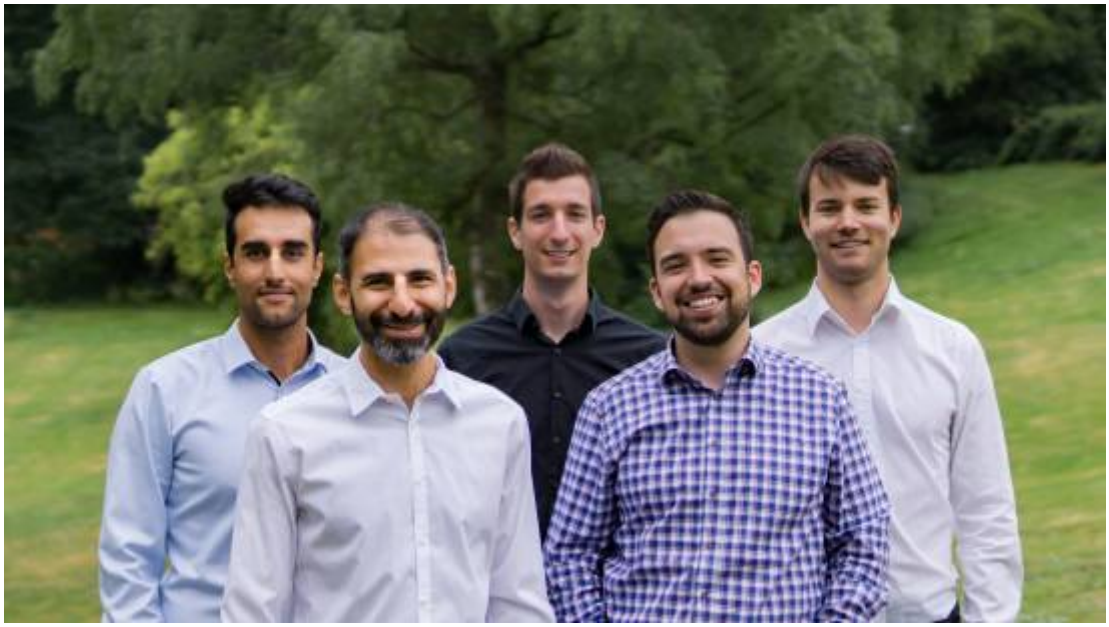
Cyber-Physical Mobility Group

Team

Member	Position / Project
Dr.-Ing. Bassam Alrifaee	Junior Principal Investigator/ Head of Group
Alexandru Kampmann, M.Sc. RWTH	UNICARagil, Localization, CPM Lab
Maximilian Kloock, M.Sc. RWTH	AutoKnigge, CPM Lab
Armin Mokhtarian, M.Sc. RWTH	UNICARagil, CPM Lab
Patrick Scheffe, M. Sc. RWTH	GROKO-Plan, CPM Lab
Barbara Schraml, M.Sc. RWTH	CPM Lab
Stefan Rakel, M.Sc. RWTH	Bicycle Safety



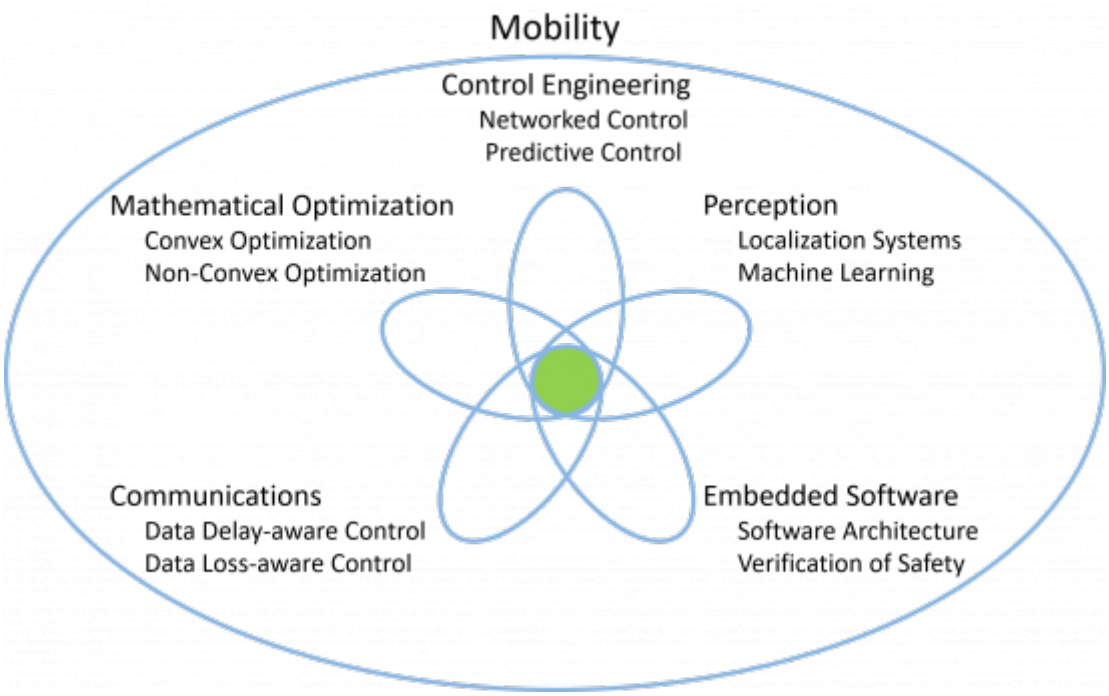
See our CPM Lab website cpm.embedded.rwth-aachen.de
Follow us on

