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# CeCar

## A platform for research, development and education on autonomous and cooperative driving

htw [ expleo ]

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# Content

# Introduction

- **Autonomous and cooperative driving**
  - After more than 40 years of development now entering into product stage
  - Extremely vibrant research and development area

- Progress is fueled by developments in specific domains, such as
  - High-performance and safe computing
  - Advanced communication
  - Computer vision and machine learning
  - Sensing technologies


Uber experimental car [1]

- Continued progress also requires
  - Affordable means to develop and test system-level and system-of-systems-level solutions
  - Skilled workforce able to master growing complexity and interdependence of technologies

# Experimental platforms

**Simulators**

- Many specialized simulators (communication, sensing, performance and control, driver interface, traffic situation…)
- Some integrated or flexible simulation platforms

- Affordable
- Good representativeness in their specific field
- Typically high effort for adaptation and integration

**Full-size cars**

- Full spectrum of technologies coverable

- Best representativeness
- Very high initial and operational cost

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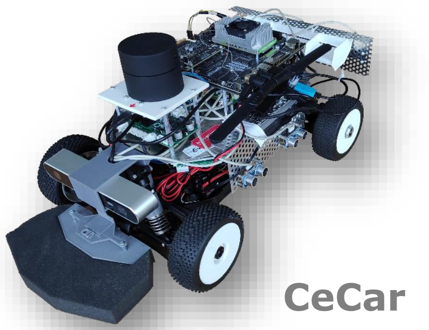
**Model-car platform**

- Full spectrum of technologies coverable

- Varying representativeness depending on aspect
- Affordable



CeCar

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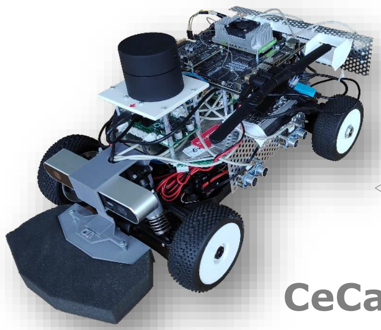

CeCar

**Full-size cars**

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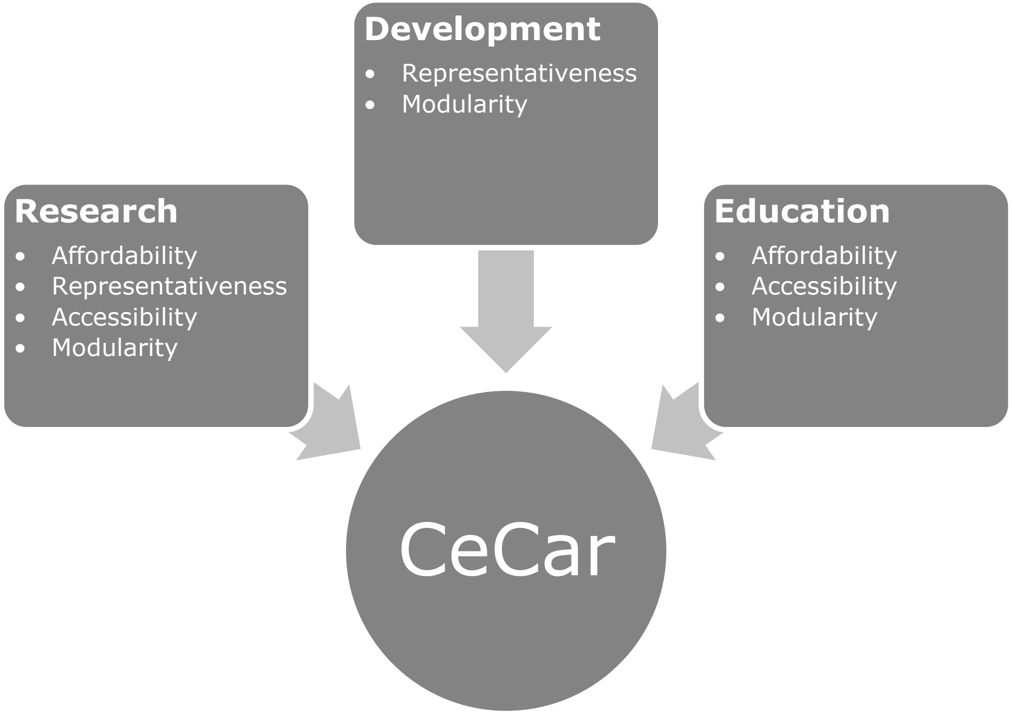
- Very high initial and operational cost

