Self-driving bikes for more realistic development and testing of systems for bike safety, part 2

Public report

Project within FFI Elektronik, Mjukvara och Kommunikation, EMK

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Content

FFI in short

FFI, Strategic Vehicle Research and Innovation, is a joint program between the state and the automotive industry running since 2009. FFI promotes and finances research and innovation to sustainable road transport.

For more information: www.ffisweden.se

― Summary

The goal of this project has been to develop self-driving bikes that will be used for validating safety functions for manual and self-driving vehicles. The bikes are intended to be used in tests together with vehicles and will be designed to behave as realistically as possible with the ability to wiggle, curve taking, and having a realistic roll angle in these maneuvers.

With these self-driving bikes, it is possible to design repeatable experiments that go beyond the scope of what has been possible with tests up to now.

The university partners have delivered 5 bikes at the end of the projects. Several more have been built during the more than 20 student projects which have been part of the projects, but some of them have been transformed to newer generations of the self-driving bike concepts. The development has been with help and advice from test engineers from the industry partners.

The algorithmic design has first been implemented and tested in a simulation environment which has been built up in the project. With that environment different bikes can be described with parameters. The test driving can be simulated and evaluated before the real test so that unnecessary mistakes are avoided.

Autoliv and Magna have built their own bikes based on the design developed by Chalmers and MDU.

A crash-worthy plastic bike has been built, and a portable version of the mechanism so it can be used on different bikes.

Test drives has been performed at Asta Zero and at the airfield in Vårgårda where various aspects have been evaluated, such as repeatability of a test. Volvo Cars has then validated that the bikes are correctly recognized by the vehicle sensor system.

Since a lot of the functionality has been developed by students in fairly short student projects, the usability of the bikes is not great. In the contrary, some work remains to make the bikes user friendly so that a test engineer can handle them with a reasonable preparation time.

From an educational perspective, the research project has been excellent for students to gain practical experience from. Algorithms has first been simulated, then implemented on the real-time hardware, and then test-driven. Smaller tests have typically been carried out at the university campus.

– Sammanfattning på svenska

Det utvecklas i rask takt nya och förbättrade aktiva säkerhetssystem som ska hjälpa fordonsförare att undvika olyckor. Kort beskrivet så ska sådana funktioner gripa in i en situation som blivit för svår för föraren att klara själv, eller undvika något som föraren inte noterat. En sådan funktion ska först upptäcka faran med hjälp av fordonets sensorsystem. Därefter ska situationen bedömas vara sådan att föraren inte klarar av uppgiften själv. Därefter ska funktionen gå in och göra en manöver, ofta en inbromsning. Alla sådana funktioner måste verifieras att de fungerar korrekt och en sorts validering är att utföra körtester där man designar och kör den farliga situationen. Om det är cyklar som ska undvikas så behövs cykel-attrapper som är tillräckligt lika verkliga cyklar så att fordonets sensorer tolkar situationen som avsett. Cyklarna ska också bete sig som normala cyklister. Detta projekt handlar om att bygga självkörande cyklar som balanserar som vanliga cyklar. Cyklisten är utbytt mot en docka för att inte utsätta någon för onödig risk.

I projektet har det designat och byggts 5 självkörande cyklar. Utvecklingen har varit inkrementell. Första generationens cyklar har utvärderats och förbättrats i nästa omgång. Det har gjorts många mindre ändringar, och några större. Cyklarna har framför allt utvecklats och byggts på MDH och på Chalmers av studenter i studentprojekt, mer än 20 studentprojekt har varit med och bidragit till resultaten som beskrivs här. Dessutom har det varit två doktorander som har varit med i algoritmutvecklingen.

Autoliv och Magna har byggt egna cyklar utgående från design och resultat från universitetens prototyper. En mekanism för att göra cykeln självkörande har konstruerats så att den lätt kan flyttas från en cykel till en annan så att det ska vara möjligt att välja cykel utgående från vad man vill testa för trafiksituation. En annan cykel har byggts i plast så att den ska vara lätt och att riskerna ska bli mindre ifall en test går fel och cykeln blir påkörd.

En simuleringsomgivning har utvecklats för att testa algoritmer innan de implementerats på cyklarna. Den kan också användas för att simulera körtester med cyklarna så att man kan utvärdera en vad en test potentiellt kan ge och på så sätt designa körtester i simulering och spara test-tid på testbanan.