- ResearchGate
- YouTube

Research

Our research in the field of Cyber-Physical Mobility focuses on the interdisciplinary intersection of control engineering, mathematical optimization, communications, embedded software, and

perception. Our research interests include distributed decision-making and verification, service-oriented software architecture, machine learning and their applications to networked and autonomous vehicles.



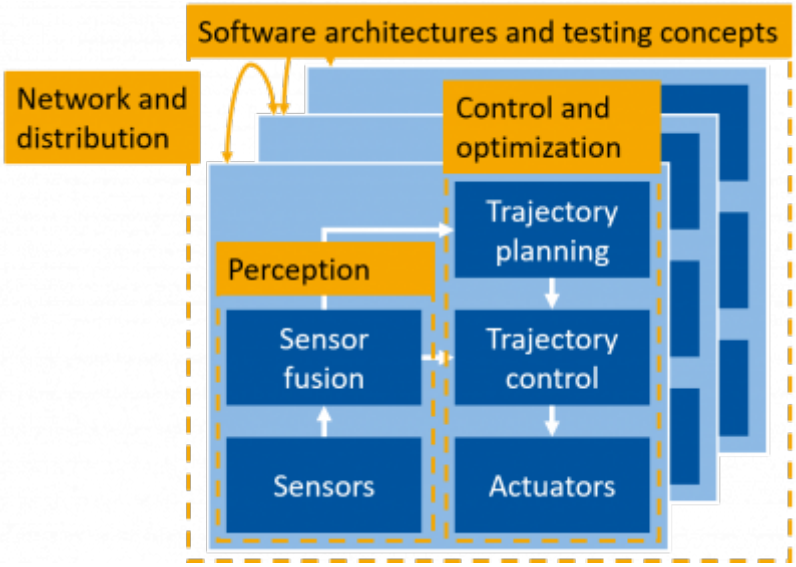
We conduct various projects in this research area funded by public organizations and industrial partners. The Cyber-Physical Mobility Lab is our group-wide project that makes our research results tangible, both for the scientific staff as well as for students.

With our research we contribute to the Future Mobility Center and to the post graduate program "Integrated Energy Supply Modules for Roadbound E-Mobility" (mobilEM). We thank mobilEM for providing a starting fund. We are also an active member of the Mobility & Transport Engineering profile area.

Education

Control and Perception in Networked and Autonomous Vehicles

We offer the course Control and Perception in Networked and Autonomous Vehicles since the winter term 2019/2020. We designed it for master's students of computer science, automation engineering, and computational engineering science. It combines theory with practical exercises in the CPM Lab. The course materials will be provided here soon.



Contact: Patrick Scheffe, M. Sc. RWTH

Practical Course

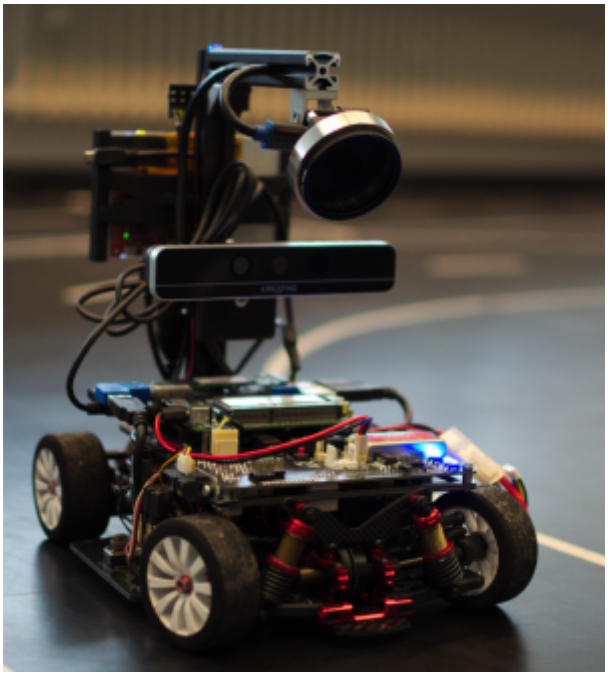
For bachelor's students, we offer a practical course software project in the CPM Lab since the winter term 2019/2020.

