driven technologies. And though many steps have been made towards autonomous and semi-autonomous driving, a lot of open challenges remain. As such, the setup offered an ideal pilot for continued hands-on challenge-based learning. The small-scale setups have been chosen to be safe, affordable, and dummy proof so that students can learn how to solve open problems in engineering.

Expected educational innovations:

- **student-driven learning** by embedding challenge-based education in the MSc program
- **professional skills with respect to coding** to prepare the graduate students for industry and graduation.

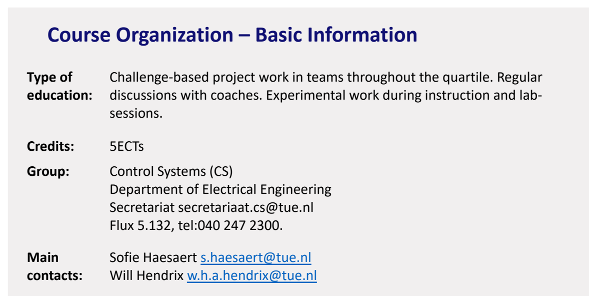
2. CBL pilot: Control challenges in autonomous driving

This section details the CBL pilot that we designed and executed in this innovation project.

Pilot course 2020/2021

We gave the challenge-based project as part of 2 courses that were running in parallel to 10 students.

- EE and AT MSc students taking the 5LMF0 course
- S&C MSc students taking the integration project 5SC26

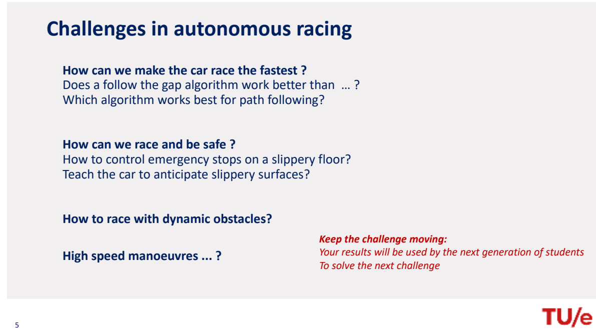


1 project 2 courses 10 students

We did the project with 10 students divided into two groups. Each group was responsible for 1 setup. The groups consisted of people working on the learning goals of two different courses, as mentioned before.

The challenge

In the first year of the project, the students received a car that couldn't drive autonomously. Therefore, a lot of basic challenges were still possible. To give the student an idea of what was feasible, we suggested some basic challenges to them.



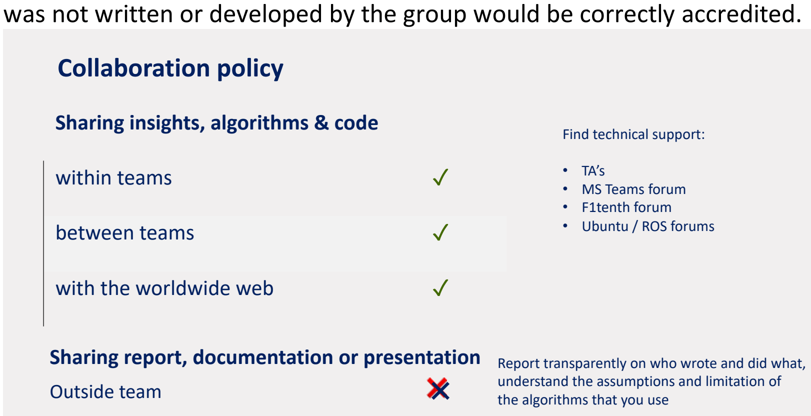
Supervision

We divided the supervision into several types:

- **Coaching:** Academic and support staff 1 hour per week coaching per group
- **Technical support:** Student TAs familiar with the setups
- **Domain experts:** Academic staff available for specialized coaching meetings
- **Students:** We allowed students to use each other as sources of information (including the other group). See also collaboration rules. Peer review for coding was also used.

Collaboration policy

We opened up the communication channels between the student groups by giving them an explicit collaboration policy. We allowed them to share code, insights, and algorithms with the one major condition that any code that was not written or developed by the group would be correctly accredited.



Organization of the project

As planned, we divided the project into three phases. A start-up phase in which we help them get started, a challenge phased, and finally, a knowledge transfer phase in which they round off the project and deliver their results in a reusable fashion.

Phase 1: Start-up phase

a. Tutorials to get you familiar with the car
b. Formulate project plan (and start working)

Deliverable
D1. Project proposal

Phase 2: Challenge phase

a. Access the lab to work on your project goal
b. Meet with coaches to discuss the progress

Deliverables
D2. Peer code review
D3. Peer review

Phase 3: Knowledge transfer phase

Final assessment

Deliverables
D4. Code & demonstration
D5. Project report & presentation
D6. Peer review.

The approach differentiated itself from the standard integration project in the following aspects:

Student-driven

- Students choose what type of problem they want to solve. They also define their own project plan.
- Students define their personal learning goals as a refinement of the learning goals of the course.
- Students can ask for help from one of the domain specialists on vehicle dynamics, machine learning, control, and perception

Mixed groups

- The students joining this class have backgrounds in AT, EE, and S&C.
- The S&C students join the project on autonomous driving but do not join the course 5LMF0. They have mostly the same learning goals with some differences in the goals wrt soft skills. S&C students need to ensure that their personal learning goals and tasks include enough control-related areas.

