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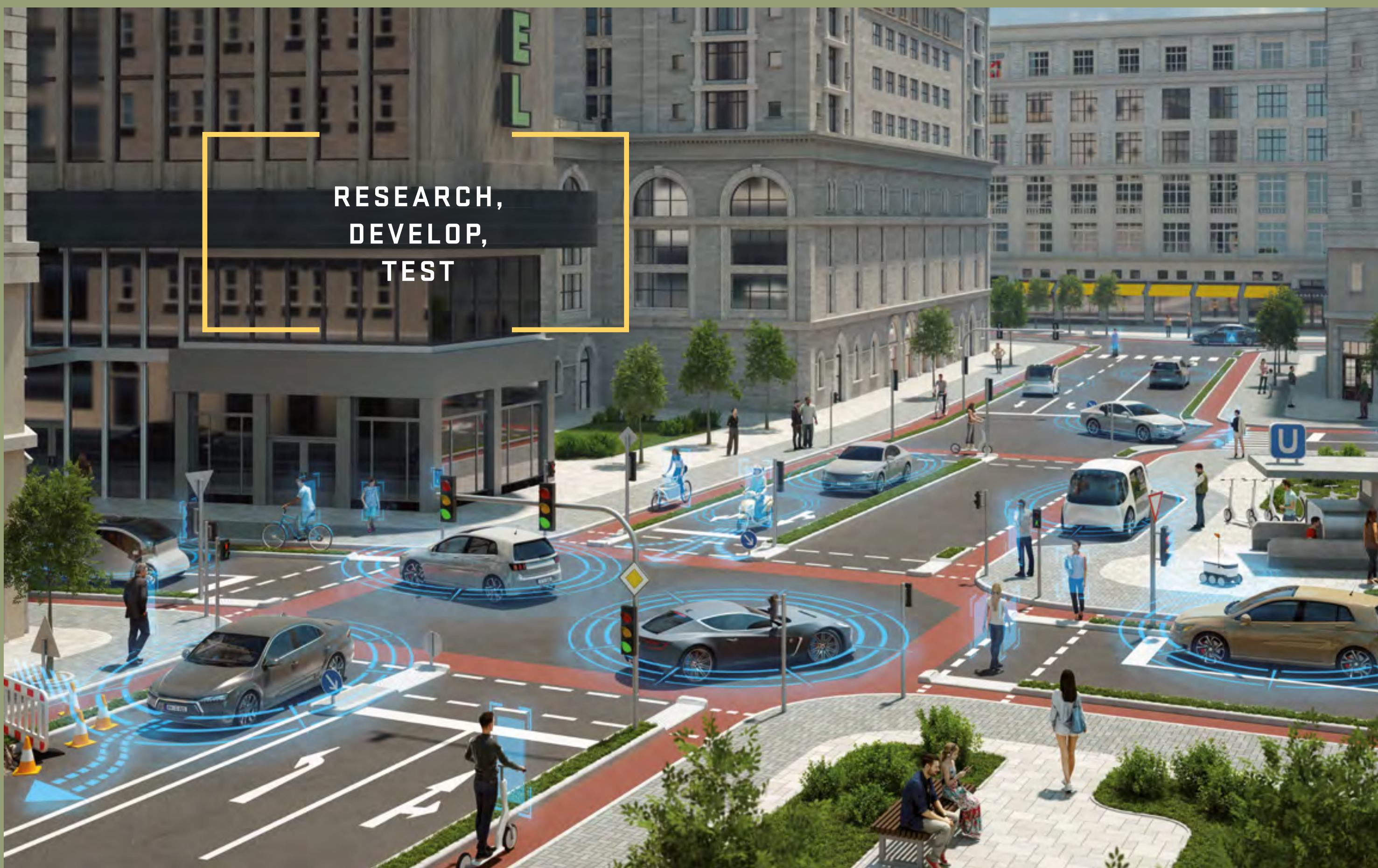
STADT:up