Företagspartnerna har stöttat med sin kompetens och gett råd till de studenter som utvecklat cyklarna. De har också definierat exjobb för studenter som bidragit i projektet.

Volvo Cars har analyserat trafiksituationer med cyklar och där man vill testa fordonsfunktioner för att undvika olyckor. De har även analyserat olycksdata för att utvärdera var det är viktigt att utveckla säkerhetsfunktioner.

– Background

For active-safety systems, the main validation is of the sensor system detecting the biker and the algorithms predicting the future trajectory of the cycle. If that information is incorrect, the safety system doesn't work as intended. Hence, to validate these systems, there is a need of test equipment, bikes, which appear as normal and behave as normal bikers. Available test methods meet the first criterion but have limitations on imitating the behavior of bikers. They can only move straight, pulled by a wire, or placed on a moving "low-rider" without any roll in curves. However, the roll angle indicates the biker's change of directions and, hence, it is a very relevant feature for an active safety system trying to predict the trajectory of the bike.

– Purpose, research questions and method

The purpose of the project has been to develop self-driving bikes, balancing in a similar way as human bikers, so that they can be used in safety tests where they behave more realistic than the alternative test methods.

The method to obtain this has been to have, mainly project students, developing parts of the system and building the electronic control systems. Two PhD students have worked on developing control algorithms which have been evaluated on the bikes.

In the application the following research questions where listed:

- Is it possible to obtain high enough position accuracy of the self-driving bikes so that they meet requirements in test standards? How do the bikes need to be modified to meet these requirements?
- To what precision is it possible to perform repeatable tests with the bike?
- How should the self-driving technique be designed so that it
    - does not change the bike's appearance of the vehicle's sensor and camera systems?
    - is not damaged in passive safety tests where the bike is crashed by a vehicle? (crashworthiness)
    - can easily be moved from one bike to another and in this way make it possible to test the vehicle's safety systems on different bike-types?
- How should a special test-bike be designed so that it can take a hit of the vehicle in the case the sensor system does indicate the bike and the EBS isn't triggered in tests of active safety systems?

– Objective

In the application it was expected that the project results in several prototypes as follows:

- Several self-driving bikes, of different types.
- Portable equipment, to be put on "any" bike to make it self-driving, including algorithms and software adaptable to the particular bike.
- A crash-worthy self-driving bike intended for testing active safety systems.
- Algorithms and software to perform tests in following standard used in industry and test tracks.

– Results and deliverables

The section is divided into subsection, one for each of the work packages 2-5. The order of the WPs has been changed.

WP4 Design and build bikes

Five working bikes had been produced by Chalmers in collaboration with MDU, shown in Figure. 1 to 4, and further down in the report, the fifth, the red bike. They are all fairly like one another with respect to the design of the self-driving electronics so that the same software system can be used to operate all of them. They are the result of several iterations of bike building where electronic hardware, microprocessor, and programming language have been exchanged between the re-builds. Most of this work has been done by regular students in student projects, more than 20 in total. This incremental development is illustrated by the titles of the student reports listed in the publications [1-21]. The second generation of a crash-worthy plastic bike is shown in Figure 4.

Figure 1 One of the bikes built. A propulsion motor, and one for the steering which is used simultaneously for balancing and direction.

The bike development progressed with weekly sync meetings held at Chalmers with Jonas as chair. **AstaZero** and **Volvo, sometimes Autliv and Magna too,** participated in the meetings to support with technical knowledge and advice regarding testing and ADAS functionality. Students also took part in the development of the indoor test equipment, like balancing rig for the e-scooter.

With that, all four objectives described above have been met, at least on a high level of description. Already here we can add that in the process of reaching the four objectives, many weaknesses have been identified. In the incremental development, some of them have been eliminated, but there is more to be done

before a good usable test object in form of self-driving bike has been obtained.

Here follows a comprehensive list of the results connecting to the design and building of the

Figure 4Bike with portable mechanism which can be moved between bikes.

Figure 3 The latest built bike with a nicer solution of the steering motor. The look of the bike is less influenced, and the belt between the motor and the steering column is removed.

Figure 2 Second generation of crash-worthy bike at test drive at Asta Zero.

The second generation of crash-worthy plastic bike looks good, but some 3D-printed parts are too weak and need to be replaced. Also, this bike is more flexible than a steel bike, and the control algorithms need to be validated.