- Expleo started development of experimental model-car platform in AMASS research project (2016-2019)
- HTW Berlin and Expleo continued to develop CeCar platform for application in research, development and education

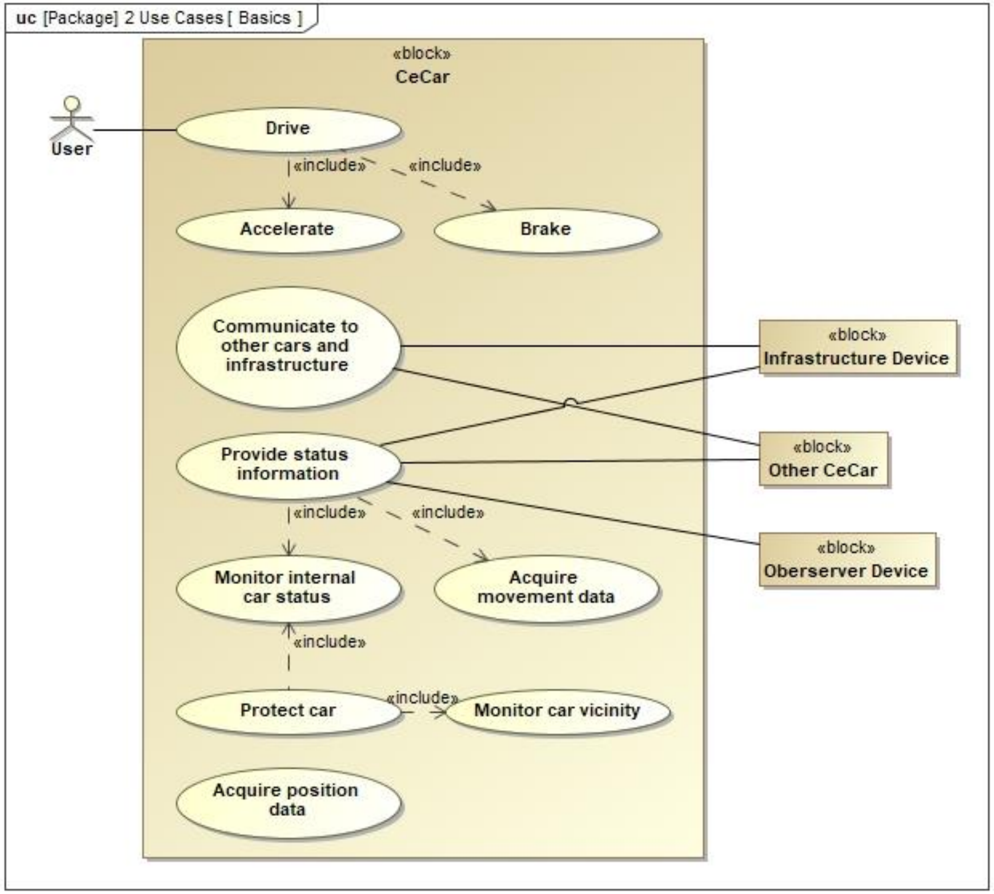
# CeCar platform
## Basic requirements

- CeCar platform intended to support research, development and education:



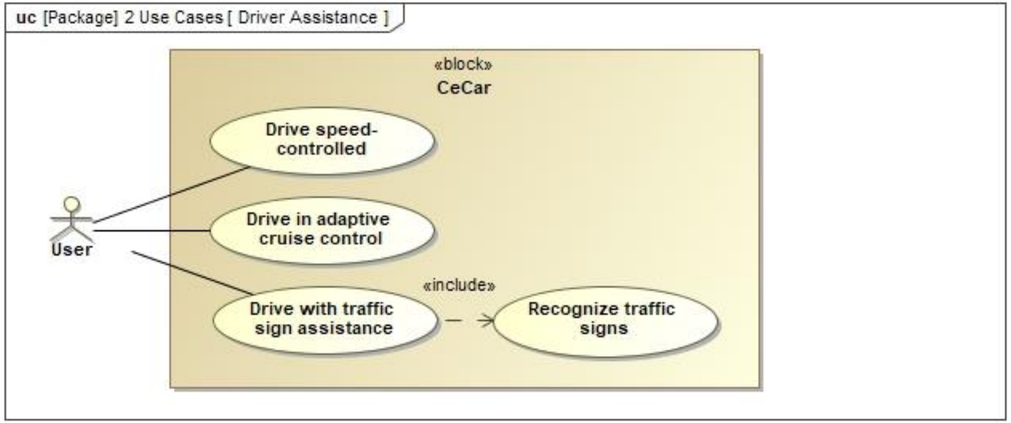
# CeCar platform
## Use cases (1)