TRAVELLING TOGETHER TOWARDS THE URBAN TRANSPORT OF THE FUTURE

Concepts and pilot applications for continuous automated driving in urban areas



Preface

Automated driving requires networked expertise

If a vision is to become reality, as we all know, as many people as possible need to share it. I am therefore all the more pleased about the broad alliance of different players who are pooling their individual expertise as part of STADT:up in order to realise continuous automated driving in the city. They are all united not only by the goal of making transport in our cities more climate-friendly, safer, more efficient and more comfortable in the future; behind this pioneering project is also the clear will to play a decisive role in shaping the far-reaching transformation processes in the mobility sector instead of leaving the field to others. From car manufacturers to suppliers, from research institutions to technology providers, a total of 20 partners are pulling together – and are also drawing on valuable findings from the project families of the VDA's flagship initiative "autonomous and connected driving". In other words: STADT:up specifically promotes pre-competitive cooperation – and at the same time acts as an important interface between business and science. This provides us with an ideal starting point for quickly turning research results into marketable products in a productive co-operation.

And while we're on the subject of togetherness: Of course, all of this is taking place in close dialogue with those responsible in cities and municipalities – for whose urban spaces continuous automated driving is to form a central component of future (intermodal) mobility concepts; be it in the form of robo-taxis that are seamlessly linked to local public transport services, shared vehicles, innovative solutions for 'last mile' deliveries or much more. The fact that we are thinking and acting in the right direction with our holistic project approach is confirmed not least by the support from the Federal Ministry for Economic Affairs and Energy. Through its comprehensive financial support, it provides a clear commitment to shaping urban mobility in line with people's needs and, of course, to Germany as an automotive centre – which wants to and will continue to occupy a leading position worldwide in the highly competitive future market of automated driving.

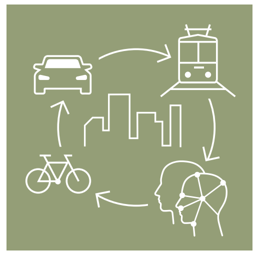
Yours,
Dr Lutz Bürkle
STADT:up project coordinator

STADT:UP BRIEFLY EXPLAINED

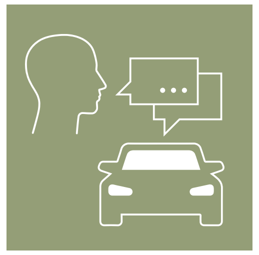
STADT:up stands for "Systems and Technologies for Automated Driving in Town: an urban mobility project". In this joint research project, 20 partners – including automotive manufacturers, suppliers and research institutions – have joined forces. Supported by the Federal Ministry for Economic Affairs and Energy, they are devoting three and a half years of project work on the challenging task of developing concepts and pilot applications for continuous automated driving in complex urban areas, using the latest AI methods and data-driven models.

THE FIVE SUBPROJECTS

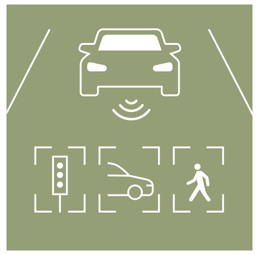
01 Prospects of Urban Mobility



02 Human Factors



03 Environment and Context



04 Situation Analysis and Planning

05 Automated Driving

PROJECT PROFILE

SUPPORTED BY : Federal Ministry for Economic Affairs and Energy

RESEARCH PROGRAMME : Neue Fahrzeug- und Systemtechnologien

BUDGET : ca. 62,2 million

TIMELINE : 2023/01/01 – 2026/06/30

PARTNER

Aptiv Services Deutschland GmbH : AUMOVIO Autonomous Mobility Germany GmbH : AUMOVIO Germany GmbH : AVL Deutschland GmbH Bundesanstalt für Straßen- und Verkehrswesen (BASt) : CARIAD SE : DeepScenario GmbH : Deutsches Zentrum für Luft- und Raumfahrt e.V. : Ergosign GmbH : gestigon GmbH : HELLA GmbH & Co. KGaA : Hochschule für angewandte Wissenschaften München Mercedes-Benz AG : Opel Automobile GmbH : Robert Bosch GmbH : Technische Universität Chemnitz : Technische Universität Darmstadt Technische Universität München : Valeo Schalter und Sensoren GmbH : ZF Friedrichshafen AG

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Forced, structured, concerted:

How STADT:up is paving the way for continuous automated driving in the highly complex urban traffic system

Almost 80 per cent of the German population lived in cities in 2022. At the same time, the millions of people who move around there in a comparatively small area are united by one need: to be mobile. With a view to the city as an area of liveable coexistence, the current design of motorised private transport impressively demonstrates the limits: from stop-and-go in daily commuter traffic to increasing emissions and the issue of road safety with vulnerable road users as the main victims.

