@CITY

Automated Driving in the City

Research into Future Mobility

Supported by:

Federal Ministry
for Economic Affairs
and Energy

on the basis of a decision
by the German Bundestag

@CITY in brief

@CITY stands for "Automated Cars and Intelligent Traffic in the City". 15 partners from industry and science have joined forces within the initiative and are developing concepts, technologies and prototype applications for automated driving in the city within a number of different subprojects. The cooperative project was launched in 2017, and will be completed by mid-2022. A total budget of around €45 million has been earmarked for this, with the Federal Ministry for Economic Affairs and Energy (BMWi) contributing around €20 million.

Moving forward together

Nowadays, even when we are travelling by car all on our own, we still often have a range of “co-drivers” by our side: they might include a camera-based lane change or lane keeping assistant, a radar-based adaptive cruise control system or a city emergency braking function, and an automatic parking assistant based on ultrasonic sensors. The fact that these and many other systems are available for just about all vehicle classes is an achievement that, not least, we have to thank the dedicated efforts of the German automotive and component supplier industry for. Piece by piece, and vehicle segment by vehicle segment, they have made driving in road traffic safer, more efficient, and more comfortable.

The developments that have emerged over the last two decades provide the starting point for the next major step forward: highly automated driving will fundamentally change our understanding of mobility – and not just on motorways and highways, but also in urban environments. Just thinking back to your last trip through any given city in Germany provides a clear idea of how extensive this undertaking, and all the challenges associated with it, will be.

In order to master this hugely complex endeavour, a diverse range of competencies will once again need to be pooled together – in exactly the way as the interdisciplinary initiative @CITY has done. This is where leaders in technology from different industries combine their know-how with that of research institutes in order to create the prerequisites for the automated urban traffic of the future. The expertise they will be contributing ranges from state-of-the-art sensor technology to digital map systems and intelligent, algorithm-based software applications. Only collaborative approaches like this will be able to deliver viable and measurable results from such sweeping projects – something, which the partners involved in @CITY have impressively demonstrated in a range of predecessor projects.

Of course, plans with a scope as extensive as this can only become reality when their relevance is also acknowledged by the political field. In the case of the @CITY initiative, they have lent their full weight to backing these plans, something, which is reflected in the financial support being offered. While the latter also provides an incentive for major companies to develop an approach to the aforementioned topics at a precompetitive stage, it particularly helps start-ups to compensate economic risks.

All in all, the support provided by the public purse is therefore making a major contribution to the (ongoing) development of key technologies – and therefore to the long-term consolidation of Germany as a hub for business and as a centre of science and research.

Yours,
Dr Ulrich Kreßel
@CITY Project Coordinator

Contents

En route to the urban traffic of the future

High-density traffic, multi-lane roundabouts, construction sites forcing drivers to switch lanes, giving way to public transport along with any cyclists or pedestrians crossing your path: driving in cities today usually isn't a motorist's favourite way of getting around. However, automated vehicles may see this situation change fundamentally within the not-too-distant future. The latest technologies will help make the urban traffic of tomorrow safer, more comfortable, and more efficient.

It will be a massive undertaking – and one that the interdisciplinary research initiative @CITY is devoting its efforts to. A total of 15 partners from the automotive industry, the software development sector and scientific fields are researching and evaluating automated driving functions for urban auto-mobility. "In comparison to the motorway, the city represents a far more complex traffic environment", @CITY project coordinator Dr Ulrich Kreßel from Daimler AG explains. "We have to deal with a huge number of variables, which we need to start by identifying, sorting and allocating when pursuing our work. This allows us to create the prerequisites necessary to use the insights gained to develop specific driving functions and strategies respectively." The approach taken is also reflected by the overarching structure of the project network, which has been organised into the two fields @CITY (new technologies, concepts and pilot applications) and @CITY-AF (automated driving functions).

The objective pursued by the scientists is that automated driving should offer tangible, additional benefits over the long term – not just for drivers, but rather for all road users making their way in urban areas. Speaking of cities: just like people, automated vehicles also require a wide range of information in order to be able to operate in urban traffic in the first place. Operating, in turn, not only requires that the traffic situation is correctly understood, but also interpreted logically. State-of-the-art sensors assume the role played by a human driver's eyes, with their data then being processed within deep neuronal networks. Seeing and thinking form the key aspects of the subproject that is looking into 'Sensing the environment and situational understanding´. However, due to the diversity of urban environments, it would not be sufficient to rely solely on onboard sensor systems to generate a consistent model of the environment – especially as the sensors reach their physical limits in poor weather conditions, for example. This is where the experts working on the subproject 'Digital map and localisation' come into play. Their task is to provide high-resolution, detailed maps, and to fuse the information they provide with the data gathered by the sensor systems. This enables an extremely precise and, at the same time, up-to-date representation of the urban environment, as the contents of the HD map are continually verified using the latest data from the sensors. Another key focus is being placed on defining landmarks that can be used by the automated vehicle to pinpoint its own location with a precision of just a few centimetres.

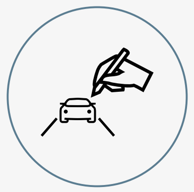
Along with an uninterrupted stream of data, automated urban mobility will also make user-oriented strategies for human-vehicle interaction necessary. The @CITY subproject of the same name is, among other things, researching how communication might proceed between the motorist, other road users, and the automated vehicle as a new protagonist. In this context, universal intelligibility has utmost priority: each and every protagonist must be able to clearly recognise what the other respective protagonist intends to do at any given moment to make cooperation in urban traffic possible. This also raises the question of which activities not immediately relevant to driving the occupants of automated vehicles are able to, and are allowed to, pursue. The results of the three interdisciplinary projects being worked on within @CITY will, in turn, provide the basis for future research activities. To start with, extensive catalogues containing urban traffic situations and specific requirements of sensor technology and HD maps will be defined within the 'Concepts and pilot applications' subproject.