Contact: Armin Mokhtarian, M.Sc. RWTH

Team GalaXIs

Since 2008, our student group Team GalaXIs implements perception and control algorithms on an autonomous model-scale vehicle in order to participate in the Carolo-Cup competition. More information can be found at galaxis.rwth-aachen.de.

We are always looking for motivated and ambitious students to join Team GalaXIs.



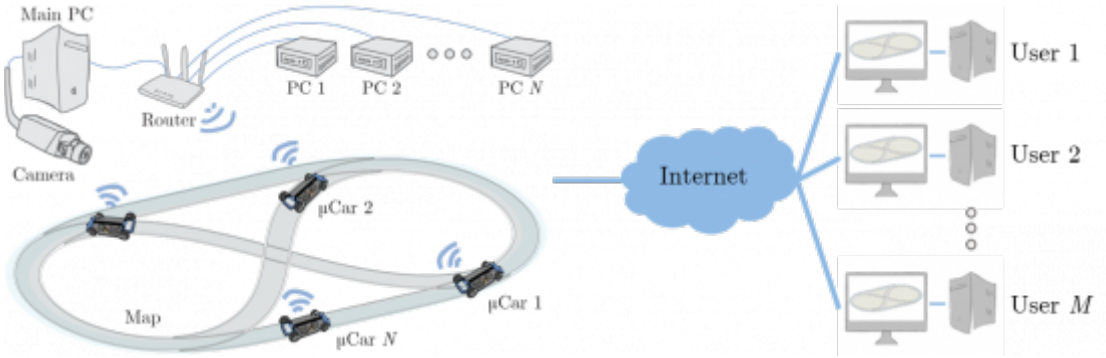
Contact: Alexandru Kampmann, M.Sc. RWTH

Projects

Cyber-Physical Mobility Lab

The Cyber-Physical Mobility Lab (CPM Lab) is an open source, remotely accessible platform for rapid algorithm prototyping for networked and autonomous vehicles. Its unique hierarchical service-oriented architecture enables synchronized computations of different complexity levels. The CPM Lab is our group-wide project that makes our research results tangible, both for the scientific staff as well as for students. Our vision in developing the CPM Lab is to **See your Ideas Develop into Reality!**

For more details on the CPM Lab visit our website cpm.embedded.rwth-aachen.de.



We thank the following programs for providing funds to the CPM Lab

- The post graduate program "Integrated Energy Supply Modules for Roadbound E-Mobility" (mobilEM)
- The project CiTi – Center for integrative Traffic investigation
- The fund "digital teaching and learning infrastructure" of the state NRW
- The quality improvement funds at RWTH Aachen University

Contact: All Cyber-Physical Mobility group members: cpm-info[at]embedded[dot]rwth-aachen[dot]de

UNICARagil

Germany's leading universities in the field of automated vehicles have joined forces with selected specialists from industry in the BMBF funded project UNICARagil to rethink automated vehicles and their architectures. UNICARagil researches disruptive, modular, and agile concepts in hardware and software architecture for fully automated and driverless vehicles. The modular vehicle concept consists of a driving platform and add-on modules, which build the basis for the UNICARagil-vehicles. The UNICARagil-vehicles can be flexibly adapted to a wide range of applications in passenger transport or logistics.