Student responsibility

- The students are made aware that the next years' students will use their results
- The students contributed substantially to the evaluation of the course.

Software development

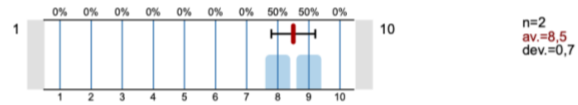
- The small race cars run on ROS. This is the Robot operating system with which you can code packages in Python and C++. Understanding ROS and working with ROS was a substantial part of this project. Software development is becoming more and more important for control engineers since control algorithms are embedded in larger software packages.
- We enforced good coding practices by letting them peer review code.
- We did not oblige the students to simulate and develop algorithms in Python or C++. Instead, they wrote most of their simulations in Matlab and only translated the algorithm to Python when they were finished.

3. Evaluation

Student evaluations

The students evaluated the course positively but also gave a lot of points for improvement. You can see this in the overall evaluation of the project course 5LMF0:

1.3) On a scale of 1 to 10, how would you rate this project (with 10 being "excellent")?



We also arranged a meeting on the 15th of July with the students. 5 students out of the 10 students that did the course joined this meeting. We had an hour-long discussion on what were the weak points of the CBL project and how we could improve it in a way that would preserve the original goal of the CBL project. This included inter alia suggestions to improve specific hardware elements, tutorials and to reschedule some deadlines.
What was very remarkable is the fact that 50% of the student took a day in their holiday to come to the university and to help us improve this CBL project. Even after the project, students still showed a high amount of ownership and responsibility towards the project.

Our evaluation

1. How much time & money does it take to maintain complex enough lab setups that offer a real challenge?

   It costs a substantial amount of time to build and maintain lab setups and their educational environment to such a degree that they can be used for education.
   - The used software needs to be updated regularly: Ubuntu, ROS, Python, and the used packages regularly change version, and the cars should be updated to avoid working with unsupported software
   - The manuals on the software and hardware of the cars need to be at a very level, substantially above the level that is needed for basic research. This also includes having guides and tutorials for setting up your own computer and starting to use the lab setup
   - Student work needs to be incorporated in the new software releases of the car to promote new challenges and to showcase the impact of student results. Of course, this is limited to successful implementations.

   We hope the effort can be worth it if the setups are not just used for 1 CBL course, but if
   - Several exactly the same setups are used, a part of which is reserved for the CBL course, and 1 or 2 are used for longer development cycles of the cars and for research with graduate students
   - The cars are also used for in-depth research projects in MSc graduation projects
   - To support state-of-the-art research in the group.

   We are now still focusing on making the software environment better and allowing for a more improved CBL project based on the reviews of the pilot course. However, looking at the future, we hope that we can use synchronize these teaching efforts with our applied research effort. From our experience, we notice that the setup that has been developed for challenge-based learning can directly be given to any MSc student or Ph.D. researcher. But the opposite doesn't hold. Setups only require a short development cycle before they can be used for research as a lower standard in documentation and tutorial developments is generally well accepted.

2. How much time per student do we need?

   Throughout the course, coaching time is limited to about 1 hour a week per group of 5 students. Aside from that, students can need one-to-one teaching on specific topics. This year, all groups arranged one or two meetings with Tijs Donkers to discuss vehicle modeling.
   The time investment for this project is especially in the good preparation of the course.

3. Does challenge-based education have a positive effect on the maturity of the graduate students?

Throughout the course, we saw the students grow as a group and individually. We noticed that forcing students to speak out their learning goals and to remind them of these personal learning goals was an effective manner to coach the students.
The setup of the course where the code of the students and their results are available to the next groups and where we gave them quite some freedom with respect to collaboration really spurred the feeling of pride and ownership. Students arranged an intergroup meeting to share experiences and used this to adjust their plans. Students also showed up to give very extensive feedback on the project.

4. How to teach control systems as an inter-disciplinary field?

   This year we had a diverse group of students joining the challenge. We asked students to make groups maximizing diversity.

5. Student workload versus learning efficiency

   One of the major issues with the course right now is the workload and the limited time that students have to get started with the project. In an ideal situation, this CBL project would be spanned over 2 quartiles and have more than 5 ECTs. Assigning 10 ECTs purely to the project could be too much, but by combining the course with optional modules on vision, vehicle dynamics, … , we could add more content to the course, spread out the project, and give students more time to digest the project. This would impose difficulties with respect to planning the course.

4. Dissemination

Local dissemination actions:

- Education day Electrical Engineering: A poster was presented to the electrical engineering faculty colleagues during the education day.
- Curriculum committee Electrical engineering: Will Hendrikx and Sofie Haesaert were part of the Electrical engineering curriculum committee that is designing the challenge-based aspects of the next BSc curriculum. Experience in setting up this project is very valuable for setting up the BSc curriculum.
- The Dynamics and control group has followed our example a while ago and has also set up a CBL like project based on the same type of cars for honor students.