Just how automated driving functions can be specifically configured for the city is being worked on by the @CITY teams in the application-based subprojects. These projects are, among other tasks, examining the question of which driving strategies will ensure that an automated passenger car can safely navigate its way through intersections, roundabouts and similarly complex challenges. Along with this 'Automated driving through urban junctions' subproject, the initiative is also directing special attention towards 'Automated driving on urban streets', referring to a city's connecting roads with all their static and dynamic constraints – everything from construction sites to the door of a parked delivery vehicle that suddenly swings open. To ensure that automated vehicles meet with long-term social acceptance, cooperative and transparent 'Interaction with vulnerable road users' is indispensable. This is also what the corresponding application-based subproject is called, over the course of which the developers will be intensively studying the recognition and understanding of different forms of communication in urban traffic, be this the direction in which a pedestrian is looking, the hand signal given by a cyclist, or simply a certain head movement, from which the technology used in the automated vehicle must draw the right conclusions. "The bottom line is that there's a lot for us to get done over the next few years", says project coordinator Dr Ulrich Kreßel, summing up the objectives. "However, only this type of detailed and labour-intensive work will ensure that we will succeed in developing a shared understanding, and allow our initiative to become a pioneer in establishing a standardised and harmonised strategy."

The subprojects

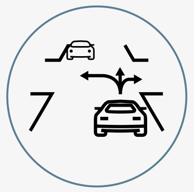
SP 1
Sensing the environment and situational understanding

SP 2
Digital map and localisation

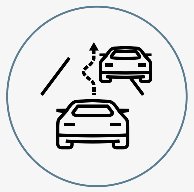


SP 3
Concepts and pilot applications

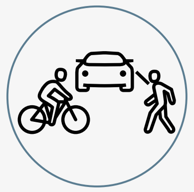
SP 4
Human-vehicle interaction



SP 5
Automated driving through urban junctions



SP 6
Automated driving on urban streets



SP 7
Interaction with vulnerable road users

Project Profile

Partners:
- Aptiv Services Deutschland GmbH
- AUDI AG
- Continental Automotive GmbH
- Continental Safety Engineering International GmbH
- Continental Teves AG & Co. oHG
- Daimler AG
- Deutsches Zentrum für Luft- und Raumfahrt e.V.
- MAN Truck & Bus SE
- Robert Bosch GmbH
- Technische Universität Chemnitz
- Technische Universität Darmstadt
- Technische Universität München
- Valeo Schalter und Sensoren GmbH
- ZF Friedrichshafen AG
- 3D Mapping Solutions GmbH

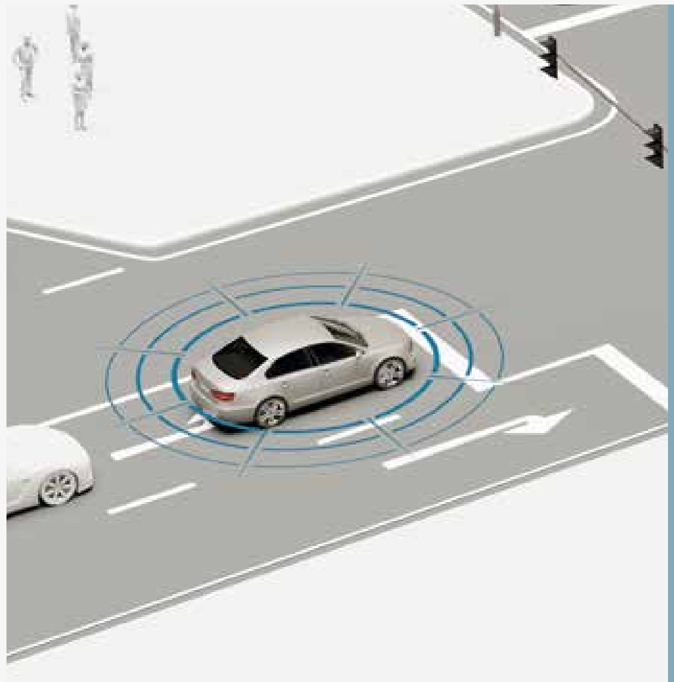
Supported by the Federal Ministry for Economic Affairs and Energy

@CITY
New technologies, concepts and pilot applications;
Automated driving functions

Timeline
September 2017 – June 2022

Budget
€45.2 million

How cars learn to think



Subproject 1

Sensing the environment and situational understanding

Driving a car in the city is one of the most challenging everyday tasks performed by people. After all, while sitting behind the wheel, we are forced to constantly register and understand innumerable impressions, and then process them immediately to obtain the right conclusions. In future, automated vehicles are being designed to provide us with extensive support for a situational awareness and appropriate acting while driving.

As a well-known fact, the first steps are always the most difficult ones to take. This is something we are reminded of when spotting a car driven by a learner driver in city traffic invokes a feeling of compassion; after all, the faces of the nervous learner drivers speak volumes: they are performing mental gymnastics to find their way through an unfamiliar situation. There's a cyclist crossing the street; elsewhere, a vehicle suddenly slams on the brakes, and a speed limit that was only just 50 km/h is suddenly reduced to a maximum of 30 km/h – and where drivers only just had the right of way, right before left suddenly applies. "The typical urban traffic situation vividly illustrates that for safe automated driving in urban areas, the perception of the respective environment needs to be precise and complete on the one hand, while on the other hand, the significance and meaning of the perceptions must be understood correctly. This requires knowledge of typical patterns of behaviour and of the context in which they occur. Just like an experienced driver who knows his way around, knowing about how traffic flows and who has right of way is extremely helpful for getting ahead in road traffic. This is why we must enable the technology to combine previously experienced and newly sensed contextual information into a comprehensive situational understanding", explains @CITY subproject manager Dr Ulrich Hofmann from AUDI AG.