- Basic use cases
  - Driving
  - Monitoring itself and its vicinity
  - Protecting itself
  - Communicating (V2V, V2I)
  - Providing information



# CeCar platform
## Use cases (2)

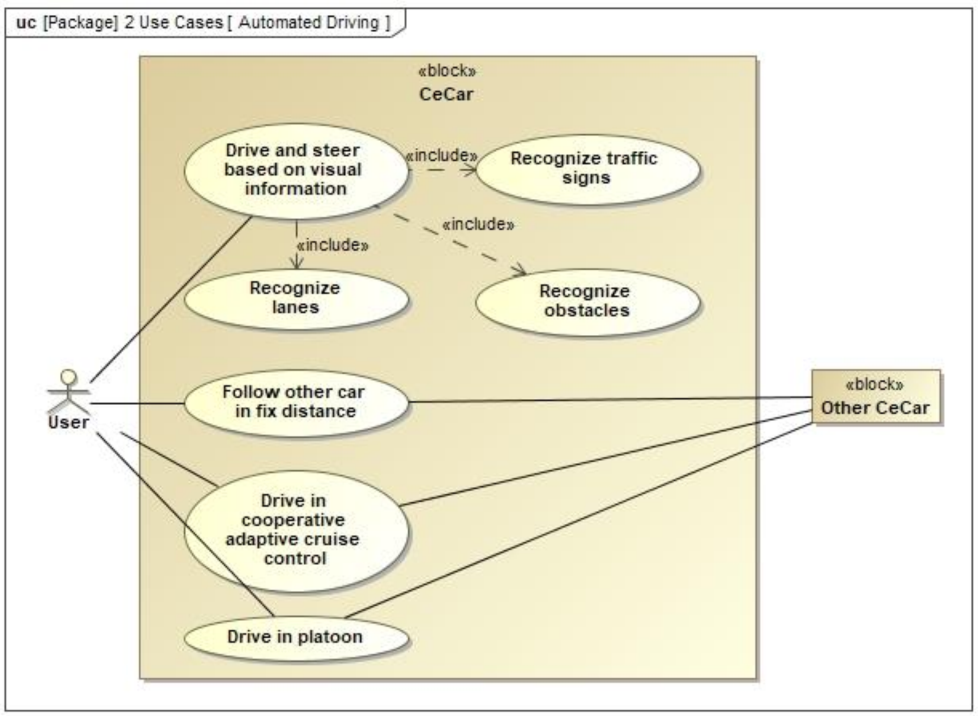
- Driver assistance use cases
  - Speed-controlled driving
  - Driving in adaptive cruise control
  - Driving respecting traffic signs
  - …



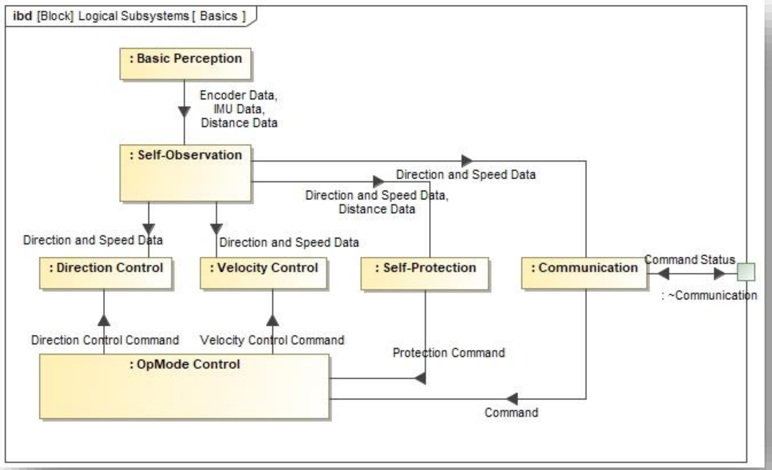
# CeCar platform
## Use cases (3)