Planned dissemination actions:

- The results of the pilots will be discussed and published in educational outlets within the control engineering community.

5. Future plans

Due to covid, we got a bit delayed in our plans and have only been able to run the CBL project once. In Q4, the project will run for the second time. We plan to evaluate certain aspects of the project after this second run. This includes aspects such as the use of knowledge transfer in CBL projects, the use of code development, and peer reviews. Additionally, we still need to evaluate the time investment to keep the course running after it has been developed fully. Therefore, we are currently working on updating the software and hardware environment of the course.

Meanwhile, we are discussing the future of this project beyond this academic year.

- We are discussing options to integrate the project with the new AIES master.
- Starting next year, the integration project 5SC26 will incorporate part of the innovative educational elements of the 5LMF0 course, such as the requested learning goals.
- We are looking at revising the S&C curriculum, and we are taking the results of this project

Technische Universiteit
Eindhoven
University of Technology

/ Department of
Electrical Engineering

Control challenges in (semi-)autonomous racing

5LMF0

Dr. Sofie Haesaert
ing. W.H.A Hendrix
Dr. M.C.F. Donkers
Prof. dr. Siep Weiland

Where innovation starts

Version: April., 2021

Contents

1 Introduction

This study guide provides the necessary information that is needed for you to work on the racing challenge. This challenge-based course is carried out in the 4th quartile of the first year of your graduate studies and is accredited with 5 ECTS. In this document, you will find the motivation for the project, its objectives and limitations, its deliverables, the important deadlines, how you will be supervised, and how your work will be graded. During the course, you will receive additional information through Gitlab, the teams' environment, and canvas. Assignments can be submitted via email and via GitLab.

Increased capabilities for sensing, processing, and communication has enables the development of advanced perception, planning and control methods with which cars can drive autonomously. The main challenge is the development of methods that ensure the safety of autonomous driving methods under all operating conditions. In this course, students will work in teams of maximally 4 and define their own challenge that includes sensing, navigation, control, and safety problems. They will develop, implement and test their results on a 1:10th scale race car with extensive sensing and control capabilities. Safety-critical scenarios present in semi-autonomous racing such as high-speed maneuvers, obstacle avoidance, and race pilot assistance are key drivers for possible challenges.
The project will consist of a start-up phase where students are coached intensively via lab sessions. After this, there will be the challenge phase. Finally, students will have a knowledge transfer phase where they report on their findings and contribute to the codebase and manuals for the next group of students.

Given the format of the course, the number of groups is limited to 2 in 2021.

Material:

[1.] O'Kelly, Matthew, et al. "F1/10: An Open-Source Autonomous Cyber-Physical Platform." arXiv preprint arXiv:1901.08567(2019).

[2.] Seshia, Sanjit A., Dorsa Sadigh, and S. Shankar Sastry. "Formal methods for semi-autonomous driving." 2015 52nd ACM/EDAC/IEEE Design Automation Conference. 2015.

2 Course Setup

2.1 General Information

Course title:	Control challenges in autonomous racing
Course code:	5LMF0
Period:	Quartile 4
Program:	Graduate School TU/e, Elective. Not an elective for students in Master program Systems and Control, these student should follow 5SC26 instead to join the project work.
Type of education:	Full time. Kickoff meeting on the 20th of April. Challenge-based project work in teams throughout the quartile. Regular discussions with coaches. Experimental work during instruction and lab-sessions.
ECTs:	5 (around 16 hours per week)
Course subject:	The course on control challenges in semi-autonomous racing is a challenge-based course in which students collaborate in teams to apply and expand their knowledge on systems and control for the modeling, validation, control and analysis of an autonomous racing vehicle. The control design and implementation has to be carried out by teams and should result in well documented code, a presentation and a report by the end of the project.
Lecturers:	dr. Sofie Haesaert (responsible lecturer) ing. W.H.A. Hendrix dr. M.C.F (Tijs) Donkers *(vehicle dynamics coach)* prof. dr. Siep Weiland
Group:	Control Systems (CS) Department of Electrical Engineering
Secretariat	secretariaat.cs@tue.nl Flux 5.132, tel:040 247 2300.

2.2 Learning Outcomes

The students should

LO.1. Be able to specify a control challenge including

- Writing a project proposal for a safety-critical control problem in autonomous driving that advances the available state-of-the-art, that includes goals, quantitative objectives with deadlines, technical challenges, and solution approaches.
- Specifying an unambiguous set of objectives, requirements for a chosen set of scenarios. This includes robustness, safety, navigation specifications and performance objectives.

LO.2. Be able to design a model-based control strategy by

- Applying one or more of the basic techniques to derive and validate a mathematical model that represents the relevant dynamics. This model can be derived from first principles and/or experiment data or a combination of both.
- Understanding and build upon available methods on sensing, navigation, control and safety problems for (semi-)autonomous driving.

LO.3. Be able to implement and validate the control strategy by

- Developing well-documented code for ROS that implements the control strategy
- Design experiments that enable the validation of the control strategy
- Perform experiments while understanding and taking into account safety issues and system constraints.