Focussing on the essentials

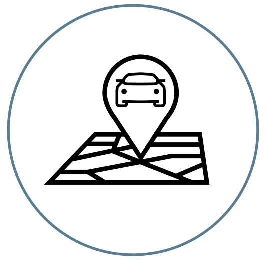
But everything in its turn. Because several project partners contribute to the subproject 'Sensing the environment and situational understanding' a common awareness of typical behaviour and decision making in selected situations is needed to be agreed on first. This, in turn, provides the basis for deriving the requirements in relation to the relevant information – for example, with a focus on the sensor systems necessary and the potential criteria for situational understanding. This all provides the (working) basis for the @CITY researchers to look into the specific methods of perception. State-of-the-art sensor technologies such as video, radar, lidar and others play an important role here. They provide a huge amount of data that now needs to be filtered according to relevance – similar to the way the human brain functions. To do this, along with model-based methods, the @CITY initiative is also utilising what are known as deep neural networks. The aim is to use these to allow the automated vehicle to recognise intersections, roundabouts or obstacles for what they are, as well as to "read" street signs and to identify the respective traffic light phases correctly. In striving to produce a model of the vehicle environment that is exhaustive, the developers are also utilising digital map data to optimally supplement the sensor system's limited field of perception.

From recognition to understanding

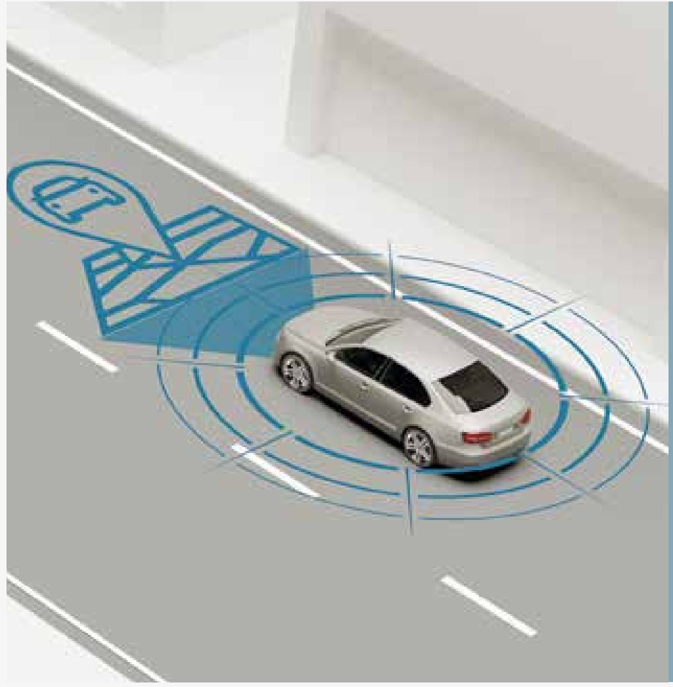
Back to the driving school: our aspiring driver can now recognise its surroundings, and knows how to distinguish relevant from irrelevant information. It now needs to learn to use the environment model to derive an awareness of the respective situation. In a space as dynamic, diverse and complex as the city, this capacity to anticipate behaviour has a decisive significance – especially for cooperation with other road users in potential conflict areas. An example: a passenger car is approaching from the right at an intersection. The system now needs to estimate the other driver's intention using its model of the environment. To do so, it calls up sensor and map data and combines with existing knowledge about traffic guidance, priority rules and behavioural patterns that – as in our case – are typical for car drivers in situations like this. Things become even more complex for the technology when a cyclist also arises at the same intersection; after all, the automated vehicle also has to establish interdependencies between the cyclist and itself, the infrastructure and any other motorists.

(Thinking) further ahead

Our future "chauffeur" is still missing one piece of the puzzle it needs for true perception and understanding the situation: namely the ability to make reliable forecasts about how the respective traffic situation will develop and how the road users involved will respond over the next few seconds. What makes forecasts like this so complex is the immense variety of types of urban traffic. In contrast to the motorway, for example, the different participants are all pursuing different goals. Some of them can be covered by rule-based processes; in addition, the project managers are planning to draw on the aid of machine learning techniques in deep neural networks here, as well. Incidentally, along with 'knowledge', the correct handling of 'missing (but relevant)-knowledge' is equally important in city traffic; for example, the vehicle must be able to manage situations in which a sign or a road user that is actually necessary to understand the situation is obscured – and nonetheless produce cooperative and risk-minimising behaviour. In exactly the same way as a successful learner driver needs to do.



High Definition Mapping



Subproject 2

Digital map and localisation

In order to move through urban spaces safely, automated vehicles need comprehensive data from sensors. However, in surroundings as complex as the city, simply relying on this information alone is not enough. This is why the researchers from @CITY are playing a second 'card': namely extremely detailed, constantly updated digital maps.