Connected, efficient and safe urban transport for everyone: In order to realise this vision, 20 project partners are working together on STADT:up.

In view of this, the STADT:up joint project, which was launched on 1 January 2023, is dedicated to two key areas: On the one hand, the prototypical realisation of continuous automated driving in the city is on the agenda. At the same time, the researchers are working on developing sustainable, intermodal mobility concepts – combined with the question of what role automated vehicles can play in this context. "Various studies clearly show the potential of these technologies. Automated driving not only offers the opportunity to significantly increase road safety; it also enables the existing infrastructure to be utilised much more efficiently. Last but not least, climate-damaging emissions can be reduced through intelligent networking with other forms of mobility", summarises Dr Lutz Bürkle from Robert Bosch GmbH. The STADT:up project coordinator goes on to explain that the latest AI-based methods are also being used in development along the entire signal processing chain to ensure that automated vehicles can handle even complex traffic scenarios in cities. In total, the project combines the expertise of 20 partners – car manufacturers, the supplier industry, technology providers and research – with the actual project work taking place in five sub-projects.

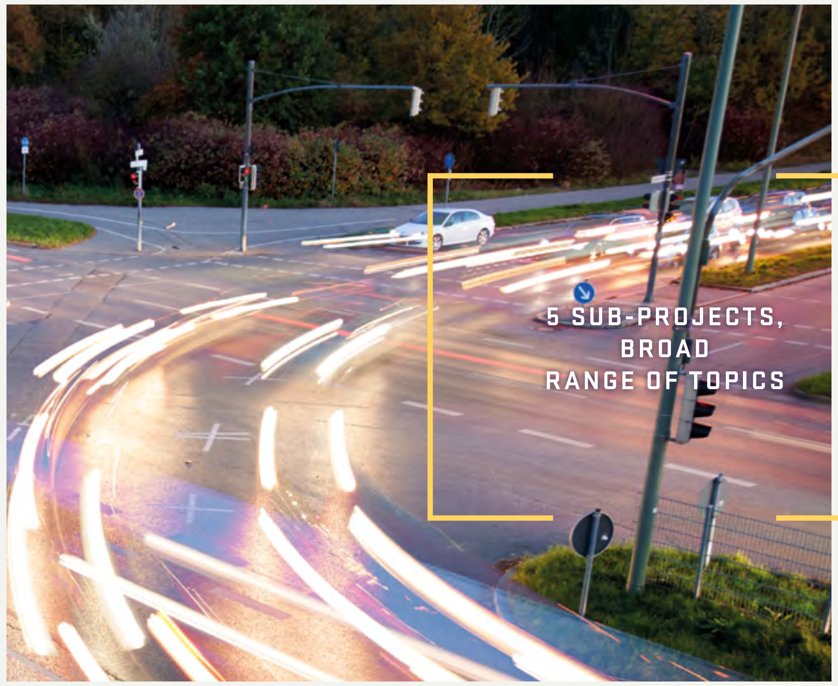
One of these, the "Environment and Context" sub-project, deals with the question of how automated vehicles can correctly recognise and interpret the traffic situation. Cameras as well as lidar and radar systems play a key role here. Sensor setups like these are supplemented by special algorithms and new approaches for data fusion. As a result, this ensures maximum reliability – even under difficult (weather) conditions or in confusing traffic situations.

The "Situation Analysis & Planning" sub-project is about planning driving manoeuvres in urban traffic in advance and making decisions. To do this, an automated vehicle needs predictive, i.e. anticipatory, capabilities. After all, it should always "keep an eye" on the options of other players. Basic interaction and cooperation models are also being developed in this sub-project, as an automated vehicle must be able to provide gaps when other cars are merging, for example, or to abort a merging manoeuvre itself if others are not cooperative. And finally, the vehicles are to be given the ability to temporarily violate the rules in exceptional cases – for example, by crossing a solid line to make way for an emergency vehicle.