LO.4. Be able to assess the risks of their method and explain the limitations and/or generality of their solution methods

LO.5. Be able to apply professional practices for code development such as use, maintain and contribute to a versioned code repository to achieve engineering goals and knowledge transfer.

2.3 Challenge-based Education

The course "Control challenges in semi-autonomous racing" is a challenge-based learning course. This means that there will *not* be regular class course hours. Instead students will have to define their own problem and work on a project to achieve the learning goals of this course. The course is set up such that students can always focus on "the next challenge" in autonomous racing. More precisely, challenges tackled by consecutive student teams can build further on the results and achievement of the previous cohort of students. This means that when the state-of-the-art changes, the challenges change with every edition of the course. To this end, results of the previous cohort need to be passed (documented) to the next cohort. This puts firm requirements on transferable knowledge and professional skills.

2.4 Position in the Curriculum, Assumed Prior knowledge

Required prior knowledge:	Control Principles of engineering systems (5SMC0) or other control courses
Valuable prior knowledge:	Prior experience with Python, or ROS and Matlab is advised, but can be mediated by following some beginners tutorials. Knowledge on basic vehicle dynamics, control, human robot interaction, or a combination thereof is preferred. Related courses are basic vehicle modeling and control courses including Vehicle Dynamics (4AT000), and Vehicle Control (4AT050), Automotive human factors (0HM310), or specialization courses in the systems and control curriculum.
Follow-up courses:	MSc courses in all fields of engineering, traineeship, graduation project.

Without some courses that could be useful for this challenge-based course (see valuable prior knowledge), your team contribution is likely to be disproportionate to the work of the other team members. In these cases, we discourage you to register for participate in this course.

2.5 Educational Format

Educational format
The course starts with a kickoff meeting that is held on 20th of April. There are 9 weeks planned to carry out the project in teams of maximally 4 students. Teams have regular (bi-weekly) discussions with project coaches and are required to schedule lab time for experimentation and implementation. The project ends with a report, code, and a presentation followed by an oral exam.

Teams
Every team works on one RC car and consists of maximally 4 members. Teams will be formed prior to the start of the quartile. Every team can subscribe to a preferred laboratory set-up. For practical reasons, team compositions cannot be changed after the first week. All teams are responsible for the organization, planning and distribution of the work among their members. Responsibilities and tasks among team members need to be clear and may be subject to questions from the lecturers. It is assumed that team members contribute in an equal manner to the project.

Outline of the Course
1. Start-up phase: During the start-up phase students will be provided a Formula 1:10th car (F1/10th), that is a 1:10th scale race car with ROS software. Through hands-on sessions students will be taught the necessary driving skills and programming blocks. This includes driving over a circuit and stopping for an obstacle. This phase will also require the students to find an interesting challenge-based problem and to find coaches to support them in solving this problem.
Deliverable 1: Project proposal with a challenge-based problem.

2. Challenge phase: During this phase students will work on their challenge. They will meet biweekly with their coach. The students will have to further define and solve sub-problems in semi-autonomous driving. This will include changes and adaptations of the sensing, navigation, control and safety algorithms in the F1/10th cars. Students develop and code algorithms that are tested and documented.
Deliverable 2: Peer review of the code repositories after the first half of this phase.
Deliverable 3: Peer review of each other's work in the team after the first half of this phase.

3. Knowledge transfer phase: During this phase students will present and compile the knowledge that they have gathered during the project. Beyond a standard report, this will also include all ROS code fragments and bug fixes. The importance of reusability or reproducibility of their results is stressed. By publishing this code on Gitlab and making reports of previous groups available to the next groups, visibility of the student's effort is made visible to the student community. Additionally, this allows students to tackle more challenging or diverse projects over the years.
Deliverable 4: Demonstration and code.
Deliverable 5: Final project report and presentation.
Deliverable 6: Peer review of each other's work in the team.

3 Deliverables and Grading

Intermediate assessment [20%]: Students are assessed based on **Deliverable 1** and students receive formative feedback during coaching sessions and via **Deliverable 2-3**.

> **Deliverable 1:**[Graded 20%] Present your project proposal explaining the what and why for this project. Video or equivalent material of controlled autonomous car that shows problematic behavior of the autonomous car for which a solution is needed Focus also on the Goals, Objectives, Technical Challenges and Approaches. (LO. 1)
> Deadline 14th of May
>
> **Deliverable 2:**[Pass/No Pass] Peer review of code (LO.5).
> Deadline 28th of May
>
> **Deliverable 3:**[Pass/No Pass] Peer review of team work.
> Deadline 28th of May

Final assessment [80%] The student groups will be assessed based on oral discussion together with the final deliverables that include code (demonstration), a report and presentation **Deliverable 4-5**. Individual grades can be adjusted based on the oral discussion and the peer reviews.

Deliverable 4: An advancement in the semi-autonomous racing with the lab cars *demonstrated* and delivered as code with documentation. Good coding practices include using unit tests and tutorials are advised (LO.5).