Some readers might still remember the days in which the 'good old' folding map was the only way to arrive at the intended destination in a different – and at times, in one's own – city. The emergence of navigation systems suddenly made locating an address like '5A Station Street' far easier. Today, now that automated driving is being developed, map technology is about to take the next step in its evolution, which at the same time is likely to be its most fundamental one yet. "We require an immense degree of depth and precision of information, because in the automotive world of tomorrow, maps will be assuming a totally new role", as Prasant Narula from Aptiv Services Deutschland GmbH has established. Within the @CITY research initiative, he is responsible for the subproject on digital maps and localisation. "In contrast to today, maps will no longer just be an aid to orientation when travelling from A to B. Instead, maps themselves will – in interaction with sensors – become protagonists that will make automated urban mobility possible in the first place." The fact is that even the most innovative sensor systems will, at some point, reach their limits – in terms of their detection range on the one hand and, on the other hand, in out-of-the-ordinary situations, such as in poor light or bad weather conditions. For maps, factors like this play no role at all, meaning that they can still 'look' around the corner even in the thickest of fogs. However, networked HD maps have not only been shown to provide valuable assistance when it comes to matters of safety, but also contribute to a more fuel-efficient way of driving, because the information gained from them – for example, before arriving at intersections, or when driving on routes through mountains and valleys – can also be used for automating the vehicle's speed.

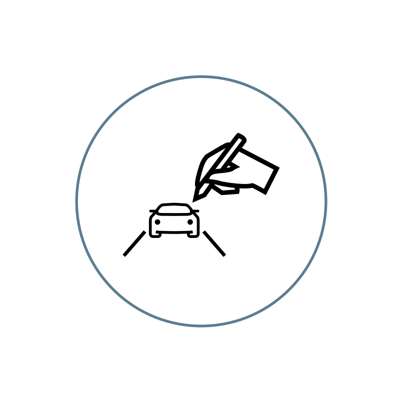
Knowing what matters

Of course, this initially poses the question of which information a digital map should contain if it is to be used to manoeuvre an automated vehicle through the city. The researchers from @CITY are looking for the answers to this in the first stage of this subproject, and are examining all manner of details for their relevance. The list extends from general traffic guidance to lane markings, signs, traffic lights and guard rails, and also includes kerbs and manhole covers. At the same time, the developers are defining specific landmarks such as corners of buildings, lamp posts and other elements in the urban environment. Above all, these play an important role when pinpointing the location of the automated car, which involves determining the exact position of the vehicle in relation to the map content.

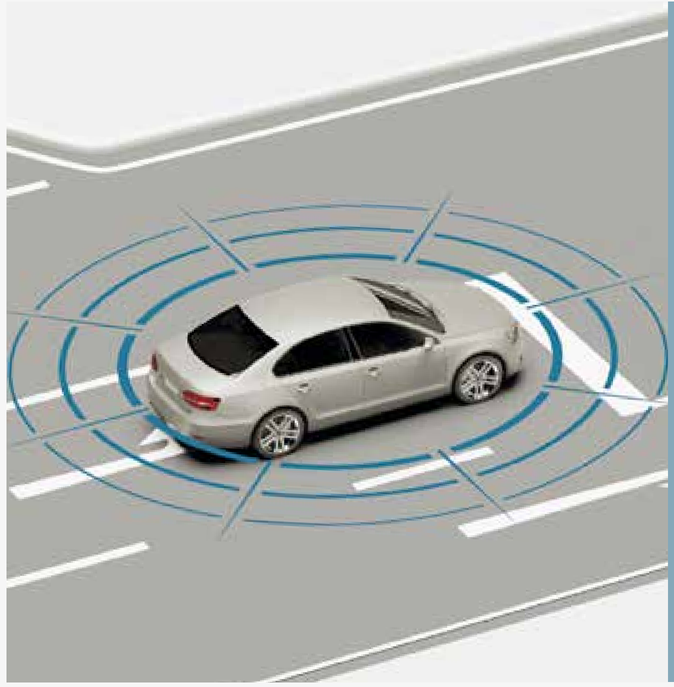
An unbeatable team: HD maps and sensors

As a principle, the reliability of a map stands and falls with how up-to-date it is. Many owners of navigation systems that were purchased a number of years ago are likely to have experienced situations in which there is a big difference between the reality presented by the map and the actual route the road takes, for example when driving through a roundabout that the navigation system identifies as an intersection, or travelling along a new bypass road that the navigation system shows as farmland. What is today still accepted (most of the time) with good humour would be an absolute no-go for an automated vehicle. After all, to bring their passengers to their destinations safe and sound, they need map data that are as plausible as possible. Which brings us to a key concept – and another focal point of the subproject: checking for plausibility. The team responsible is working on developing strategies suitable for an optimal fusion of map and sensor data. On the one hand, the contents of the HD maps need to be continuously evaluated using the information from the sensors, and be updated when appropriate. In this case, the experts refer to 'self-healing' map systems. On the other hand, the HD map also provides information to the sensors and allows the vehicle to distinguish abnormal situations on the road, such as a guardrail that has been knocked over or a tree that has fallen across the road, from regular road conditions.

This intelligent interplay between sensor technology and HD maps will result in the generation of a reliable knowledge base – and therefore create a fundamental prerequisite for making safe, automated headway through the city traffic of the future.



When one pair of eyes isn't enough



Subproject 3

Concepts and pilot applications

Narrow streets through residential areas with oncoming traffic, crowded bus stops and cyclists racing around corners without warning: the turbulent traffic we are faced with in the city means that we actually need more than two eyes to maintain an overview of everything that's going on…

What humans aren't capable of will soon be done for them by technology: automated driving in the city not only aims to maximise safety, but also to optimise the flow of traffic. The demands being made of an automated vehicle are correspondingly high: it must have an all-encompassing overview of its environment, and be perfectly prepared for every potential situation. The researchers from the @CITY initiative are therefore compiling a catalogue containing a multitude of conceivable types of incidents in urban traffic within the scope of this subproject. Particular attention is being paid to urban junctions, connecting roads within cities, and interaction with vulnerable road users. The aim is, ultimately, to develop the first pilot applications for the particularly challenging scenario faced when dynamic constraints occur.