- Autonomous driving use cases
  - Autonomous driving based on visual information
  - Autonomous valet parking

- Cooperative driving use cases
  - Fix distance following
  - Cooperative driving in platoons
  - Cooperative crash prevention
  - …



# CeCar architecture
## Logical systems architecture



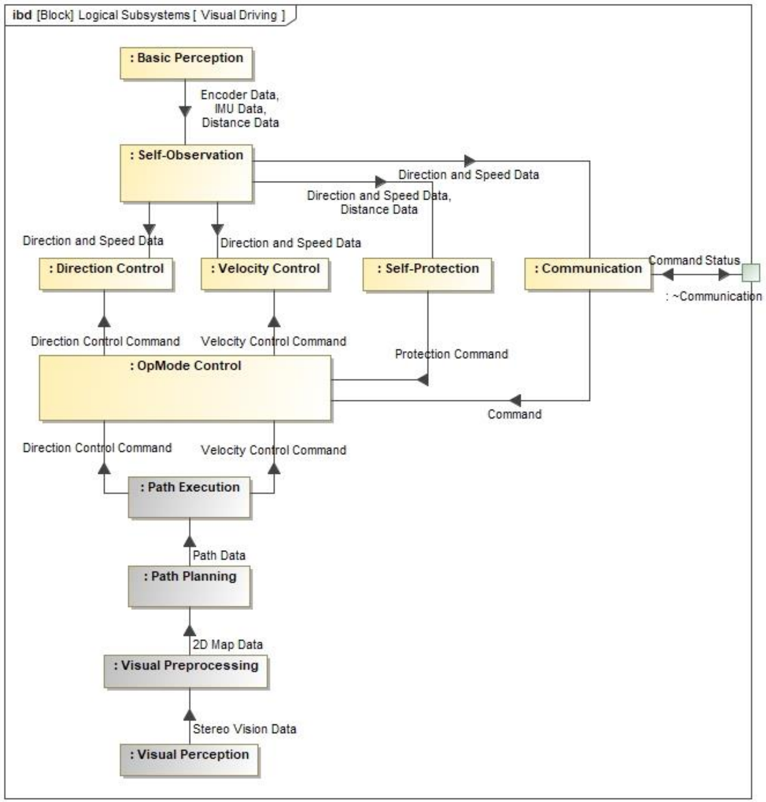

Basic logical system architecture, covering basic use cases

- Logical architecture composed of clearly separated functional components
- Logical architecture extensible and adaptable to cover additional use cases

- Basic set of components (covering basic use cases, see p7)
  - Basic Perception
  - Self-Observation
  - Direction Control and Velocity Control
  - OpMode Control
  - Communication

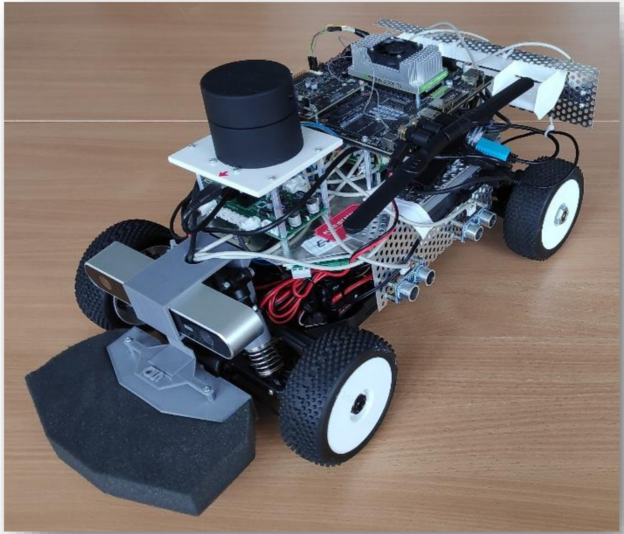
# CeCar architecture
## Logical systems architecture

- Logical architecture extensible and adaptable to cover additional use cases
  - By addition of functional components
  - By replacement of functional components with different functionality
    (but respecting the inherited interface)




Logical system architecture for computer-vision-based driving
(simplified, additional functions in grey color)