Deliverable 5: Final project report and presentation. The **report** consists of a quality documentation on the work performed in a maximum of 25 pages. It should contain the motivation for the project and the specifications (LO.1), the modelling and model-based algorithms, experimental results (LO.3), together with a discussion and assessment of the developed methods (LO.4). The report clearly indicates the individual contributions of the team members to the project. Every team will also give a 20 minutes **presentation** covering the highlights of the project. The questions after the presentation will count towards the oral defence of your work.

Deliverable 6: Peer review of each other's work in the team.

Final grade: The final grade is the weighted average of the final assessment and the intermediate assessment. Only passing grades for the final assessment count towards the final grade.Âă To pass the course need to achieve a passing grade for the final grade.

4 Scheduling and Calendar

Kickoff meeting 20th of April at 15:30. See canvas for more information on the rest of the schedule.

5 No Resits

It is important to remark that due to the teamwork of the project, there are no opportunities for resits of (parts of) this course. It is therefore important to adhere to the indicated deadlines of project deliverables.

6 Feedback and Evaluations

Comments and feedback can be provided through the canvas forum, by email or in person. Because of the novelty of this teaching format and the RC racing cars, we highly appreciate if you take the time to evaluate the course. In doing so you contribute in improving the curriculum of the graduate school of TU/e for the students after you.

Project execution

This section gives the overall timeline over which the project was executed and the changes that were made in the plans.

1. Implementation phase

August 2019-April 2021

a. Build the setup,
b. Developed software for setups
c. Developed Gitlab repository for students
d. Defined project as a pilot course for the EE curriculum of 2020
e. Submitted and received approval from OC for 20/21
f. Prepared educational material

Due to Covid-19, the planned trial run of the cars in the integration project could not be executed as the integration project had to go fully online.

2. Experience phase February 2020 – July 2021

- Started using the setups in an MSc internship project and BEP project.
- Teaching the course for the first time Q4 2020/2021: **"Control Challenges in autonomous racing" 5LMF0.** We have offered the challenge-based project as a course to 2 multidisciplinary groups consisting of Systems and Control students, EE students, and Automotive students that are specializing in Control Systems. This was offered as a challenge-based course will be a 5ECTs elective course for MSc students.

3. Decision making

- Positive outcome of course in 2020/2021
- Course will run again in 2021/2022
- Making plans for future

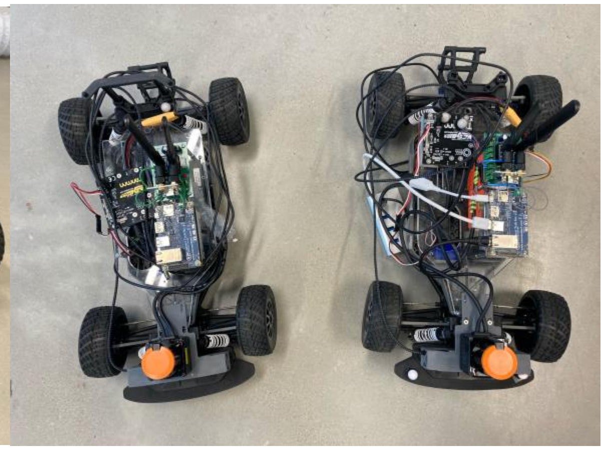
4. Work packages

6.1.1 WP1 BUILDING THE REQUIRED LABORATORY INFRASTRUCTURE

6.1.2

Task 1.1 Building and preparing the F1/10th cars

Progress: Two cars are in use. 2 additional cars will be built to enable more students to access to the cars. Additionally, some hardware components on the first cars will be improved.



Task 1.2 Setting up the ROS software framework and basic software for driving on loop/circuit
Progress: The software for the cars has been fully developed. Also, tutorials have been developed to guide students towards being able to let the cars drive in a loop. Further improvements are being considered based on the feedback from students that followed our pilot course.

The Robot Operating System (ROS) is often used as middleware for robots. ROS consists of tools and libraries developed by the robotics community and offered with an open-source BDS-3 license. Students will be allowed to use, develop and adapt packages in ROS to control the F1/10th cars.

Throughout the project, we will maintain open-source ROS libraries for the students to use. Though there is already software available for the f1/10th cars, we expect that getting the software to run for the latest version of ROS will require quite some work. To enable semi-autonomous driving, students need to be able to experiment with the people driving cars semi-autonomously. For the students, the real people will likely be themselves, and the cars will be tiny toy cars. Still, to make this more realistic for experiments, we will provide them with access to our motion capture system (task 1.3) and also with a steering wheel setup whose measurements can be read out (task 1.4).

Task 1.3 Interfacing with the Motion Capture system
Progress: This task has been executed.

The control systems group at electrical engineering systems has recently invested in a new Autonomous Motion Control Lab. This lab will combine research with drones, cars, and other autonomously moving systems supported by the staff of the control systems group. The new lab includes a top-notch motion capture system in which different objects can be tracked in 3D (6DOF) with high precision and high bandwidth. By embedding the challenge-based learning Lab in the AML, the students will be connected to and get to know the research and the people in the autonomous motion lab and have the opportunity to use the professional motion capture infrastructure for realizing their solutions. Thus, without becoming a full-time research project, this project will serve to inspire and motivate students by giving them exposure to the ongoing research in the control systems group and to the top-notch lab space.