The bike software is a combination of LabVIEW, mainly used to communicate with hardware components, and C which is used for the signal processing and control. Extensive time was spent on getting this software platform to work properly for the basic functionality which was finally accomplished. This code too needs additional polishing to be easier to use. For example, the state estimator and controller must be different depending on if the bike is running outdoor with GPS available, or indoors on a roller without GPS. Today, prototype code for these cases exists, but must be better organized.

Additional support functionality is needed. Tod ay, fractions of it exists from the student projects. These functions include such as:

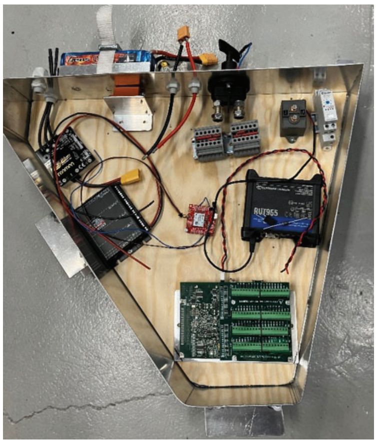
- calibrate tests to use at
- startup. Failure detection and messages informing
- the user. Support for test data analysis.

A testimony from one of the students who was part-time employed technician in the project can be found on LinkedIn:

https://www.linkedin.com/feed/update/urn%3Ali%3Aactivity%3A7253098904374706 16/?midToken=AQG1r9tYRZ4Zqw&midSig=1voMmmCHrWNHs1&trk=eml-email_notification_single_mentioned_you_in_this_01-hero_notification_cta-0-1ep~cta&trkEmail=eml-email_notification_single_mentioned_you_in_this_01-hero_notification_cta-0-1ep~cta-null-kj1vo~m2f1dtsp~hi-null-null&eid=kj1vo-m2f1dtsp-hi

At the project webpage (https://sites.google.com/view/autobikes/project-overview?authuser=0) more photos of the bikes and films from some of the test driving can be found.

Magna has been part of meetings and discussions regarding selection of hardware and definition of system requirements. We had a student worker during summer break to build a copy of the self-driving bike. Unfortunately, the summer worker did not have enough time to complete our own version of the self-driving bike and below one can see pictures of this work. As an example, we have built a new control box for the main computer, the sensors, and all electrical components.



Magna decided to use a slightly different hardware setup and replaced the main computer to a “Single board RIO 9626”. It’s a National Instruments hardware with a more powerful computer. Magna has previous experience with this hardware and is developing its own software program for controlling and running the system. The software has been further developed and improved during the project and one of our goals is to make it compatible with ISO 22133 protocol and thereby also with other test systems.

During 2023 and 2024 **Autoliv Development AB** designed a bike more suited for testing physical interaction between a bike and other road users and evaluating different safety measures for bicyclists.

The bike has the same basic design as the design by Chalmers but with features to make the bike as robust as possible for crash testing. The drive motor, the location of the main control unit and the battery have been changed. There have also been design changes to be able to place a crash dummy on the bike.

Autolivs design of the bike.

Autoliv uses the suggested drive motor from Chalmers. This motor is normally for front wheel applications but to make it less exposed to damage in crash testing it is mounted on the rear wheel.

The location of the main control unit is at the back of the bike. Then the fragile components are less exposed in crash testing and the main control unit does not interfere with a crash dummy.

The location of the battery is at the center of the bike. This is good for the stability of the bike since the weight of the battery is not to be neglected. The battery will also not interfere with the crash dummy.

The design of the steering device is not optimal for using the bike for crash testing. The hardware is exposed in the front.

Autolivs design of the steering device.

There are improvements planned for the Autoliv bike.

In addition to this design there will be support wheels to make it possible to start and stop driving with a full-weigh crash dummy. These support wheels will just be activated during start and stop. The design draft of these support wheels is ready and will be finalized.

There will also be a structure designed around the handlebar to protect the steering device. This is to make sensitive hardware more robust.


Autolivs design of the main control unit

During the process of designing the bike control **Autoliv** has been guiding for some aspects. The goal was to make the bike possible to control with a crash dummy on the bike. There are also other important specifications for designing the bike control. The bike should be able to go with a certain speed and be able to impact an object or another vehicle at a specified spot.

A crash dummy weighs around 77,7 kg and is 177 cm tall. We refer to a Hybrid III dummy. To be able to use this dummy to sit on a bike there is needed to do some modifications inside the dummy. This is for the dummy to have good posture.