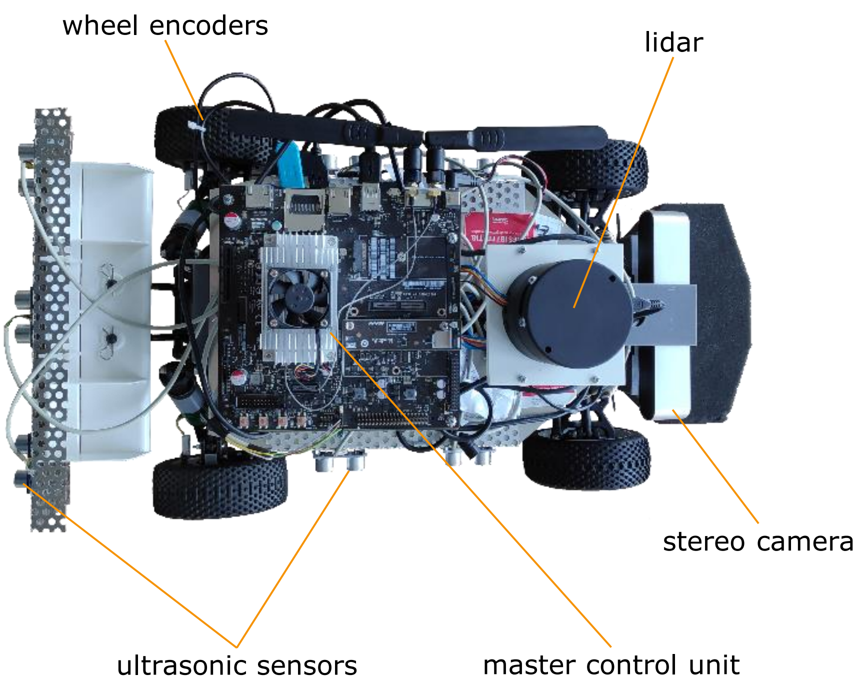
# CeCar architecture
## Technical systems architecture (1)



- Based on a commercial 1/8-scale model racecar kit (Losi 8IGHT-E 4WD Buggy)
- Two computation boards
  - STM32-based real-time control unit (RCU), running FreeRTOS for lower-level control tasks
  - NVIDIA Jetson TX2 master control unit (MCU) under Linux for higher-level control, navigation etc.
- Mechanical system adapted to higher weight
- Mounting points for sensors added
- ROS applied as middleware on MCU
  - Hardware abstraction, device drivers, communication
  - Predefined software modules for commonly used functionality
- MCU and RCU communicating via MAVLink protocol

# CeCar architecture
## Technical systems architecture (2)

- Various sensors, depending on addressed use case
  - Wheel encoders, inertial measuring unit, compass…
  - Ultrasonic sensors, time-of-flight sensors
  - Stereo camera
  - Lidar
  - …



# CeCar architecture
## Modularity

### **Capability layer**

"consists of"

**Hardware capabilities** | **Software capabilities**

"requires"

*Example (computer-vision-based driving)*

| Hardware capabilities | Software capabilities |
|---|---|
| Basic sensor set | Basic functions |
| Stereo camera | Visual Perception |

### **Application layer**

Visual Preprocessing
Path Planning
Path Execution

# Application in research

## Example: Cooperative driving demonstrators

- **Context**
  - Research project AMASS [1] (Architecture-driven, Multi-concern and Seamless Assurance and Certification of Cyber-Physical Systems)
    - Created an open tool platform, ecosystem, and community for assurance and certification of CPS
    - Applied the developed methods and tools to different application areas, including cooperative driving
  - Research project CrESt (Collaborative Embedded Systems) [2]
    - Developed methodological building blocks for collaborative embedded systems
    - Applied the building blocks to use cases from different domains, including cooperative driving

- **Challenge**
  - Implement automotive-type use cases to demonstrate applicability of developed methods and tools onto real-world examples
  - Apply VeloxCar / CeCar platform to evaluate and demonstrate SiReSS reconfiguration methods

- **Status**
  - Demonstrators implemented and methods / tools validated

[1] AMASS (2016 – 2019) was funded by the EU ECSEL JU. [2] CrESt (2017 – 2020) was funded by the German Ministry for Education and Research

# Application in research
## Example: Adaptive systems of systems method development

- **Context**
  - Research project SiReSS [1] (Safety-related reconfiguring systems-of-systems)
    - Aims to develop reconfiguration methods for open systems-of-systems that take into account qualitative and quantitative safety properties of involved systems
    - Use cases from automotive and factory automation domains
- **Challenge**
  - Implement automotive-type use cases such as platooning situation with safety-related reconfiguration
  - Apply CeCar platform to evaluate and demonstrate SiReSS reconfiguration methods
- **Status**
  - Specification and implementation of reconfiguration method in progress

[1] SiReSS is funded by the Berlin Institute for Applied Research (IFAF).