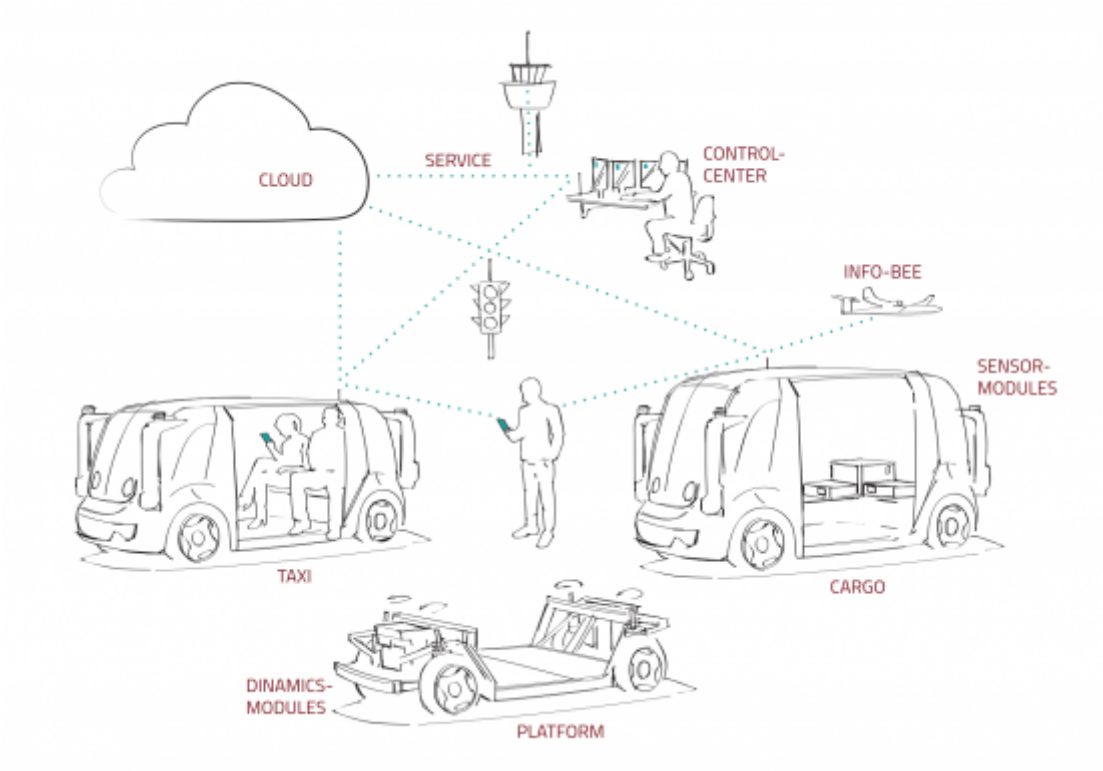
The RWTH Aachen University is involved in the project with the Institute of Automotive Engineering (ika), the Institute and Chair of Flight System Dynamics (FSD) and the Chair of Computer Science 11 - Embedded Software (i11). The i11 is mainly responsible for conceptualization and implementation of a **service-oriented software architecture** as well as an **architecture of cloud-based services**.

Dr.-Ing. Bassam Alrifaee is responsible for the coordination of the digital architecture. Alexandru Kampmann, M.Sc. RWTH and Armin Mokhtarian, M.Sc. RWTH are responsible for the conceptualization and implementation of the service-oriented software architecture and the architecture of cloud-based services.

One outcome of this project is **embeddedRTPS**, a portable DDS implementation for embedded systems that is based on FreeRTOS and lightweightIP. It is available under MIT license on Github.

Read more on the service-oriented software architecture.

Read more on the architecture of cloud-based services.



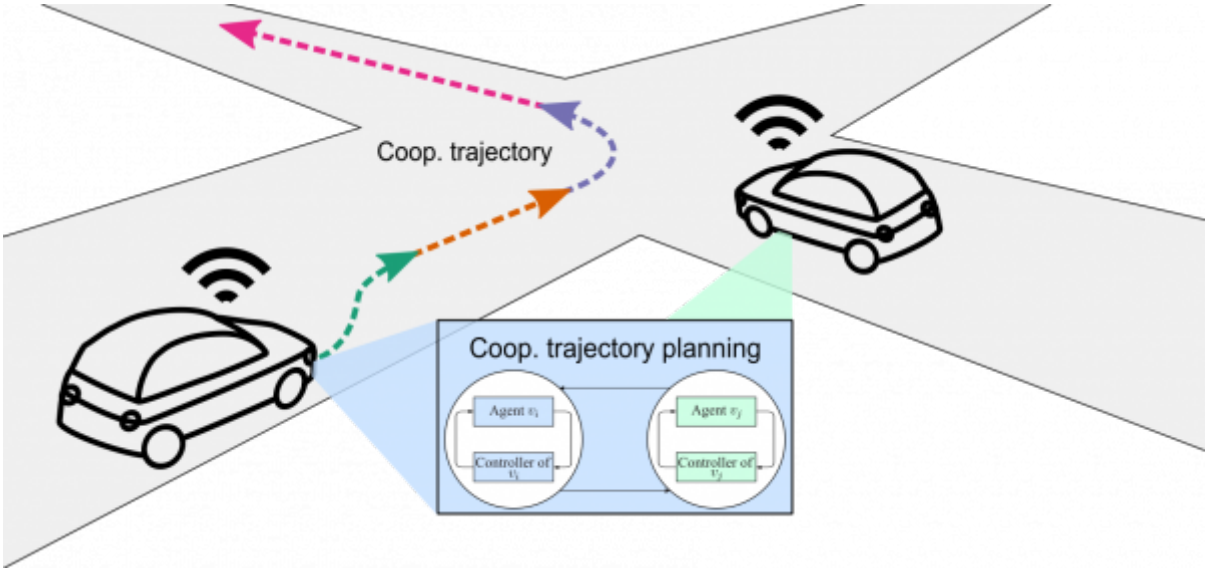
Contact: Alexandru Kampmann, M.Sc. RWTH, Armin Mokhtarian, M.Sc. RWTH