Of course, these and countless other driving manoeuvres could not be carried out safely without the vehicle interacting and communicating with other road users. Besides communication with the outside world, the project participants are also dedicated to developing understandable and acceptance-promoting operating and display concepts for the vehicle interior. A central starting point is the prototypical implementation of an empathic assistant that recognises the emotional states of passengers and reacts to them according to the situation.

The final fifth sub-project of STADT:up, "Automated Driving", will make it possible to experience how continuous automated driving can ultimately function in the city. For this purpose, both simulators and test vehicles are used to test and demonstrate automated driving on the test track or in real traffic. These demonstrations focus on challenging traffic situations that are commonplace in urban traffic – i.e. complex junctions, threading into heavy traffic, passing obstacles when there is oncoming traffic, interacting with vulnerable road users or other imponderables typical of urban traffic.

But automated driving functions can not only literally take individual transport – whether in private cars or robo-taxis – to the next level. They also harbour valuable potential for the entire urban mobility chain, for example through the intelligent networking of autonomous shared vehicles with public transport services. These and other forward-looking mobility concepts are the subject of the sub-project "Prospects of Urban Mobility". The basis for this is provided by a broad-based dialogue platform with extensive participation formats. They help, for example, to collect city-specific needs and expectations, transfer them into a realistic simulation (digital twin) – and ultimately derive new approaches for the diverse urban transport space.



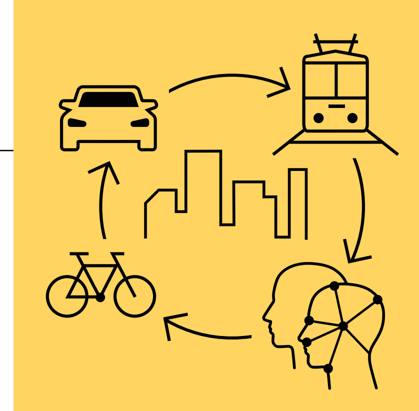
01

Prospects of Urban Mobility

One thing is certain: No two cities are the same, from the cityscape and population structure to the economic conditions and the respective traffic concept. What unites them all, however, is the task of making their inner-city mobility flows future-proof in environmental, economic and social terms. From these aspects, automated driving is a reasonable addition to urban mobility – but how can automated driving be best integrated as a building block in the intermodal urban mobility of tomorrow?

From the dialogue to the model to planning options

Bicycle lanes, conversion of car parks into bicycle parking facilities or even open-air bar areas for restaurants, more frequent public transport services, implementation of measures to improve the quality of life and the quality of stay ... When it comes to transport planning, German cities are currently taking a wide variety of paths towards the future – also out of an intrinsic interest in meeting the sometimes rapidly changing needs of residents in the best possible way. "Before the pandemic, working from home was the exception rather than the rule – today, this working model is standard in many industries. At the same time, in recent years we have seen an increasing shift in mentality towards a more environmentally sustainable lifestyle. We have to take all of this into account if we want to generate real added value with the integration of autonomous mobility in cities", says Prof Dr Klaus Bengler from the Technical University of Munich. Together with his colleague Prof Dr Klaus Bogenberger, he is responsible for the STADT:up sub-project "Prospects of Urban Mobility". According to Bogenberger, it was therefore no coincidence that a broad-based dialogue platform was placed at the beginning of the project work. In expert interviews with the technology partners involved in STADT:up, the researchers first get an idea of the technical possibilities in the field of automated and connected driving – before they determine the city and resident-specific needs in dialogue with city representatives. The information gathered will then be collated in a synthesis workshop in order to derive potential future scenarios for intermodal mobility concepts.



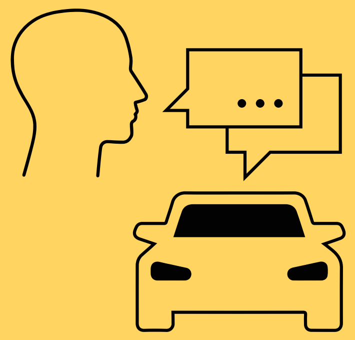
Who moves when, with what – and where?