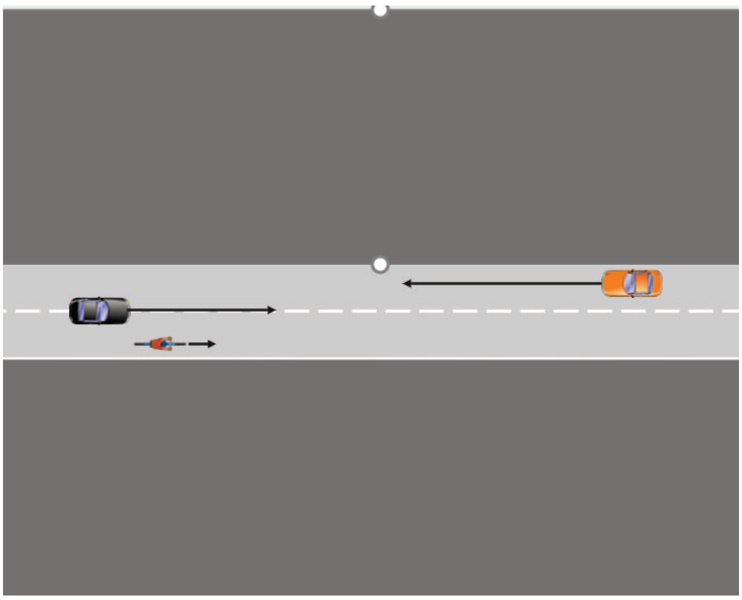
WP2 report Bike control and validation of performance

At Chalmers a simulation environment has been developed so that bike tests can be simulated before executed on a real bike. The simulation environment also serves to evaluate changes in design, both of hardware and in software. It has been used extensively to investigate and validate the software and algorithms. The bikes are described with a number of parameters so that the particularities of each bike can be properly described in the model. Before performing a test drive, the test can be simulated and the result can be pre-evaluated so that tests can be optimized in an easy way, and mistakes can be discovered at an early stage, making the test-driving more efficient. After being developed over a number of student project, the simulation environment needs to be cleaned up so that it becomes more user-friendly

Spring 2023 A Master thesis was performed by one student with supervision and funding from **AstaZero**. This resulted in the report named “Trajectory control with Kalman Filter-based State Estimation for bicycle”[15].

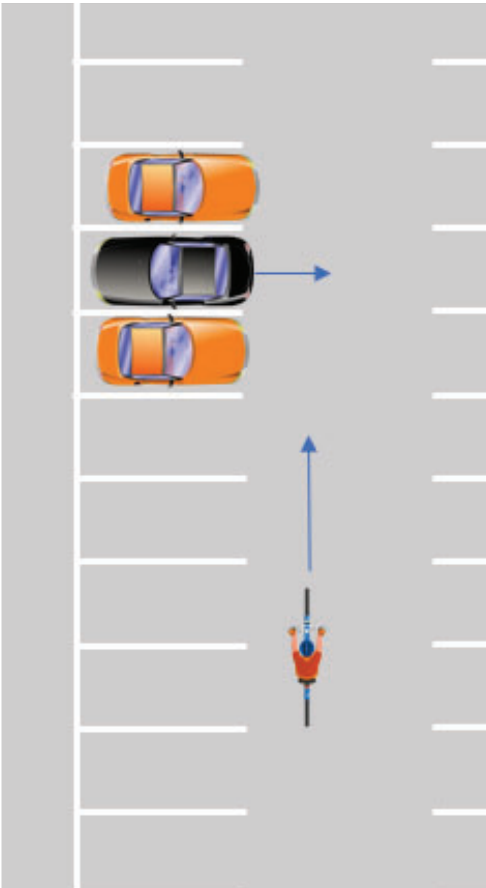
Spring 2024 Master thesis with two students for **Volvo Cars** with the task to enable paths by the bikes that can be used in testing. E.g. take a selected scenario and implement it in the micro targets, including how well the path is followed. The report is still in its review phase.
Volvo have analyzed bicycle/e-scooter accidents from Customer data to select some scenarios to be used in this thesis and project.