Task 1.4 Build steering-input and camera input for semi-autonomous driving
Progress: This task has been executed. The camera input tends to give slow results, and this needs to be further evaluated to see whether there is a hardware issue. See 1.5.

In addition to the F1/10th cars, we will enable the use of sensors to measure and use driver behavior. This will include a basic steering wheel and camera. For this, a TA will program in Python an interface that *measures the steering angle. These programming will be made available to students as blocks and tools in ROS. Available resources for this include the following thread in ROS, several open-source Linux packages for commercial gaming wheels (url) including the available Python-based driver package in Github, and the online-available instructions for creating an analog circuit url.*

Task 1.5 Evaluate and update laboratory environment

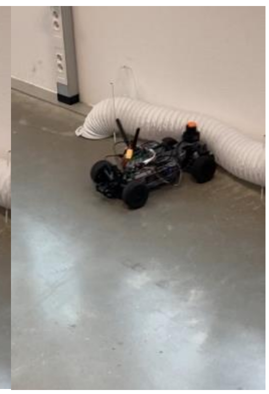
Progress: This working package is growing with time:

- Further extension with IMU sensors
- Improvement required of the brace of the lidar
- Investigation of the VESC software for the speedcontroller

We have already added safety barriers to the lab environment to avoid expensive crashes. See pictures below.

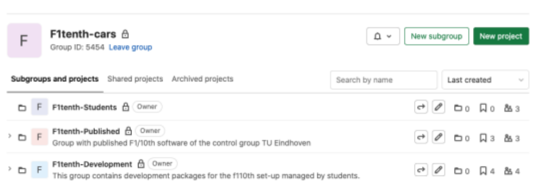
Based on experiences and possibly new insights the laboratory environment (car's HW/SW, sensor systems) might need small modifications.

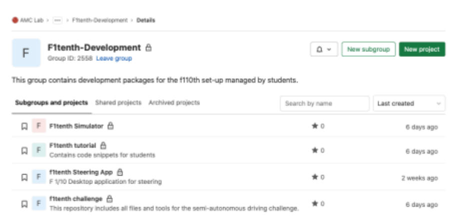




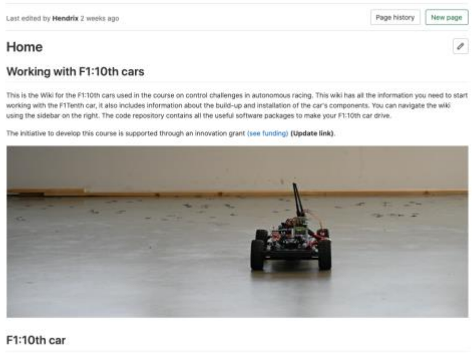
Task 1.6 Documentation and manuals

Progress: We have used the software and hardware manuals in the course and are now making updates. All software is being updated (Ubuntu 18, ROS Kinetic). This will enable the embedding of ROS SLAM methods.





See below fragments of the extensive wiki that includes the manual with information that students need to solve their challenge on the cars.



We have also made several tutorials to help students become familiar with the codebase and the car.

All software and hardware components and their system integration will be documented and made available as open-source (GitHub).
Manuals needed for students doing their challenged-based assignment will be made.

6.1.3 WP2 CHALLENGE-BASED ASSIGNMENTS AS PART OF THE CURRICULUM

Task 2.1 Design challenged-based assignment for a pilot in the Integration project (5SC26)
Progress: See also appendix for draft study guide.

- The course design has been approved by the opleidingscommittee for EE. We have now a course code 5MLF0 and will give the course in Q4 of 2020-2021.
- We are setting up tutorials that students can use to get hands-on experience with the cars early on.

This task prepares for offering the first challenged-based assignment to a pilot group of students in the Integration project (5SC26), this includes:

1. *Working out possible solutions ourselves (TA with CS-staff)*
2. *Deriving the required software components and documentation from the developments in WP1 to offer the students a starting point*
3. *Prepare introduction and training session*
4. *Agree on coaching style with all people involved.*
5. *Selecting students*

~~**Task 2.2 Supervise first groups in the integration project**~~
This was infeasible due to COVID. We were able to let 1 BSc project and 1 MSc project run with the setups.

Task 2.3 Design challenged-based assignment for ~~Q2, Q3, Q4~~ Q4
Progress: See also appendix
The project has been designed as a new course. This limits the run time to Q4, but it does allow us to give the course to more diverse students.
Similar to task 2.1 but now with possible adjustments based on the evaluation done in T3.1.

Task 2.4 Supervise ~~Q2, Q3,~~ Q4 pilot groups
Similar to Task 2.2 but now with possible adjustments based on the evaluation done in T3.1.

6.1.4 WP3 EVALUATION & DISSEMINATION ACTIONS

Task 3.1 Evaluate via pilot in integration project for S&C students
Progress: Due to covid, this task could not be executed. The BSc and MSc projects have been used as an informal evaluation.
In this task, the set of evaluation criteria will be defined as a first step. These criteria will be input to T2.1. As a second step, the evaluation of the pilot done by the selected students from the integration project (T2.2) will be done. This will result in points for further improvement in both the educational part and possibly the laboratory environment (input to T1.5).