To illustrate this, the participants in the sub-project are modelling a so-called digital twin of urban mobility in a second step. Information from mobility tracking and other traffic data sources, such as automated vehicles as future "super sensors", which will constantly collect important data about the traffic situation while driving or parked, will be used for this purpose. The realistic simulation created in this way conveys a tangible overall picture of urban traffic, with the main focus on all those who move from A to B in cities on a daily basis using a wide variety of means of transport: whether in their own car, on a bicycle, in an on-demand shuttle or on a bus that runs on a fixed schedule. A further focus is therefore on the digital image of the user, the identification and modelling of information requirements, experience and movement in the transport system. In this context, interfaces between the individual modes of transport naturally also play an important role. This consistent focus on users is deliberate; after all, key aspects such as trust, acceptance and the reduction of uncertainty are crucial to the success of future urban mobility concepts.

Integrative, intermodal, realistic

The needs of all stakeholders have been recorded, the technical possibilities clarified and transition points between different types of mobility identified. In the further course of the sub-project, the digital twin can now be used to simulate and subsequently evaluate specific use cases as part of a shared mobility system. This is done both at the level of individual vehicles (microscopically) and on the basis of simplified driving models (mesoscopically). The researchers expect this to provide answers to fundamental questions that cities are facing with regard to the integration of automated vehicles into their mobility chains: How can the user experience of efficient transport systems in particular be significantly improved compared to the current situation? How can the locations of entry, transfer and exit points be optimised? And which business models are suitable for economically and environmentally sustainable operations? How do the visions of cities regarding the integration of automated vehicles match the needs and acceptance of potential users? Through this holistic approach, the sub-project – in accordance with its name – opens up concrete perspectives: On the one hand, this helps cities to drive forward their mobility planning in line with the needs of their residents and at the same time to invest in the right technologies. On the other hand, the results obtained provide the automotive and supplier industry with a reliable planning horizon for developing automated vehicles and technologies that can be precisely integrated into future urban mobility concepts.

New perspectives required: To keep cities liveable in the long term, traffic flows and mobility needs must be considered holistically.



People at the centre

Enhanced safety, fewer emissions, more efficient traffic flows: As reasonable as the concept of continuous automated driving in the city may be from a fact-based perspective, human factors will ultimately determine the success of the project. What does it take for the occupants to trust the automated vehicle? How can the technology recognise and react to the respective dispositions of the people on board? And which solutions are suitable for internal and external communication? In the second sub-project, "Human Factors", the STADT:up project partners are researching suitable answers.

What a decade ago was mostly reserved for higher-end cars has long since established itself on a broad front: Modern driver assistance systems that can intervene in the driving process can now be found in almost all vehicle classes – right down to small and very small cars. And yet it is still a strange feeling for many people when, for example, the active lane departure warning system noticeably counter-steers for the first time when crossing the lane boundary or the adaptive cruise control automatically reduces speed. "Ultimately, the acceptance of these assistants on the part of the users has made a decisive contribution to their high market penetration", states Stephan Cieler from AUMOVIO Germany GmbH. "If we now look at the envisaged technological leap towards truly continuous automated driving, it quickly becomes clear: The greatest possible sense of security, system trust and comfort experience are key enablers for the success of our project", explains the project manager of the second STADT:up sub-project.

Human Factors 02

Empathy as a key competence

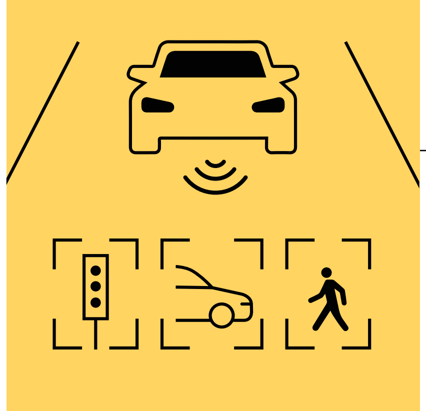
As part of a holistic approach, the project participants are therefore working on designing adaptive operating and lighting concepts for automated vehicles. Solutions are also being developed to continuously record the emotional states of passengers using various sensor systems: Are the people on board relaxed, nervous, overwhelmed or possibly even angry? Does automated driving even go hand in hand with discomfort? The researchers will develop a prototype empathic assistant to interpret such emotional states and the corresponding reaction to them – in other words, a confidence-building system that acts as a kind of "co-pilot". And as with the example of driver assistance systems mentioned above, the same naturally applies with regard to highly automated driving: At some point, the users have become accustomed to using it. Accordingly, the interfaces to be researched – so-called Human Machine Interfaces (HMI) – should be able to take such learning effects into account.