Surveying the world of traffic

Rush hour: we've pulled up at an intersection known for heavy traffic, the traffic light turns green and we're about to turn the corner when a cyclist crosses our path and we're forced to slam on the brakes. A conceivably close call. We slowly continue on our way, yet the next obstacle is waiting just around the corner: a delivery van is parked outside a bakery – and oncoming traffic is visible. "We need to study traffic situations like this, and similar ones, to determine highly specific performance requirements for the automated vehicle technology", Dr Alexander Nagel, subproject manager from Valeo, explains. "To do so, we have to develop a comprehensive catalogue of usage scenarios." The experts start by using this catalogue to work out the corresponding requirements for identifying the environment: both the static and dynamic environment need to be precisely mapped. High-resolution HD maps are required to survey the traffic situation, whereby the GPS system will be supported by a landmark-based process. The dynamic environment not only includes normal traffic, but also a wide range of unforeseeable incidents that can occur simultaneously. Perfect 360-degree detection of the environment is the solution for this – by means of a fusion of multiple, partly redundant sensor data.

Overcoming dynamic constraints strategically

Along with formulating the requirements of the technology, the researchers are also tasked with developing optimal driving strategies on the basis of the scenario catalogue. The pilot application case represented by dynamic constraints is a particularly complex challenge here. A static constraint mutates into a dynamic constraint as soon as aspects such as oncoming traffic, cyclists, vehicle doors opening etc. are factored into the system design. A manoeuvre tailored exactly to the respective situation is being developed for each of these potential incidents within the scope of @CITY, and will thereby make it possible for the automated vehicle to handle the traffic situation with aplomb. Another problem is presented by the actions of vulnerable road users. At times, they only signalise their intentions by gestures or even subtle facial expressions – for example, when crossing the road. In this case, typical use case scenarios that could represent a problem for automated vehicles need to be identified and be solved using suitable technological tools, such as a sensor-based intention detection system. Last but not least, those moments that bring the system to its limits also need to be factored in – which makes a suitable strategy for transferring control of the vehicle back to the driver necessary.

Testing automated driving

In order to send test vehicles onto a test track, as is necessary to implement a prototype of the pilot application case for dynamic constraints, extensive vehicle modifications need to be made: the installation of environmental sensors, retrofitting the vehicle with control computers and measuring technology, modifications to the actuator technology and the integration of the elements to allow human-vehicle interaction. To ensure that all components operate in perfect synchronisation, the cooperative project is conducting extensive measuring and calibration work on test tracks. A particular focus is being directed at cyclists as road users. Accordingly, a cycling simulator is being deployed which is used to examine the cyclists' motivation and how they develop a cycling strategy. Situations in which a cyclist turning a corner is only – as in our example above – noticed with no time to spare should therefore soon become a thing of the past in urban traffic. After all, the automated vehicles of the future will have 'eyes' everywhere.

Of communication and cooperation

Subproject 4

Human-vehicle interaction

In the not-too-distant future, automated vehicles will be moving through urban traffic as a matter of course – and will communicate with their environment autonomously. The prerequisites for this new type of cooperative interaction are being created by the @CITY research initiative within the subproject addressing human-vehicle interaction.

Where traffic flows, constant communication must take place: the cyclist who makes a hand gesture to signalise that he plans to turn left; the car driver who 'waves' a pedestrian across the road or who slows down to indicate that he is prepared to allow the person driving next to him to cut in. As different as these typical urban traffic situations are, what they all have in common is that the communication has, to date, taken place between two protagonists: the car driver and the other road user, respectively. With the development of automated vehicles, a third protagonist will be added, the integration of which into the communication process is being studied by the @CITY researchers within this subproject. A requirement that is central to this endeavour is that the information transmitted using all these channels must be free from inconsistencies: between the automated vehicle and the vehicle user, between the vehicle user and other road users, and between the automated vehicle and all the other protagonists in everyday urban traffic.

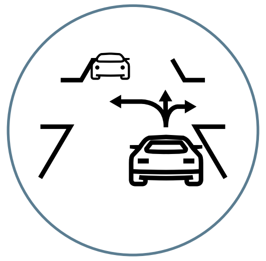
Who is saying what?

Sending and receiving messages, recognising explicit and implicit communication, and processing it suitably – this presents immeasurable challenges for automated vehicles. In order to pursue their long-term goal of mastering these challenges, the researchers started by examining the question of which paths of communication are actually of importance in urban traffic, and which scenarios they are used in, respectively. Easy-to-understand display and interaction concepts that are suitable for practical use and that are, above all, intuitive need to be devised on the basis of the insights gained, and the development of them will involve the use of state-of-the-art virtual reality technology, among other resources. An important step, especially after the introduction of the technology, the self-driving vehicles will have to share the roads with the (operators of) manually steered passenger vehicles for a long time to come.

