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

Date: 1st draft Friday 8 October 2021, 2nd draft Monday 29th of November 2021
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 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.

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.
- **Evolving challenges** where achievements of previous generations of students are available to students and the challenge can grow and evolve based on it.

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

Course Organization – Basic Information

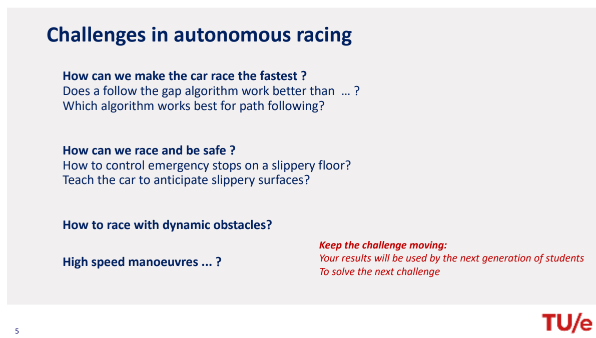
Type of education:	Challenge-based project work in teams throughout the quartile. Regular discussions with coaches. Experimental work during instruction and lab-sessions.
Credits:	5ECTs
Group:	Control Systems (CS) Department of Electrical Engineering Secretariat secretariaat.cs@tue.nl Flux 5.132, tel:040 247 2300.
Main contacts:	Sofie Haesaert s.haesaert@tue.nl Will Hendrix w.h.a.hendrix@tue.nl

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.



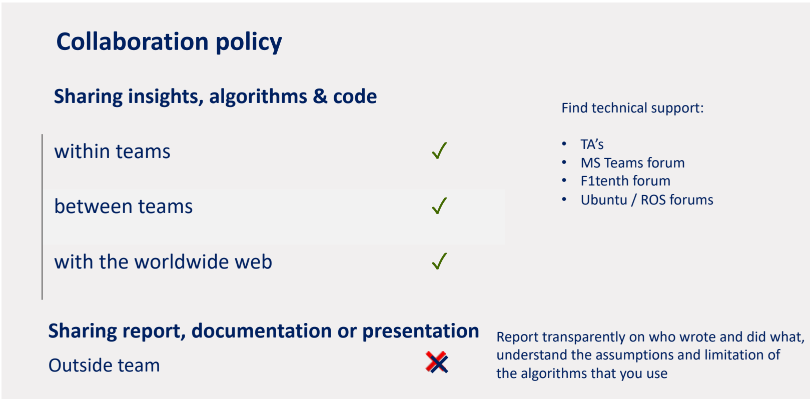
Supervision

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.

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.

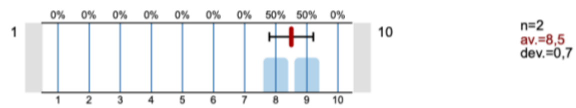
- We did not oblige the students to simulate and develop algorithms in Python or C++. Instead, they wrote most of their simulations in Matlab and only translated the algorithm to Python when they were finished.

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 detailed 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
   - The setups 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.