Smart solutions for remote interventions

The development of user-centred solutions is also the focus of another work package in this sub-project. Among other things, the focus is on the question of how operating and display concepts must be designed so that a smooth transition between different levels of automated driving (Level 1-5 according to the SAE standard) can take place – ergo: If, for example, a particular situation requires a change from Level 3 (the driver may temporarily turn away from the traffic situation) to Level 2, where permanent human monitoring is required, the vehicle must be able to communicate this to the person behind the wheel. The prerequisite for this is a reliable assessment of the current state of attention based on physiological and psychological data. If it turns out that a handover to a human is not possible – for example as a result of a medical emergency – teleoperation can come into play. In addition to the technical supervision of automated vehicles required by law, this also includes the possibility of remote intervention. That is to say: The STADT:up project partners will test how a teleoperator can take control of the automated vehicle so that risks can be minimised if the worst comes to the worst.

Clear communication

Back to the aforementioned human-machine interfaces: These not only play a fundamental role in the interaction between the vehicle and passengers. If automated cars are to operate safely in urban mobility contexts, they must of course communicate with numerous other road users and clearly express their intentions. This could be done, for example, in relation to a human driver who wants to enter a busy road – and for whom the automated vehicle provides a gap in the sense of cooperative behaviour. For these and other cases (especially communication with vulnerable road users), light-based HMI concepts are being developed as part of the sub-project, which should enable situationally adapted interaction in a 360-degree radius.



See what is – and understand what's going on

A clear field of vision at all times, two lanes in each direction for many kilometres – on which only cars, commercial vehicles and motorbikes travel: Automated vehicles cannot count on all this "luxury" in urban mobility contexts. And yet, even under difficult conditions, they must be able to reliably detect what is happening around them at all times. The STADT:up project partners are researching how this mammoth task can be solved using state-of-the-art sensor technology and algorithms in the "Environment and Context" sub-project.

Not a diagram from a driving school test: This is a good example of the details of the environment that automated vehicles have to recognise and classify.

What characterises us humans is not only the ability to absorb a gigantic flood of information in fractions of a second with the help of our senses. At the same time, the human brain can compare, evaluate and categorise this information almost immediately with what it has learned. A concrete example from urban road traffic: You are driving along a road and see that there is a zebra crossing some distance away. The traffic knowledge we have learnt tells us: Pedestrians have priority here. Shortly afterwards, a person becomes visible approaching the zebra crossing, but stops a few metres before the crossing and crouches down. The comparison with learnt knowledge shows: Either the person has lost something or wants to tie their shoe – so they may not continue walking on the zebra crossing. All these processes of recognition and categorisation happen so casually that we only become aware of the work behind them when we break them down into their sub-steps. "To put it simply, that's exactly what we do in our work packages", emphasises Dr Alexander Nagel from Valeo Schalter und Sensoren GmbH, who is responsible for development in the third sub-project of STADT:up. "We are therefore looking at how automated vehicles in urban traffic can perceive their environment holistically, contextualise the information they gather and localise themselves precisely, even under challenging conditions or in unusual or unexpected situations. To do this, we make extensive use of methods from the fields of artificial intelligence and machine learning".

Everything in view - at all times

In the first work package, the researchers are therefore focussing intensively on the topic of environmental perception. The radar and lidar sensors and camera systems installed in the vehicles play a key role here. Not only must they act as reliable "eyes" under all external conditions, they must also be trained to distinguish dynamic objects in traffic from static ones. At the same time, it must be ensured that an automated vehicle can correctly categorise even unknown yet relevant objects – from lost cargo to new types of vehicles, construction machinery, etc. To this end, so-called open-world models are to be investigated, which place comparatively weak requirements on the respective object characteristics – in other words, they work in a less template-like manner.