CoInCar

The DFG priority program CoInCar (Cooperative Interacting Automobiles) gathers an interdisciplinary group of researchers to develop a system-theoretical framework for cooperative traffic involving autonomous automobiles. The program promotes research on several topics including

- Cooperative maneuver and trajectory planning
- Situation prediction
- Cooperative perception
- Data and information base
- System ergonomics
- Cross-cutting issues

We are working on two subprojects of the priority program, namely AutoKnigge and GROKO-Plan. Our subprojects belong to the first research area of cooperative maneuver and trajectory planning. In both subprojects, we focus on **distributed decision-making and safety-verification** of interacting vehicles while meeting real-time constraints of traffic.



The figure sketches distributed trajectory planning, where two vehicles communicate necessary data so that each vehicle can plan a collision-free trajectory. Major challenges of distributed trajectory planning are (I) dependability of planned trajectories, (II) real-time compliance of the optimizer on board of the vehicles, and (III) a realizable communication effort between vehicles. The first challenge arises since conflict-free trajectories are mandatory. The second challenge is due to high-dimensional non-convex optimization problems, as they occur when many road users must be considered. The third challenge is caused by the interaction, i.e., to solve the distributed optimization problem on one vehicle while parts of the optimization problems of other road users must be exchanged. In order to meet these challenges, we develop novel methods for networked trajectory planning that reduce the computation time and communications requirements while enhancing the feasibility and quality of control.

AutoKnigge

In the subproject AutoKnigge (Modeling, Evaluation and Verification of Cooperative Interacting Automobiles), we research trajectory planning methods for networked vehicles and methods for safety-verification of the vehicles' motion with our project partners of the Institute for Automotive Engineering (ika) and the Chair of Computer Science 3 - Software Engineering (i3). We plan trajectories using Networked Model Predictive Control (Net-MPC). The planning algorithms use a receding horizon approach in a continuous planning space. The cost function and constraints of the planning problem model the coupling of agents. We research on novel methods for distributed MPC for reducing the complexity of the planning problem. We verify the resulting trajectories using formal methods.

Contact: Maximilian Kloock, M.Sc. RWTH

GROKO-Plan

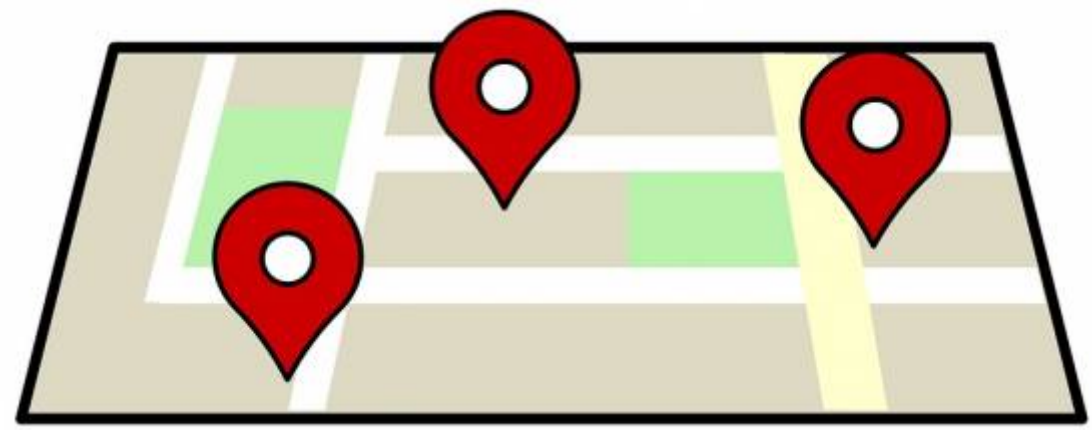
In the subproject GROKO-Plan (Graph-based, Optimal and Cooperative Trajectory Planning for Interacting Automobiles), we research trajectory planning methods for networked vehicles using graph-based methods with our project partner of the Saarland University. The networked planning is

characterized by a receding horizon approach in a discrete planning space. Maneuver automata model the dynamics and couplings of agents. We use graph search algorithms and hybrid optimization to find trajectories in the coupled automata. We focus on developing novel methods for distributed computations in order to reduce the complexity of the planning problem.

Contact: Patrick Scheffe, M. Sc. RWTH

Infrastructure-based Localization

Global Navigation Satellite Systems (GNSS), such as GPS or Galileo, can suffer from performance degradation in urban areas, caused by non-line-of-sight or multipath propagation. Therefore, autonomous vehicles additionally use localization algorithms based on heuristic features extracted from sensor data to alleviate the aforementioned problems. While these algorithms tend to perform better in urban areas than GNSS, these approaches have their own drawbacks. Even state-of-the-art approaches suffer from issues with long-term stability, scarcity or ambiguity of the features. This project pursues the development of a low-cost localization system that is aided by infrastructure-based features to overcome the problems of both approaches.