Task 3.2 Evaluate pilot challenge-based assignments Q2, Q3 Q4 for S&C, EE, and AT
Progress: Expected in Qs 2021
Done.
Similar to T3.1 but now for the new pilot groups (T2.3).

Task 3.3 Evaluate project and decide on next steps
Progress: Still ongoing. See also the main part of the project.
Final evaluation of the project.

Task 3.4 Disseminate experience
Progress: See the main part of the report
Dissemination will take place during, and after the pilot groups in Q2, Q3 and Q4 are working on the challenged-based assignment. We will report about this activity on our website and will present our results to colleagues at EE education day and other events.

Survey results for the course

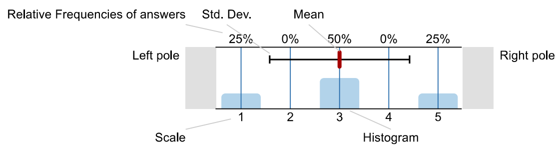
5LMF0 - Control challenges in autonomous racing 2020/2021 B4

Total number of recipients: 7
Number of responses: 2
Response rate: 28.6%

Survey Results

Legend

Question text



n=No. of responses
av.=Mean
dev.=Std. Dev.
ab.=Abstention

1. General Questions

1.1) Please select your bachelor's or master's degree program:

M Automotive Technology	50%
M Electrical Engineering	50%

n=2

1.2) Overall, how would you describe the level of difficulty in this project?

very easy – very difficult

1	2	3	4	5
0%	0%	0%	50%	50%

n=2, av.=4,5, dev.=0,7

1.3) On a scale of 1 to 10, how would you rate this project (with 10 being "excellent")?

1 – 10

1	2	3	4	5	6	7	8	9	10
0%	0%	0%	0%	0%	0%	0%	50%	50%	0%

n=2, av.=8,5, dev.=0,7

1.4) How relevant was this project for your study program?

not relevant at all – very relevant

1	2	3	4	5
0%	0%	0%	0%	100%

n=2, av.=5, dev.=0

1.5) Did you have sufficient prior knowledge and/or skills to follow this project?

yes	100%
no	0%

n=2

1.7) The educational setup (e.g. structure, content, teaching/learning methods, level, and coherence) worked well and was suitable for this project.

strongly disagree – strongly agree

1	2	3	4	5
0%	0%	50%	0%	50%

n=2, av.=4, dev.=1,4

1.8) The project was well organized (e.g. availability of lecturers/supervisors, availability of information, scheduling, and planning).

strongly disagree – strongly agree

1	2	3	4	5
0%	0%	50%	50%	0%

n=2, av.=3,5, dev.=0,7

1.9) The project description was clear and motivated me to work on this project.

strongly disagree – strongly agree

1	2	3	4	5
0%	0%	50%	0%	50%

n=2, av.=4, dev.=1,4

1.10) The effort I applied to complete this course corresponds with the number of credits (5 ECTS = 140 hours).

much less effort	1	2	3	4	5	much more effort	
	0%	0%	50%	0%	50%		n=2 av.=4 dev.=1,4

1.11) How many hours did you spend on this project in total? Note that 1 ECTS is equal to 28 hours of work.

135 - 167	50%	n=2
168 - 200	50%	

2. Educational form: Coaching

2.1) This educational form contributed to my understanding of the subject matter.

strongly disagree	1	2	3	4	5	strongly agree	
	0%	50%	0%	0%	50%		n=2 av.=3,5 dev.=2,1

3. Assessment as a whole

3.1) The assessment as a whole was appropriate (e.g. methods used, relevance and clarity of the assignments).

strongly disagree	1	2	3	4	5	strongly agree	
	0%	0%	0%	50%	50%		n=2 av.=4,5 dev.=0,7

3.2) The assessment criteria were clear.

strongly disagree	1	2	3	4	5	strongly agree	
	0%	0%	50%	50%	0%		n=2 av.=3,5 dev.=0,7

4. Teacher Selection

4.1) Please select your teachers out of the following list:

dr.ir. S. Haesaert	100%	n=2
ing. W.H.A. Hendrix	100%	
None of the above	0%	

5. Lecturer: dr.ir. S. Haesaert

5.1) The lecturer explained the content in a clear and comprehensive way.

no, definitely not	1	2	3	4	5	yes, definitely	
	0%	0%	50%	0%	50%		n=2 av.=4 dev.=1,4

5.2) This lecturer motivated me (e.g. content, interaction, use and variation of teaching methods).

no, definitely not	1	2	3	4	5	yes, definitely	
	0%	0%	50%	0%	50%		n=2 av.=4 dev.=1,4

6. Lecturer: ing. W.H.A. Hendrix

6.1) The lecturer explained the content in a clear and comprehensive way.

no, definitely not	1	2	3	4	5	yes, definitely	
	0%	50%	0%	0%	50%		n=2 av.=3,5 dev.=2,1

6.2) This lecturer motivated me (e.g. content, interaction, use and variation of teaching methods).