New fusion concepts for more reliability

As indicated at the beginning, the second sub-project step now involves combining data from a wide variety of environmental sensors (fusion). This results in a precise overall picture of the vehicle's surroundings and also makes it possible to compensate for any incorrect information – for example, if an optical sensor is unable to work correctly due to strong sunlight. The scientists are utilising new concepts for the fusion of raw sensor data. The advantage: Since no filtering takes place in advance, a maximum amount of information is available, which in turn contributes to a highly consistent perception of the surroundings. At the same time, the sensor data are linked with learned prior knowledge (such as traffic rules or behavioural patterns). This enables the technology to correctly assess potentially ambiguous situations such as the aforementioned case of the kneeling pedestrian in front of the zebra crossing. Based on this scene interpretation, it is then possible to make predictions about behaviour, which the researchers in sub-project 4 are working on. It goes without saying that highly precise self-localisation is essential in the context of the tasks described for automated vehicles. The necessary prerequisites for this are detailed, high-resolution digital maps – although the researchers are investigating the extent to which these can be enhanced by sensor-based maps. This is because, as with the Perception and Fusion work packages, the main aim of positioning is to ensure the greatest possible reliability and, at the same time, the highest level of topicality.

Environment and Context 03

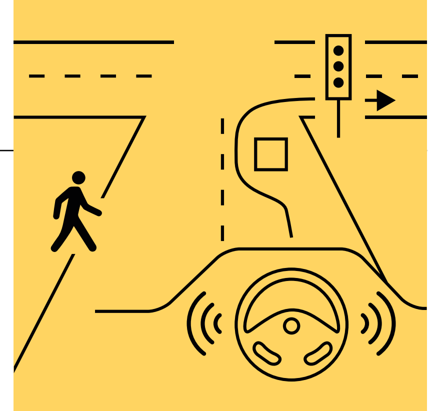
04

Situation Analysis and Planning

Think ahead, act prudently

As part of the "Environment and Context" sub-project, self-driving cars are being enabled to reliably perceive their surroundings and at the same time understand what is happening there. This is precisely where the fourth sub-project of STADT:up picks up seamlessly – namely with the questions that arise as a logical consequence: How could other road users possibly behave now and what patterns of action would this result in for the automated vehicle?

This situation is the undisputed classic of every theory driving test – and regularly gives even experienced drivers sweaty palms: Four vehicles meet at a city centre junction without traffic lights or priority signs. Who gets to drive first in this tricky situation? If you want to stick to the well-known "right before left", each person would have to give way to their neighbour on the right ... which would ultimately lead to a standstill. "These and other challenging traffic scenarios can only be resolved if the people behind the wheel analyse what is happening in detail and plan their own driving manoeuvres based on this. In our project work, we are also looking at giving automated vehicles these highly complex capabilities", emphasises Prof. Dr Fabian Flohr from the University of Applied Sciences in Munich, who is responsible for the fourth STADT:up sub-project "Situation Analysis and Planning".



Working together in a complex coexistence

A central focus is the intensive examination of various models of interaction and cooperation. After all, strict adherence to traffic rules does not always lead to success in such a diverse and dynamic situation. Purposeful cooperation is required here: In the intersection example mentioned, for example, only "negotiating" the order of priority can prevent the traffic flow from stalling – while providing gaps ensures smooth progress when two lanes are narrowed to one. To ensure that automated vehicles are equipped for all eventualities, the researchers are proceeding in several steps: Firstly, interaction and cooperation models are being developed using neural networks, which are then trained using data from observations of real traffic events.

From the forecast to productive behaviour

Before automated vehicles can plan driving manoeuvres autonomously, another crucial skill is required: the ability to anticipate the intentions of other players involved in traffic. For such a prediction, dynamic information – from flashing or warning signals to body movements and hand gestures of vulnerable road users – must be correctly interpreted. In certain cases, for example when an automated vehicle encounters a pedestrian, a "look into the future" of a few seconds is usually sufficient. The situation is different in challenging traffic contexts such as multi-lane roundabouts: In this case, a significantly longer time interval and a significantly higher number of options must be taken into account. The STADT:up project partners are once again using data-driven modelling to develop reliable forecasts.
Data-driven is also the keyword in the "Behaviour and manoeuvre planning" work package. The researchers are also combining model-based and AI-based planning processes; while the latter ensure that the vehicle can adapt its behaviour to a wide variety of situations, model-based processes make it possible to integrate prior knowledge and safeguard the planned actions – for example with regard to traffic regulations. As a result, self-driving cars will be able to react appropriately to the situation at all times and contribute to smooth, safe traffic flow by intelligently planning their own routes. This also includes constructive reactions to rule violations by others (such as aborting a merging manoeuvre if no one leaves a gap) or the ability to break the rules yourself for a short time. Specifically, this could be necessary if an ambulance is approaching from behind and a restricted area needs to be crossed to form a rescue lane. The project partners involved are also focussing on using automated driving functions in shared mobility vehicles. In order to be able to safely handle arrivals and departures at dynamic stops in urban areas, more specific behaviour and manoeuvre planning is required here – unlike in private transport.