Contact: Alexandru Kampmann, M.Sc. RWTH

Bicycle Safety

Especially in recent years the number of bicycles on the road is increasing. In contrast to all other traffic participants, the number of accidents for bicycles is increasing as well. While multiple active safety systems exist for cars, such systems are rare for bicycles and pedelecs. The Bicycle Safety project aims to develop a low-cost and portable active safety system for bicycles. This system shall warn riders before a potentially dangerous situation occurs. Possible dangerous situations are sharp corners and changing road surface.

Contact: Stefan Rakel, M.Sc. RWTH

Finished Projects

eNav

The project eNav aimed at the development of a navigation system for disabled electric wheelchair users. For a selected navigation goal, eNav computes a route that

- avoids inaccessible routes for an electric wheelchair
- avoids uncomfortable routes for the electric wheelchair user
- considers the state of charge of the battery
- offers a multi-modal route by combining rides using the electric wheelchair with rides using public transportation systems.

The system can be transferred to research of other electric vehicles, e.g., e-bikes. Read more on the project website.

Statistical Road Surface Model for Improved Positioning

This project pursues the development of a state-of-the-art GNSS/INS, which receives input from a Statistical Absolute Position Estimator (SAPE) for an additional update step. SAPE uses features of the road surface in order to determine the absolute location of the vehicle. More specifically, Hidden Markov Models (HMM) are used for classification of inputs from acceleration sensors. The project has been implemented using a Pedelec.

Open Positions

We are always looking for motivated and ambitious students to join our team. We offer student assistant positions as well as theses in the following areas

- Cyber-Physical Mobility Lab
- Software for networked and autonomous vehicles
- Cooperative interacting vehicles
- Localization of autonomous vehicles

Current open PhD positions can be found here. Additionally, initiative applications for PhD positions, student assistant positions, and theses are welcome. You can send your application to the

corresponding member of the group, or to all members: cpm-info[at]embedded[dot]rwth-aachen.de. For PhD positions, please contact Dr.-Ing. Bassam Alrifaee.

Please include in your application: transcript of records (Bachelor and possibly Master), CV, and certificates.

Participation in Committees

Our group contributes to different national and international committees, e.g., to

- Mobility & Transport Engineering profile area of RWTH Aachen University
- Examination board of the Master's study program Automation Engineering of RWTH Aachen University
- MATLAB-AG of RWTH Aachen University
- IFAC Technical Committee 7.1 on Automotive Control
- IFAC Technical Committee 9.4 on Control Education

We also contribute to the organization of meetings and conferences in our research area, e.g., by organizing special sessions.

Publications

[KST+20]
PDFBIB

Kloock, M. M., Scheffe, P., Tülleners, I., Maczijewski, J., Kowalewski, S., and Alrifaee, B., "Vision-Based Real-Time Indoor Positioning System for Multiple Vehicles", *IFAC-PapersOnLine*, vol. 53, iss. 2, pp. 15446-15453, 2020

Vision-Based Real-Time Indoor Positioning System for Multiple Vehicles

Bibtex entry :

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@article {  KST+20,
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[LvW+20]
PDFBIB

Lampe, B., van Kempen, R., Woopen, T., Kampmann, A., Alrifaee, B., and Eckstein, L., "Reducing Uncertainty by Fusing Dynamic Occupancy Grid Maps in a Cloud-based Collective Environment Model", in *Proc. 2020 IEEE Intelligent Vehicles Symposium (IV) / publisher: IEEE*, Piscataway, NJ, 2020, IEEE, pp. 837-843.

Reducing Uncertainty by Fusing Dynamic Occupancy Grid Maps in a Cloud-based Collective Environment Model

Bibtex entry :

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@inproceedings {  LvW+20,
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Lampe, B., van Kempen, R., Woopen, T., Kampmann, A., Alrifaee, B., and Eckstein, L., "Reducing Uncertainty by Fusing Dynamic Occupancy Grid Maps in a Cloud-based Collective Environment Model", , p. 7, 2020

Reducing Uncertainty by Fusing Dynamic Occupancy Grid Maps in a Cloud-based Collective Environment Model

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[MKA+20]
PDFBIB

Mokhtarian, A., Kampmann, A., Alrifaee, B., Kowalewski, S., Lampe, B., and Eckstein, L., "Agile Requirement Engineering for a Cloud System for Automated and Networked Vehicles", in *Proc. 2nd International Workshop on Autonomous Systems Design : ASD 2020, March 13, 2020, Grenoble, France, converted to a virtual event due to COVID-19, held in April 2020 / edited by Sebastian Steinhorst, Jyotirmoy V. Deshmukh*, Saarbrücken/Wadern, Germany, 2020 in OpenAccess Series in Informatics, Schloss Dagstuhl - Leibniz-Zentrum für Informatik GmbH, Dagstuhl Publishing, August, p. 4:1-4:8.