# Application in research
## Experience made

- **Advantages**
  - Very well supports test and demonstration of autonomous and cooperative driving functions
  - Complexity of underlying vehicle system with multiple sensors, connected functionalities and limited redundancies well represented
  - Vehicle dynamics and other “hardware” effects induce “real-world disturbance” into experiments and help to harden solutions

  - Modularity helps to adapt car to different use cases and demonstration scenarios
    - ROS good for car-internal modularity and for communication (internal and V2V / V2I)
    - ROS giving access to features and tools of ROS framework

- **Challenges**
  - Considerable effort going into development and maintenance of CeCar platform
    - Effort needs to be spread over several projects

# Application in development
## Experience made

- Use for pre-development and pre-validation of algorithms, before going to full-size tests cars
  - Prototyping and testing car-local sensor-based algorithms
  - Prototyping and testing connected-car algorithms

- **Advantages**
  - Works well for algorithms that do not depend on detailed sensor characteristics and sensor positioning
  - Results can be easily transposed to full-size cars due to white-box nature of CeCar
  - Provides a very affordable testbed for prototyping and pre-validation

- **Challenges**
  - Low representativeness for environmental sensing algorithms that depend on sensor quality and physical positioning of sensor (ultrasonic sensor, radar, lidar)

# Application in development
## Experience made

- **Advantages**
  - CeCar well suited to different applications fields due to modularity
  - Modularity also allowing to stepwise extent functionality
    - Allows to implement complex functionality within students coursework projects
    - Mimics typical development situation of building onto something inherited from other engineers

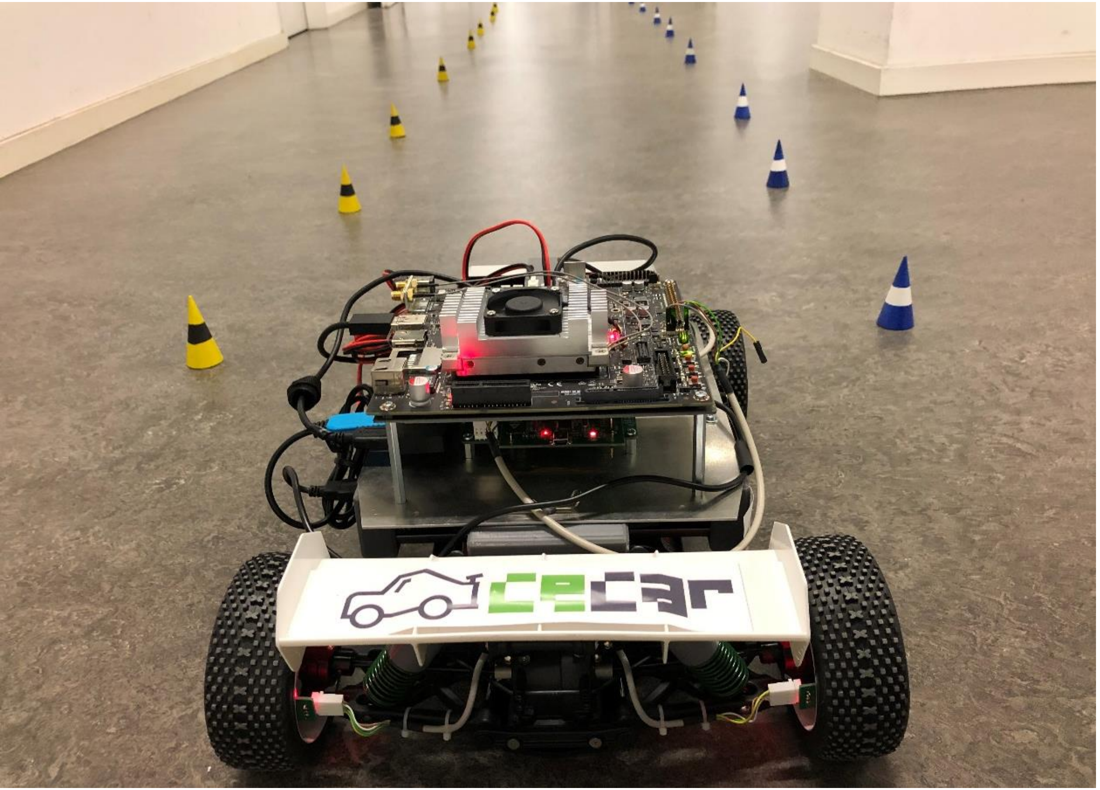
- **Challenges**
  - Platform is complex. Clear system structure and very good documentation required for “quick start” on individual students’ project
  - Person required that permanently “owns” design and acts as “chief engineer” to ensure adequacy and consistency of solutions (not a student)