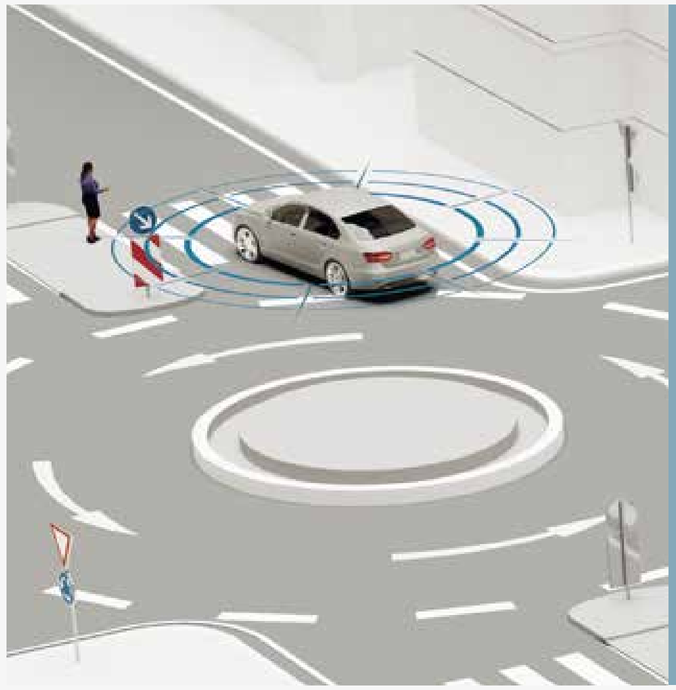
The best way: creating trust

However, it is not only for communication with others that clear rules for interaction need to be established. The passengers on board should also remain informed of all planned manoeuvres at all times, and always be able to understand why the vehicle is doing what it is doing. This high degree of transparency decreases the likelihood, on the one hand, that the passengers will be tempted to communicate with other road users of their own account during the automated trip; in the worst case, they would end up giving signals that cannot be factored into the vehicle's driving strategy. On the other hand, the transparent approach makes so-called transfer situations easier, in which the driver can take control of the vehicle without any complications on the basis of the extensive information available. Structuring these processes to be as convenient and safe as possible is one of the key challenges facing this area of research within @CITY. "Neither the user of an automated vehicle nor other road users should ever have the feeling that the car is endangering them, or others, with its decisions", emphasises Stephan Cieler from Continental Automotive GmbH, who is responsible for the subproject on human-vehicle interaction. "This is why the principle guiding for all the communication concepts that we are developing in our subproject is that everyone must feel that they are able to trust the automated vehicle."

Only then will the passengers on board be in the state of mind necessary to calmly concentrate on activities not related to driving – be they a business call, preparing a presentation on a tablet PC, or simply relaxing while surfing the internet. In other words, concentrating on doing everything behind the wheel that has never before been possible, or, if at all, only possible to a limited extent.



A critical junction



Subproject 5

Automated driving through urban junctions

"Careful, you're approaching a roundabout."
"Pay attention, there's an intersection up ahead."
Words that the front passenger often lets slip.
And rightly so. Urban junctions such as intersections or roundabouts are still considered one of the hot spots when driving in city traffic. This makes the work being done by the @CITY initiative in developing automated driving functions all the more ambitious.

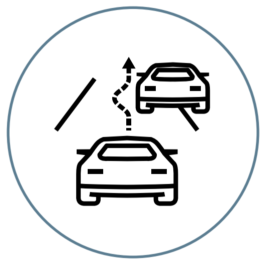
Chaotic, confusing, bumper to bumper: given the constantly and quickly changing situations, we often have problems passing intersections and roundabouts in urban areas without complications, or at least, without becoming stressed. To 'blame' is not only the often extremely complex patterns of traffic guidance in these areas; sensory overload, communication problems or sheer inattentiveness increase the frequency of accidents at these critical spots in city traffic. Automated vehicles may be able to provide relief – providing it is possible to develop technology that can correctly identify the large number of conceivable scenarios and can make the right decision at the right time. This is exactly what the @CITY researchers within the subproject 'Automated driving through urban junctions' are aiming to do. One particular challenge, for example, is the fact that high-density traffic makes it necessary to pinpoint the location of the vehicle with extreme accuracy.

A clear advantage

If you compare a human driver with an automated vehicle, then the latter has an indisputable advantage: it doesn't get tired, and there's nothing else that will distract or upset it. Instead, its sensors and functions observe the area around urban junctions exactly, interpret it and combine the available urban map data for the junctions with situational dynamic and static environment sensor data. The outcome? A reliable and valid situational understanding to benefit the driving function, and computation of the driving strategy for the automated drive through inner-city junctions. To use a roundabout as an example: when it comes to driving strategy and vehicle control, the greatest 'challenge' already awaits when approaching. The technology – building on the findings from @CITY subprojects 1 and 2 – must then be able to instantaneously assess whether safe entry to the intersection is possible – and both interpret and predict the intentions of all other road users correctly. Specific algorithms are also being developed for intersections, which make the vehicle capable of taking measures proactively, cooperatively and safely. In doing so, the experts are proceeding in several steps, taking a similar approach to the roundabout: first of all, the automated vehicles need to learn how to drive straight ahead across an intersection, whereby they need to factor in all rules governing right of way, as well as any traffic lights and cross traffic. In this case, the vehicle is steered using data from the digital HD map and by means of lane markings. Turning right, which is step two, involves factoring in the parallel traffic travelling to the right of the vehicle and any pedestrians or cyclists crossing the destination lane, as well. Remains the left turn: in this case, the systems face the challenge of handling in the parallel oncoming traffic as well as guiding the vehicle safe into the destination lane using a defined path.