Agile Requirement Engineering for a Cloud System for Automated and Networked Vehicles

Bibtex entry :

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@inproceedings {  MKA+20,
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PDFBIB

Mokhtarian, A., Kampmann, A., Alrifaee, B., and Kowalewski, S., "The Dynamic Service-oriented Software Architecture for the UNICARagil Project", in *Proc. 29. Aachen Colloquium Sustainable Mobility : October 5th-7th, 2020, digital event / scientific management: Univ.-Prof. Dr.-Ing. Lutz Eckstein, Univ.-Prof. Dr.-Ing. Stefan Pischinger ; organizational management: Michaela Wacker (M. Sc.), Jonas Müller (M. Sc.) ; organized by: Institute for Automotive Engineering, RWTH Aachen University; Institute for Combustion Engines, RWTH Aachen University. - 1: October 6th, 2020*, Aachen, 2020, Institute for Automotive Engineering, RWTH Aachen University ; Aachen : Institute for Combustion Engines, RWTH Aachen University, pp. 275-284.

The Dynamic Service-oriented Software Architecture for the UNICARagil Project

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[SMK+20]
PDFBIB

Scheffe, P., Maczijewski, J., Kloock, M. M., Kampmann, A., Derks, A., Kowalewski, S., and Alrifaee, B., "Networked and Autonomous Model-scale Vehicles for Experiments in Research and Education", *IFAC-PapersOnLine*, vol. 53, iss. 2, pp. 17332-17337, 2020

Networked and Autonomous Model-scale Vehicles for Experiments in Research and Education

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[KAK+19]
PDFBIB

Kampmann, A., Alrifaee, B., Kohout, M., Wüstenberg, A., Woopen, T., Nolte, M., Eckstein, L., and Kowalewski, S., "A Dynamic Service-Oriented Software Architecture for Highly Automated Vehicles", in *Proc. The 2019 IEEE Intelligent Transportation Systems Conference - ITSC : Auckland, New Zealand, 27-30 October 2019 / IEEE, IEEE-ITSC 2019, ITSS - IEEE Intelligent Transportation Systems Society*, Piscataway, NJ, 2019, IEEE, pp. 2101-2108.

A Dynamic Service-Oriented Software Architecture for Highly Automated Vehicles

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@inproceedings {  KAK+19,
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PDFBIB

Kloock, M., Kragl, L., Maczijewski, J., Alrifaee, B., and Kowalewski, S., "Distributed Model Predictive Pose Control of Multiple Nonholonomic Vehicles", in *Proc. IV19 : 30th IEEE Intelligent Vehicles Symposium : 9-12 June 2019, Paris / publisher: IEEE*, [Piscataway, New Jersey], 2019, IEEE, pp. 1620-1625.

Distributed Model Predictive Pose Control of Multiple Nonholonomic Vehicles

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Keilhoff, D., Niedballa, D., Reuss, H., Buchholz, M., Gies, F., Dietmayer, K., Lauer, M., Stiller, C., Ackermann, S., Winner, H., Kampmann, A., Alrifaee, B., Kowalewski, S., Klein, F., Struth, M. M., Woopen, T., and Eckstein, L., "UNICARagil - New architectures for disruptive vehicle concepts", in *Proc. 19. Internationales Stuttgarter Symposium : Automobil- und Motorentechnik / herausgegeben von Michael Bargende, Hans-Christian Reuss, Andreas Wagner, Jochen Wiedemann*, Wiesbaden, 2019 in Proceedings Springer eBooks, Springer Fachmedien Wiesbaden, pp. 830-842.

UNICARagil - New architectures for disruptive vehicle concepts

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        and Ackermann, Stefan and Winner, Hermann and Kampmann,
        Alexandru and Alrifaee, Bassam and Kowalewski, Stefan and
        Klein, Fabian and Struth, Michael Manfred and Woopen, Timo
        and Eckstein, Lutz },
    title = { UNICARagil - New architectures for disruptive vehicle
        concepts },
    booktitle = { 19. Internationales Stuttgarter Symposium :
Automobil- und
        Motorentechnik / herausgegeben von Michael Bargende,
        Hans-Christian Reuss, Andreas Wagner, Jochen Wiedemann },
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    pages = { 830-842 },
    series = { Proceedings Springer eBooks },
    year = { 2019 },
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    organization = { 19. Internationales Stuttgarter Symposium :
Automobil- und
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    author = { Kloock, Maximilian Martin and Scheffe, Patrick and Botz,
        Lukas and Maczijewski, Janis and Alrifaee, Bassam and
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    title = { Networked Model Predictive Vehicle Race Control },
    booktitle = { The 2019 IEEE Intelligent Transportation Systems
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        IEEE-ITSC 2019, ITSS - IEEE Intelligent Transportation
        Systems Society },
    publisher = { IEEE },
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    pages = { 1552-1557 },
    year = { 2019 },
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Conference,
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    typ = { PUB:(DE-HGF)7 },
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    url = { http://publications.rwth-aachen.de/record/773727 },
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Bibtex entry :