no, definitely not	1	2	3	4	5	yes, definitely	
	0%	50%	0%	0%	50%		n=2 av.=3,5 dev.=2,1

8. Course specific questions

	Question		1	2	3	4	5		
8.1)	The course pays attention to the relationship between the discipline and the future work field.	strongly disagree	0%	0%	50%	50%	0%	strongly agree	n=2 av.=3,5 dev.=0,7
8.2)	The way this course was given motivated me to study.	strongly disagree	0%	50%	0%	0%	50%	strongly agree	n=2 av.=3,5 dev.=2,1
8.3)	The way this course was given facilitated interaction between teacher(s) and students.	strongly disagree	0%	0%	50%	0%	50%	strongly agree	n=2 av.=4 dev.=1,4
8.4)	The way this course was given facilitated collaboration between students.	strongly disagree	0%	0%	0%	0%	100%	strongly agree	n=2 av.=5 dev.=0
8.6)	Having to work with ROS to be able to work on the setups in the cars was worth it.	strongly disagree	0%	50%	0%	0%	50%	strongly agree	n=2 av.=3,5 dev.=2,1
8.7)	The TA's were generally able to help us when we had problems.	strongly disagree	0%	0%	0%	0%	100%	strongly agree	n=2 av.=5 dev.=0

Comments Report

1. General Questions

[1.6)] If your answer above was no, please explain:

The evaluation will not be displayed due to low response rate.

7.2) What would you like to improve in this course/project?

- Currently one is thrown completely into the deep which makes it difficult to get an idea of what one wants to do or is expected to do. Perhaps lectures about previous work / autonomous racing strategies would help with this.

  It felt like the coaching session only made the project more confusing as one week we got the feedback to make something more complex and the other week to make something simpler. Perhaps it is better for the team if the coaches hint more towards the right direction if the team is lost.

- Sometimes we were confused about the goal we should select or the deliverables of the project. They were all clarified by the instructors but a better documented explanation of these may be helpful. I wish we had more time to work on the challenge but I am not sure if this could be improved.

8. Course specific questions

8.5) Are there elements of this course that you would recommend to keep online, even when 100% on-campus education is possible again? If yes, what elements?

- Nothing, as a team we really noticed that meeting in person was a lot more beneficial for the progress of the project.
- The tutorials that we have not worked on the car can be continued online.

8.8) What were the positive elements of the challenge-based educational format in this course?

- As we had to determine which method we should be using for each task, it enabled me to learn about many new things. Also, being able to work in the lab and observing the results of our work on the car was really fun and motivating.

- Being able to experiment in a lab and seeing the results of the algorithms you have made gives a lot more satisfaction if it goes well. It also allows students to experience problems that arise in a real life situation and be able to debug and fix these problems.

8.9) How can the challenge, infrastructure, and documentation of this course be improved?

- - Introductory lecture(s)
  - A bigger lab for testing

5LMF0 Course review

Present: Will Hendrix, Sofie Haesaert, Chenchen D., Dana V., Bram H., Bas T., Mert E.
15th of July 2021
16:00-17:00

Issues

- The course was (too) hard a lot of time was spent on this course ~160 hours
- Students loose quite some time because the field is large and there are many things they could do. Since not all students are familiar with autonomous driving this makes it very challenging.
  action: Give the students a general idea of the field and of the types of solutions that could try to achieve. These pointers will reduce time the students are wandering around in the literature.
- Connections issues also causes quite some time loss when in the lab. The car does not always connect well to the wifi and has a changing IP.
  Resolve connection issues
- Not having a TA in the beginning or not using a TA enough throughout the course causes quite some time delay.
  Give option to schedule TA together with lab time and force groups to do this regularly in the beginning
- Writing learning goals was fine, but felt a bit constrictive later on because they were not adjustable.
  Allow for some minor refocus or adjustment of the learning goals
- The simulation is not working well.
- The deadlines of the intregration project are not always clear and seem to appear at random in the project. Better notify everyone of the upcoming deadlines for the integration project
- Academic writing is focused on how to combine sentences not how to write a formal paper or report
- The walls kept falling. Add more supports in between
- The lidar was not mounted horizontal on car 2
- Have undercharge protection for the batteries
- Make sure that batteries are regularly charged and tell students how to charge.
- Reserve the space before the integration project demonstration
- Plan the demonstrations on two separate days in the afternoon.

What went fine:

- Making teams and working in teams
- Teamwork in masters ☺

Improvements:

- Time is waisted at the beginning of the project: start full speed. Put project proposal deadline earlier (and lower weight on project proposal). 2nd week Friday or Sunday
- Point students more clearly to the website of Richard for the Gotcha chart
- Point students harder to the wiki pages: via study guide and intro slides
- Add list of pages to the wiki (at the end of the contents)
- Add gitlab tutorial based on dominics tutorial
- Advise which packages to use for software: Winscp, steeringwheel=putty, filezilla, pycharm, (atom?)/github disktop
- Introduction to ROS with video that student have to/should watch (before the tutorials?)
- Be clear about what is expected for the report. Perhaps with a couple of pages from a good report.