Green light for the planned route: To do this, the vehicle must first correctly predict the behaviour of other road users.

05 Automated Driving

In the fifth sub-project of STADT:up, "Automated driving", the threads are now coming together: The focus here is on integrating the technologies (further) developed in sub-projects 2 to 4 into an overall system. With the help of simulators and test vehicles, continuous automated driving is being tested and optimised on testing grounds and in real urban traffic.

Demonstrate, evaluate, optimise

"The image of a hurdle race fits well with automated driving in the city in two respects: On the one hand, this concerns the extremely demanding development process of the required functions; the second run takes place in practice when it comes to dealing correctly with the real challenges of typical urban traffic", explains Dr Ulrich Kreßel from Mercedes-Benz AG. The central keyword in the fifth STADT:up sub-project for which he is responsible is continuity. For example, the automated vehicle has to reliably assess in which situations automation can be offered and to what extent, i.e. specifically: when can the person behind the wheel take their hands off the wheel or temporarily turn away from the traffic situation – and how is it possible to design user-friendly transitions between the automation levels? In addition, it is important to ensure continuity across all road classes (and traffic situations) – from urban motorways to dense city centre traffic and shared space environments. All of this is being tested and optimised both with simulators and in test vehicles that make it possible to experience an automated journey along an inner-city route. For testing in simulation, the researchers are using open-loop test systems, among other things, in which the entire previously processed active chain is visualised and tested for robustness: Do the sensors reliably detect the objects around the vehicle? Can the automated vehicle generate a consistent image of the surroundings? Does the vehicle react appropriately in traffic situations? Are the system limits correctly assessed? Can passengers be involved in good time if the worst comes to the worst? Only with the prototype implementation in test vehicles can it be determined how automated vehicles cope with urban traffic under real conditions, how they react to the behaviour of other road users and where optimisations are required.

Playing it extra safe

Of course, automated vehicles also have to master particularly challenging situations in urban traffic. Three work packages of this sub-project are therefore dedicated to the targeted optimisation of the systems in such contexts. Vulnerable road users such as pedestrians, people on bicycles and e-scooters and, last but not least, children require special attention. One of the main challenges for the technologies is to correctly assess the intentions of these players so that even extremely agile situations (such as crowds of people at the end of school) can be safely controlled. The researchers are not only using camera-based methods, but are also merging data from camera and lidar systems for the first time. The advantage: Even minor body posture, for example, should make it possible to predict the possible route of a pedestrian much more reliably. The scenarios depicted in sub-project 5 range from constellations at pedestrian crossings, traffic-calmed areas and electric charging points to interactions with children in play streets and with people who disobey traffic rules.

Load tests: from roundabouts to zipper merge

Another work package deals with the management of complex junctions in urban traffic. Such neuralgic points are real stress tests for automated vehicles, especially when traffic volumes are high during typical commuting times in the morning and evening. The development partners involved are focussing their project work on multi-lane roundabouts or junctions with several lanes or suboptimal visibility conditions. Automated vehicles are also being optimised in the way they deal with uncooperative road users and in their ability to carry out demanding merging and passing manoeuvres. The latter refers, for example, to sensible overtaking decisions: Of course, the automated vehicle has to handle a tailback at a junction completely differently to a vehicle parked in the second row. In contrast to previous research projects, STADT:up will also make it possible to safely pass lane blockages (this could be a parked delivery vehicle, for example) with oncoming traffic. The ability to anticipate the behaviour of road users in the opposite lane and to "negotiate" a driving order in mutual communication is crucial for doing this.

Everyday – but extraordinary: automated vehicles also have to master challenging traffic situations

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