# Application in education
## Projects at HTW Berlin

- Use as experimentation platform in systems engineering master project (three semesters)
  - Support additional use cases by extending application layer
    - Computer-vision-based driving
    - Lidar-based localization
    - Map-sharing and central visualization
  - As required, extend capability layer (e.g., adding new sensors)

- Use as experimental platform in bachelor theses / master theses
  - Extend or improve specific aspects or elements of functionality
    - Improve motor controller
    - Implement distance measuring functionality using time-of-flight sensors

# Application in education
## Example: computer-vision-based driving




- **Challenge**
  - Automated driving (steering, stopping) based on computer-vision algorithms (no AI)
  - Driving track layout similar to “Formula Student” autonomous driving challenge
- **Status**
  - Project just finished
  - Autonomous steering and stopping in straight and curved tracks well done
  - “Infinity” track layout not yet mastered

CeCar and driving track

# Application in education
## Example: machine-learning-based driving

- **Challenge**
  - Autonomous driving based on machine-learning algorithm
  - Driving track layout similar to “Formula Student” autonomous driving challenge

- **Status**
  - Existing solution (including trained network) ported from MIT RaceCar platform to CeCar platform
  - Modularization and testing still to be done

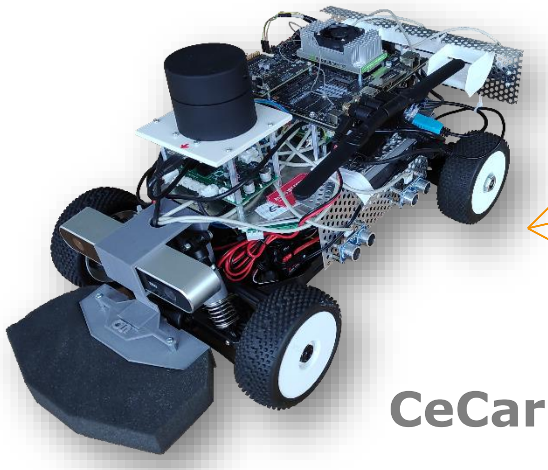
Original MIT RaceCar version of the machine-learning-based autonomously driving model car [2]

# Application in education
## Experience made

- **Advantages**
  - CeCar well suited to different applications fields due to modularity
  - Modularity supporting stepwise extension of functionality
    - Allows to implement complex functionality within limited-time coursework projects
    - Mimics typical development situation of building onto something inherited from other engineers

- **Challenges**
  - Platform is complex. Clear system structure and very good documentation required for “quick start” on individual students’ project
  - Person required that permanently “owns” design and acts as “chief engineer” to ensure adequacy and consistency of solutions (not a student)

# Summary




Affordable development and test platform for autonomous and cooperative driving

Very suitable for applications in research and education

Also usable for prototyping in commercial development, depending on scope and representativeness

- Next steps
  - Porting of platform to ROS2, and re-visiting of some basic technical solutions (motor control, communication between RCU and MCU)
  - Improving CeCar documentation and placing development data online

# References


[1] Dllu (Wikimedia, CC-BY-SA-4.0, https://commons.wikimedia.org/wiki)
[2] P Baumann et al. / HTW Berlin (https://www.deep-teaching.org/courses/robotic-autonomous-driving)

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