Excellent equipment features

That covers the requirements that have been defined, and the theoretical parts. How these planned driving strategies can be implemented in practice is now being researched by the project participants with different test vehicles. "We're equipping vehicles suitable for this with a whole phalanx of sensors, including cameras, radars and lidars", explains Dagmar Lang from ZF Friedrichshafen AG, who is responsible for this subproject. "Furthermore, we are also integrating digital map information, along with a range of systems that are suitable for interaction with the driver, including displays, tools for monitoring the driver and other audio-visual components." In addition, if necessary, new actuators for precise linear and lateral control over the experimental vehicle's movements will be added. To effectively respond to any unpredictable factors associated with the use of these components, the researchers are also installing the corresponding emergency systems and safety concepts in the test vehicles. Once the integration of all these systems is able to be successfully completed, then it will finally be time to conduct extensive test runs. After all, whenever automated vehicles used in urban traffic drive through roundabouts and intersections of all types in future, they should be able to announce that they have successfully navigated a critical junction.



Setting the right course

Subproject 6

Automated driving on urban streets

Anyone who drives a car around a city regularly will be more than familiar with the fact that connecting streets in urban areas sometimes have an unwelcome surprise in store. In a few years, automated passenger cars could help us to get through this daily 'obstacle course' feeling relaxed and safe.

Everything looked so easy on the city map. Start by taking the ring road, remain in the right lane, and after the sixth exit there are only 200 metres left to the hotel. You'd worked out the route so well, and yet, as is so often the case when theory is faced with reality, the latter proves to be unimpressed by even the best-laid plans. One lane of the two-lane ring road has been closed due to construction works, and after taking the exit, a detour leads the driver through a dense residential area where schoolchildren are getting off a stopped bus – and just before arriving at the destination, a double-parked delivery van makes the entrance to the booked accommodation almost impossible to access. "Typical situations like these illustrate quite vividly that when driving in city traffic, it's not only intersections and roundabouts that present drivers with numerous challenges, but also the route from A to B; it is because of these challenges that we're devising suitable driving strategies in the 'Automated driving on urban streets' subproject", explains Patrick Ernst from MAN Truck & Bus SE, who is responsible for the subproject.

From knowledge...

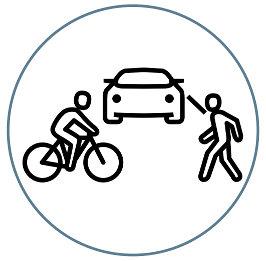
The researchers are also using insights gained from other @CITY subprojects for their work, and are refining them for their own purposes. This is, for example, the case for the environment model and situation sensing area: information from the HD map is, amongst other data, verified by the on-board environment sensors, producing a consistent, static environment model, which, in turn, then provides the vehicle with important information about infrastructure on urban connecting streets, such as the exact location of a traffic island or the exact position of a barrier used for traffic-calming. In this context, the teams of developers also define appropriate landmarks within the urban area in order to allow the vehicle to pinpoint its own location with extreme precision. At the same time, the self-driving vehicles must, of course, be able to capture the dynamic vehicle environment, such as other road users that are in front of, next to, or behind the car. This is done – building on the results of the 'Sensing the environment and situational understanding' subproject – by means of a fusion of several, partly redundant sensor data, as well as an ongoing re-evaluation of the current situation.

...to the strategy...

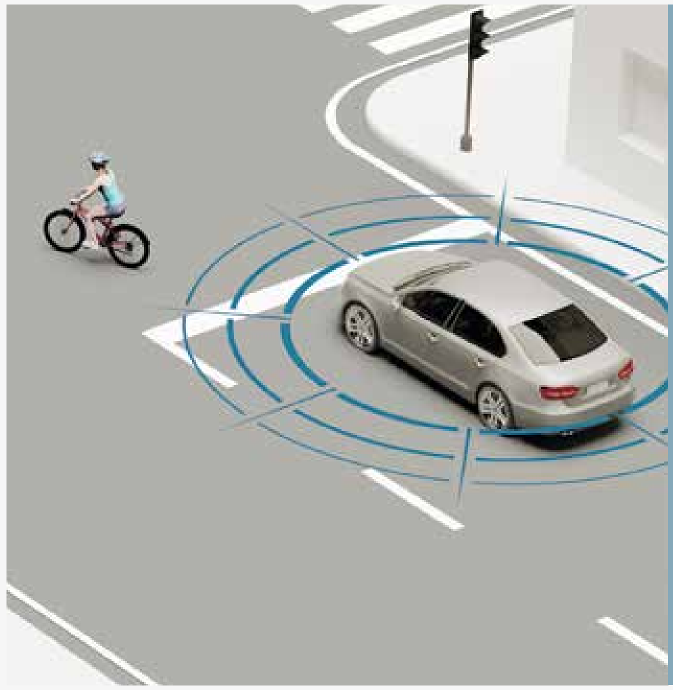
How to actually behave on urban connecting streets – i.e. how to deal with obstacles, disruptions of traffic flow and encounters with other road users – is being examined in this @CITY subproject in particular. The main focus is put on so-called static and dynamic narrow traffic situations, as they appear in a huge variety of forms in an urban context. A classic example is an oncoming bus manoeuvring its way around a narrow corner. In order to master such a highly complex dynamic constraint with the right driving strategy, the technology must consistently identify the movements made by the bus correctly, which in turn determines the free space left to drive in and consequently allows the vehicle to steer itself into the right lane at the right speed. A similar strategy applies in interplay with vulnerable road users, such as cyclists or pedestrians. In addition, together with the 'Human-vehicle interaction' subproject the scientists devise suitable strategies to hand over control of the vehicle to the driver. After all, even the most robust technology reaches its limits in certain situations – and at this point at the latest, the human driver needs to 'take the wheel'.