- In the first scenario a bike is wiggling (like pedaling uphill) on a rural road and is overtaken by a VUT (Vehicle Under Test) and at the same time there is an oncoming vehicle, making the road narrow and the car may collide with the bike or push it out of the road. (pictured below)
- The VUT passes through an intersection when a bicycle enters the bike lane from the right to continue in the same direction as the VUT. In certain timings and for a short period, the situation appears like it may end up in a collision if the bike just continues straight. There is a risk of making the wrong decision by the algo and issue a brake.
- A bicycle is passing parked vehicles when the VUT is reversing out of the parking spot, and a collision might occur.



Example on situation 1: VUT passing bike with oncoming traffic

Example on situation 2 : intersection.



Example situation 3: VUT reverses out of parking spot and might collide with passing bicycle.

Volvo cars contributed with analysis of accident data from customer cars of bike/e-scooters and vehicle interactions to be able to propose suitable and valid test scenarios for the micro targets, whenever a target is ready. Data was taken from internal data of real crashes that has been analyzed and from customer fleet data, where function activation occurred. Data was filtered on pedestrians and micro-targets, such as bikes and e-scooters.

WP3 Adaption to ATOS

A couple of student projects have worked on implementing the control system on the bikes, for example [15-16] with support from AstaZero and Chalmers. This proved to be a far too complex task for the time provided in the project courses. So far, only preliminary results exist,

WP5 Test drives and Sensor validation

At the project webpage (https://sites.google.com/view/autobikes/project-overview?authuser=0) films from some of the test driving can be found.

Volvo: During 2021-2023 a method of performing tests with targets, without colliding and still estimate the impact speed, was developed together with the Hällered test team. The bike from this project was not in good enough state so an alternative target was used. Method presented at the test conference in Stuttgart June 2023[ADAS & Autonomous vehicle testing Conference, Europe]

During 2023 mainly virtual tests of bicycle scenarios performed at Volvo, no physical testing performed. Rating scenarios implemented in the SIL environment at VCC. Internal Master students working on sensor models for radar based on physical tests., report [22]. They improved the physical model of the radar sensor, with a new method based on measured FOV.

During 2024 the two-master thesis students together with their Chalmers fellow students, planned and executed three test drive days on the test track during the spring and summer. The students simulated the scenarios and focused on the balancing of the e-scooter on the track time. By driving in 8 figures and circles, to compare with the simulation.
The track tests were backed up with testing on the open areas outside Chalmers as preparation. During the track days a Volvo test car including extended test equipment was available to take logs when possible and suitable. E.g the plastic bike used some snapshots from the logs taken, in their work. The Volvo vehicle registered the bike as a bicycle target when propelled over the test track with a dummy attached. During the third test day, all bike students performed a demo that was visited by Swedish television and radio.

Link : https://www.svt.se/nyheter/lokalt/vast/har-testas-sjalvkorande-robotcyklar-utanfor-boras

Details about the master thesis work is described in the Master thesis report [not yet published].

AutoLiv: During the project there have been several occasions for evaluating the progress of the design.

For these occasions Autoliv has supplied with a light-weight dummy representing something that could look like a real person. It does not have the right weight but can help evaluating how the algorithms can manage the wind.

Autoliv has participated in these testing occasions mostly to help understanding the difficulties around this kind of test and to learn.

Chalmers bike driving with Autolivs light-weight dummy at AstaZero

In 2023 Autoliv was involved in a project (MICA2) evaluating safety measures for a bike interacting with a car. For this scenario there was a need for a crash dummy sitting on a bike going into the side of a car. The bike was supposed to drive into the car at an angle of 45 degrees. This traffic scenario was tested at Vårgårda Airfield. Since the self-driving bike was not yet finished Autoliv designed a simplified version. A standard bike with support wheels that could only drive straight was designed.

A lightweight dummy was used instead of a full-size crash dummy. Since the goal in this test was not to measure any data from the dummy showing risk of injuries.

For this kind of testing a self-driving bike would have been an extremely useful tool.
In the testing using this simplified version of a bike it was obvious that the bike could run several times without any damage.

Autoliv performed test at Vårgårda Airfield in 2023. A simplified self-driving bike driving into the side of a car.

– Dissemination and publications

.1 Dissemination

How are the project results planned to be used and disseminated?	Mark with X	Comment
Increase knowledge in the field	X	See list of publications. A lot of insights on what is easy and what is difficult.
Be passed on to other advanced technological development projects	X	The bike will be continued developed and start to be used in other projects in house at companies, and at Chalmers.
Be passed on to product development projects		
Introduced on the market		
Used in investigations / regulatory / licensing / political decisions	X	This is the intention. We are not there yet.