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    author = { Kloock, Maximilian Martin and Scheffe, Patrick and
        Marquardt, Sascha and Maczijewski, Janis and Alrifaee,
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    title = { Distributed Model Predictive Intersection Control of
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        IEEE-ITSC 2019, ITSS - IEEE Intelligent Transportation
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    publisher = { IEEE },
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    url = { http://publications.rwth-aachen.de/record/773728 },
}
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Bibtex entry :

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@inproceedings {  KWA+19,
    author = { Kampmann, Alexandru and W{\"u}stenberg, Andreas and
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    title = { A Portable Implementation of the Real-Time Publish-
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    booktitle = { The 2019 IEEE Intelligent Transportation Systems
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        - ITSC : Auckland, New Zealand, 27-30 October 2019 / IEEE,
        IEEE-ITSC 2019, ITSS - IEEE Intelligent Transportation
        Systems Society },
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    pages = { 443-448 },
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    cin = { 122810 / 120000 },
    url = { http://publications.rwth-aachen.de/record/773701 },
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    author = { V{\"o}lker, Marcus and Kloock, Maximilian and Rabanus,
Leon
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    title = { Verification of Cooperative Vehicle Behavior using
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    volume = { 52 },
    number = { 8 },
    year = { 2019 },
    address = { Frankfurt ; M{\"u}nchen [u.a.] },
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    organization = { 10th IFAC Symposium on Intelligent Autonomous
Vehicles,
        Gdansk (Poland), 2019-07-03 - 2019-07-05 },
    doi = { 10.1016/j.ifacol.2019.08.055 },
    typ = { PUB:(DE-HGF)16 },
    reportid = { RWTH-2019-08318 },
    cin = { 122810 / 120000 },
    url = { http://publications.rwth-aachen.de/record/766778 },
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    booktitle = { 2018 IEEE Intelligent Vehicles Symposium (IV) : 26-30
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    year = { 2018 },
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    organization = { 2018 IEEE Intelligent Vehicles Symposium, Changshu
(Peoples
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    doi = { 10.1109/IVS.2018.8500634 },
    typ = { PUB:(DE-HGF)7 },
    reportid = { RWTH-2018-229489 },
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    url = { http://publications.rwth-aachen.de/record/748563 },
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    author = { Grochowski, Marco and Schweigler, Martin and Alrifaee,
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    title = { A GPS-aided Inertial Navigation System for Vehicular
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    journal = { IFAC-PapersOnLine },
    pages = { 121-126 },
    volume = { 51 },
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    year = { 2018 },
    address = { Laxenburg },
    issn = { 2405-8963 },
    organization = { 3rd IFAC Conference on Embedded Systems,
Computational
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        2018-06-06 - 2018-06-08 },
    doi = { 10.1016/j.ifacol.2018.06.247 },
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[WLB+18]
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    author = { Woopen, Timo and Lampe, Bastian and B{\"o}ddeker, Torben
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        and Kowalewski, Stefan and Moormann, Dieter and Stolte,
        Torben and Jatzkowski, Inga and Maurer, Markus and
        M{\"o}stl, Mischa and Ernst, Rolf and Ackermann, Stefan and
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    booktitle = { 27. Aachen Colloquium Automobile and Engine
Technology :
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        scientific management: Univ.-Prof. Dr.-Ing. Lutz Eckstein,
        Univ.-Prof. Dr.-Ing. Stefan Pischinger ; organizational
        management: Benedikt Hammerm{\"u}ller (M. Sc.), Dipl.-Ing.
        Rainer Wolsfeld ; organized by: Institute for Automotive
        Engineering (RWTH Aachen), Institute for Combustion Engines
        (RWTH Aachen) },
    publisher = { Institute for Automotive Engineering, RWTH Aachen ;
Aachen :
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}
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@inproceedings {  AMA17,
    author = { Alrifaee, Bassam and Maczijewski, Janis and Abel, Dirk
},
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        Collision Avoidance },
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and
        Applications : Kohala Coast, Hawai'i, August 27-30, 2017 :
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        SICE },
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Applications,
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