...to practice

These, along with other insights gained, are then incorporated into the development of test vehicles and even automated buses. The aim is to test the performance of the map and sensor technology, along with the effectiveness of the driving strategies developed for the specific use case that inner-city connecting streets represent. Among other things, this also includes both the installation and the calibration of environment sensors, equipping the vehicle with control and measuring technology, the integration of functional components for human-vehicle interaction and the modification of the control unit software. At the end of the day, wishful thinking and reality should preferably not clash with each other when travelling in an automated vehicle on urban streets – regardless of which 'creative scenarios' both the city and its road users come up with again tomorrow.



Looking (out) for each other



Subproject 7

Interaction with vulnerable road users

We're waiting at a pedestrian crossing with a traffic island: an old lady is standing on the footpath and seems uncertain – does she want to cross the road, or continue on her way on the same side of the street? Her hands grip her rollator, and the direction she is looking in is the only thing that will reveal her intentions. Can an automated vehicle cope with this situation?

This is exactly what the experts working on the @CITY subproject 'Interaction with vulnerable road users' have made their goal – and they are relying on artificial intelligence to achieve it: both explicit gestures and subtle signals, such as a line of vision or body language, are to be analysed and interpreted using so-called deep neural networks in order to elicit the corresponding responses from the vehicle system. One key advantage of this technology is, once again, found in the uninterrupted vigilance it offers – after all, in contrast to humans, artificial intelligence functions is neither distracted nor becoming fatigued.

The fact is that around 90 percent of all traffic accidents today resulting in injuries or fatalities can be attributed to human error – whereby most of these occur within built-up areas. In many situations – think of the particularly dangerous 'crossing pedestrian' accidents – inattentiveness plays a role. And it is exactly this factor, which can be minimised with the aid of the 'thinking' neural networks mentioned above.

Who's there – and how many of them are there?

To ensure all these functions in practice, the different types of vulnerable road users do, of course, have to be recognised as such – from a police officer to a wheelchair user, from a small child to a teenager on a longboard. It becomes particularly difficult to identify the individual protagonists when light is poor, or when they suddenly enter the field of vision. The @CITY researchers are utilising special stereo cameras, laser scanners and high-resolution radar sensors for this, which can map out all movements with outstanding precision and excellent spatial resolution. By using a fusion of sensors, the information from the different sensor sources can then be merged to form one consistent image.

The art of interpretation

After the road users have been recognised, their behavioural patterns need to be understood. Any non-verbal communication, such as hand gestures and body language, plays a key role in this. The entire undertaking becomes even more complicated when the signals are subtle – such as direction of sight, posture and head movements.

"The automated systems must be in a position to recognise the indications given, regardless of how subtle, and use them to interpret the road user's intention", project manager Dr Lutz Bürkle from Robert Bosch GmbH explains. "Over the course of a large-scale study, we will be analysing a wide range of gestures in order to be able to utilise them for reliable intention recognition and scene interpretation." If, for example, a pedestrian looks in the direction of a vehicle, then the likelihood that the pedestrian has noticed the vehicle and is paying attention is high. If, in contrast, the pedestrian's gaze is focussed on the other side of the road, this allows the conclusion to be drawn that the pedestrian intends to cross the road. There are many subtle differences that need to be learned by neural networks, and that need to be retrievable at all times.

It's all based on reciprocity

This only leaves the communication on the part of the automated vehicle. This means: how do you replace, for example, the typical 'swiping gesture' that drivers use to signalise that a pedestrian is free to cross the road? The experts working on the @CITY project are also concentrating their efforts on answering this question and are, for instance, examining, which communication channels are best suited for interaction between vehicles and humans. At the forefront of their deliberations is how to generate actions that are as intuitive and standardised as possible. Along with specific design rules that everyone can understand, the development of special smartphone apps would be conceivable in this case, provided that pedestrians, cyclists and other vulnerable road users are prepared to share their location data with drivers.

As this already implies, systems like this need to succeed in integrating all road users – from the old lady with her rollator to the driver behind the windscreen – to the highest possible degree. Only then will automated urban traffic meet with (social) acceptance in the long term.

Outlook: Re-imagining the city

What do we understand to be a liveable city? Although people with all sorts of different interests encounter each other in the city, there should be a broad consensus about the answer to this question – at least in terms of mobility. Just about every wish list includes points such as ‘more safety’, ‘more space for people’, ‘less stress’, ‘fewer emissions’ and ‘mobility products that are attractive for everyone’. Turning these desires into reality as soon as possible is a matter of urgency. Only then will we succeed in reacting to ever-increasing urbanisation in a sustainable manner. After all, the level of urbanisation around the world has already reached more than 50 percent, with current forecasts predicting that two-thirds of all people will call cities home by the year 2050.

“This makes it all the more important that the metropolises of tomorrow actually do cater to human needs”, Dr Ulrich Kressel, project coordinator for the @CITY initiative, accentuates. “And we want to make a key contribution to this with our research.” In doing so, the scientists are creating a fundamental shift in perspective: “The traffic of the future must adapt to the city – and not the other way around. The solutions that we are developing over the course of our cooperative project do not make any interventions in existing infrastructure necessary. We don’t require any special routes of our own, nor any time-consuming building work to modify intersections and other crossroads.”

This means that automated vehicles should be able to assimilate into urban traffic seamlessly, and in doing so, increase the level of safety, convenience and efficiency. “Looking ahead, one particular challenge will be presented by the coexistence of all sorts of different protagonists”, Dr Ulrich Kreßel forecasts. “Automated vehicles must interact with both conventional passenger vehicles and, in future, with fully driverless vehicles, as well as all other road users – such as pedestrians and cyclists. If we can implement this successfully and if the technology remains affordable, then quality of life will have ‘right of way’ in our cities over the long term.”

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