The projects also received some nice attention in the media at the final test driving in August 2024: *Rapport, Sveriges Television, https://www.svt.se/nyheter/lokalt/vast/har-testas-sjalvkorande-robotcyklar-utanfor-boras , SVT Västnytt, Landet Runt, samt P4 Sjuhärad, see links at https://sites.google.com/view/autobikes/media?authuser=0*

.2 Publications

More than 20 student projects have been carried out during the projects. A list of the projects and their reports is found at https://docs.google.com/document/d/1JlRMOWsn7pjzUla233oXOO_jJ8VSU_VUCdVLi2K5enU/edit . See also [1-21].

Two licentiate theses have been presented based on work in the project, [2], [3]. The results in the licentiate theses have been presented at international conferences. Additional to these, the result on lateral control was published at an IEEE conference in Bogota [1].

Yixiao Wang was expected to finish with a PhD during the project, this was not accomplished and instead he finished with a licentiate degree [2]. Nevertheless, he developed two important algorithms for the bikes; 1) one of them gives a framework how to adapt the algorithm for balancing the bikes as a function of the speed, [1], and a second one which improves reproducibility of drive tests using Iterative Learning Control, [6]. These algorithms need to be implemented in the standard software on the bikes.

Scientific Publications

1. Gain-scheduled bicycle balance controller based on system identification, Yixiao Wang, Fredrik Bruzelius, Jonas Sjöberg, Proceedings of the 16th International Symposium on Advanced Vehicle Control, Milan, Italy, 2024.
2. Lateral Control of a Self-driving Bike, G. Wen and J. Sjöberg, 2022 IEEE International Conference on Vehicular Electronics and Safety (ICVES), Bogota, Colombia, 2022, pp. 1-6, doi: 10.1109/ICVES56941.2022.9986548.
3. Iterative learning trajectory tracking control of an autonomous bicycle , Yixiao Wang, Fredrik Bruzelius, Jonas Sjöberg, Proceedings of the 16th International Symposium on Advanced Vehicle Control, 2024
4. *A Comparative Analysis and Design of Controllers for Autonomous Bicycles, Controllers for Autonomous Bicycles*. In European Control Conference (ECC), 2021
5. Trajectory Tracking and Stabilisation of a Riderless Bicycle, Niklas Persson, Martin Ekström, Mikael Ekström, Alessandro V. Papadopoulos, In International Conference on Intelligent Transportation Systems (ITSC), 2021.

Two licentiate theses have been produced during the project.

Licentiate theses

1. An autonomous robot bicycle for active safety tests, Yixiao Wang, licentiate thesis, Chalmers, 2024, https://research.chalmers.se/publication/542758

2. CONTROL AND NAVIGATION OF AN AUTONOMOUS BICYCLE, Niklas Persson, Mälardalen University Press Licentiate Theses, No. 336, 2024

The project has mainly been carried out by students in student projects. These have been projects in project courses, bachelor thesis projects and master thesis projects. A notable number of students have been Erasmus students from various European countries. Some of the reports have similar or even identical names. This is typical due to that several student projects were needed to finish that topic.
The list bellow is the main part of the reports from the student projects.

Student reports

1. Stabilization and path tracking of a bicycle using MPC, Daniel Hultgren , Pontus Svensson, Josip Kir Hromatko, Carlos Canelada Martinez, Albin Lindmark, Johan Martinsson, Gustav Rosin, Jakob Wadman, report, Chalmers, 2020.
2. Reinforcement learning of a nonlinear bike controller, Project report, Chalmers, 2020.
3. Balancing a stationary bicycle, Chalmers, https://drive.google.com/file/d/1RnYf58tDqUpj2P8HXr_4c4jnLUgNxSTA/view?usp=drive_link, 2020
4. Control performance of a self-driving bike depending on design parameters, Chalmers, https://drive.google.com/file/d/1oNhy8Vg6P7ns2yjqWWk3TaDwGVQf5Ov1/view?usp=sharing, 2022
5. Controlling a Self-Driving Bike Using Compiled Simulink Code, Chalmers, https://drive.google.com/file/d/1Ia9G5Jn9GWULGwhyJHhSW3cq7P3L_8vE/view?usp=sharing, 2022,
6. Project Autobike, MDH, https://drive.google.com/file/d/1sQ13xrA28rpw1CpLql6EHYjyYxeeA07f/view?usp=sharing, 2022
7. Programming a Self Driving Bike: Implementing a Balancing Algorithm in a Self Driving Bike, Chalmers, https://drive.google.com/file/d/1wd2_fkzLng-SuDsjk8xsJOJkIYtgxLQB/view?usp=sharing, 2022
8. Universal enclosure mount and general improvements of hardware on autonomous bicycle, Chalmers, https://drive.google.com/file/d/12o9guP6shSzo-HRFa_V4g3Z2RPxeD8Cq/view?usp=sharing, 2022
9. PROJECT E-SCOOTER, MDH, https://drive.google.com/file/d/11Pa7HBLTBXVv40ZcWSCpOKlP3RU0nUo4/view?usp=drive_link , MDH, 2023
10. Trajectory control implementation in autonomous bicycles, Chalmers, https://drive.google.com/file/d/1U-tmINK6E23Vu1IVmBdGhiXoEi41Ared/view?usp=share_link, 2023

11. Trajectory tracking and robust control of self-driving bicycle using MPC, Chalmers, https://drive.google.com/file/d/1wZZZ7zzGOBIf9Ax6fpgOtdcn6yoN5R87/view?usp=drive_link, 2023
12. Speed control, Chalmershttps://drive.google.com/file/d/1A1dqFt9HjrUdErCvmKMXXQPvdtz-M_5m/view?usp=drive_link, 2023
13. Speed control, Chalmers, https://drive.google.com/file/d/11QL_IkPjc7TKhneH55gDt8QgyUMgSs-L/view?usp=drive_link, 2023
14. Speed control, Chalmers, https://drive.google.com/file/d/1vcxPg77eHgWhoTtEAiMJ-Ar9zPQcLhha/view?usp=drive_link, 2023
15. Trajectory control with Kalman Filter-based State Estimation for bicycle, Chalmers, http://hdl.handle.net/20.500.12380/307267, 2023
16. Adapting self-driving bikes to meet the ATOS standard, Chalmers, https://drive.google.com/file/d/1Ye4YiAavjMWH3h_1JEIIoknG4vCz23Zc/view?usp=drive_link, 2024
17. Improved trajectory control of self-driving bikes, Chalmers, https://drive.google.com/file/d/1NvP0xaReJZjGgmuQOJvXq3MW0sEAe1RX/view?usp=drive_link, 2024
18. Analyze and Improve Control of a flexible Self-Driving Bike, Chalmers, https://drive.google.com/file/d/1AM21_C8ag2JuUsR7PRZj-U9Py0kSsN5A/view?usp=drive_link, 2024
19. Implementing a Speed-Controller in a Self Driving Bike, Chalmers, https://odr.chalmers.se/handle/20.500.12380/307713, 2024
20. Design av en lätt, kraschvänlig och självkörande cykel, Chalmers, https://odr.chalmers.se/bitstreams/2f556a99-e039-4337-aaaf-680d5bbd4c00/download, 2024
21. Gain scheduling and Linear interpolation based on velocity for an adaptive trajectory control of a self-driving bike, Chalmers, https://drive.google.com/file/d/1KwzCfqY7DJNSd5WlWZJr8s_Oxvuvf4Md/view?usp=drive_link, 2024
22. Design, Implementation, and Evaluation of Radar Sensor Models in a Virtual Environement, Carlback, Jacob, Mjöberg, Sara, Chalmers 2023, https://odr.chalmers.se/items/8ab6335c-3b47-4308-8168-1a2f5eb233f5

– Conclusions and future research

Most of the project goals have in principle been reached. The only clear one which hasn't been reach is the implementation of ATOS. There are however clear shortcomings in the present state of the bikes and the functionality to handle them. They can manly be divided into robustness problems with the hardware. This includes mainly smaller modifications as better mounting of electronic equipment, better wiring and protecting certain parts. During the project there were uncountable faults caused by these weaknesses. The other shortcoming is with the algorithms and the software. There is a need of several support functions making it easier to handle the bikes.

Although the main part of the basic technical validation has been done, it remains to evaluate to what extent the bikes can mimic a human biker. The plan is to perfume this work in connection with other research projects where the bike is used and needed to perform test-driving.

– Participating parties and contact persons

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