Clear View **from Afar**

Research and industry around the globe are working to bring autonomous driving to our streets. Dr. Frank Diermeyer and his team, though, are convinced that situations will still regularly occur that exceed the capabilities of autopilot. That is why they have developed a type of remote control for cars. In future, this will allow service staff at a remote command center to steer cars safely through traffic when autopilot hits its limits. TUM's smart demo vehicle, Mute, shows just how well this teleoperated driving concept can work.

Picture credit: Eckert

Remote driving: An operator takes control of the car and steers it safely through the traffic, based on video and sound information transmitted from the car to the operator's console.

Picture credit: Eckert

Tim Schröder

Durchblick aus der Ferne

Weltweit arbeiten Autohersteller intensiv an Autopiloten. Das Team um den Maschinenbauingenieur Dr. Frank Diermeyer vom Lehrstuhl für Fahrzeugtechnik aber schlägt jetzt ein neues Kapitel des autonomen Fahrens auf. „Wir arbeiten an der Fernsteuerung von Autos, dem teleoperierten Fahren", sagt Diermeyer. Damit sprengt er das Paradigma vom völlig selbständigen Auto. „Wir sind davon überzeugt, dass es immer wieder knifflige Situationen geben wird, die Fahrerassistenzsysteme nicht von allein lösen können", sagt Diermeyer. „Es wäre hilfreich, wenn ein Assistenzfahrer einspringen könnte, der in einer Fernsteuerzentrale sitzt."

Die Forscher koppeln dafür das Versuchsfahrzeug der TUM, das Elektroauto Mute, über eine schnelle LTE-Mobilfunkverbindung mit einem von ihnen entwickelten Fernsteuerplatz. Dieser verfügt über drei große Bildschirme, auf die die Kamerabilder aus dem Mute übertragen werden: der Blick durch die Windschutzscheibe, durch die Seitenfenster und aus der Heckscheibe. Im Cockpit befinden sich ein bequemer Autositz, ein Armaturenbrett und die Pedale für Gas, Bremse und Kupplung, mit denen das Auto ferngesteuert wird. Eine solche Fernsteuerung ist nach Ansicht von Diermeyer zum Beispiel für ältere Menschen sinnvoll, die sich mit ihrem Auto kaum mehr in die Innenstädte trauen. Autopiloten können diesen Job bislang nicht übernehmen, weil auch sie in den Innenstädten schnell überfordert sind. Derzeit geht Diermeyer davon aus, dass das teleoperierte Fahren zuerst in Städten bei der Suche nach Parkplätzen zum Einsatz kommen wird. Hat man das Ziel erreicht, wird man aussteigen und dem Operator das Auto übergeben, der es zu einer freien Parkbucht lenkt.

Für die Fernsteuerfunktion mussten die Forscher eine Fülle technischer Probleme meistern. So gibt es einen Zeitverzug, mit dem die Kamerabilder aus dem Auto in der Fernsteuerzentrale ankommen. Dieser führt zu einer ungleichmäßigen Bildschwankung, die einen Operator schnell nervös macht. Die Experten der TUM verzögern die Signale deshalb künstlich um 500 Millisekunden und erhalten damit einen zwar verzögerten, aber gleichmäßig fließenden Datenstrom. Damit der Operator trotzdem exakt die Position des Autos kennt, wird im Kamerabild die vom Computer errechnete reale Position des Autos als einfaches Viereck angedeutet.

Mittlerweile haben Diermeyer und seine Kollegen mehrere Anfragen von Industrieunternehmen für eine Zusammenarbeit erhalten. Diermeyer hofft, dass der Mute in drei Jahren soweit ist, dass er tatsächlich ganz allein und ohne Sicherheitsfahrer an Bord auf öffentlichen Straßen fahren kann. Wenn man sieht, wie sicher der Mute schon jetzt seine Bahnen fährt, glaubt man das gern – und auch, dass nicht allein dem Autopiloten, sondern auch der Teleoperation die Zukunft gehört. □

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Diermeyer's group is currently testing teleoperated driving in a mass-produced vehicle, which is also equipped with sensors monitoring its surroundings.

An SUV appears outside the Institute for Automotive Technology at TUM's Garching campus. A quick glance behind the steering wheel rivets you to the spot – the driver's seat is empty. The SUV can steer itself! It zips past, weaving its way through an obstacle course of red and white traffic cones, veering left here and right there. Taking a closer look, you might start to think again, reflecting that perhaps it is not really all that surprising for a car to be driving itself around these days. After all, many researchers and industrial enterprises are now advancing autonomous driving worldwide. Electric carmaker Tesla, for instance, is actively pushing the driver assistance capabilities of its sedans, which enable cars to cruise along highways almost by themselves. Other manufacturers, too, are equipping their models with cameras, radar and laser sensors to support features such as active brake assist, lane departure warning and stop-and-go in heavy traffic. Now, though, mechanical engineer Frank Diermeyer and his team from TUM's Institute of Automotive Technology are marking a new departure in the autonomous driving story. They demonstrated their technology 2013 in Mute, a compact electric runabout developed from the ground up by various TUM working groups over the past few years. Now, Diermeyer's group is also using mass-produced cars for their tests. "We are working on controlling cars remotely through teleoperated driving," confirms Diermeyer, thus challenging assumptions around fully autonomous cars. Most experts claim that they are aiming to bring fully automatic cars to the streets within the next few years, able to navigate independently with the aid of sensors. "We, however, are convinced that tricky situations will keep arising that driver assistance systems will not be able to resolve by themselves," explains Diermeyer. "In these cases, it would be helpful if an assistant driver could intervene from a remote command center."

Teleoperated driving on TUM campus

TUM researchers can already show us what a remote center like this might look like. They set up a type of simulator cockpit in their lab. Inside hang three large screens, displaying camera images from Mute: the view through the windshield, through the side windows and to the rear. The cockpit also contains a comfortable car seat, a dashboard, and gas, brake and clutch pedals for remote control of the vehicle. When Mute drives around outside, the simulator makes you feel as though you are in the car yourself. But why go to all the effort? If the autopilot fails, the car's driver could surely step in and resolve the situation themselves. "That's true," acknowledges Diermeyer. "But in some cases, remote control makes perfect sense." Here, he is thinking of older people, in particular, who still like to drive their cars on rural roads away from cities but would not usually be confident in downtown traffic any more. As it stands, autopilot cannot help here either, since these systems also quickly reach their limits in busy cities. Signpost clusters, double-parked cars and obscured lane markings usually still trigger an emergency stop. According to Diermeyer: "I don't see these autopilot problems being solved in the next few years, so an alternative here would be an operator in a remote command center." The weather, too, currently stumps autopilot – particularly fog, heavy rain and driving into the light. All situations that quickly overwhelm older people as well. Snow drifts are also problematic for self-driving cars: while a human driver can assess how deep the snow is and whether the car can get through it, autopilot simply stops in front of the white obstacle. "In any case, we don't see teleoperated driving as competition, but as a valuable addition to automated driving," clarifies Diermeyer. "In combination, the two technologies could help seniors to stay mobile for longer. And, especially for people living in the countryside, that plays a role in combatting social isolation too."

Truck drivers also stand to benefit from teleoperated driving. They have to take a break every few hours, but with a com- ▷

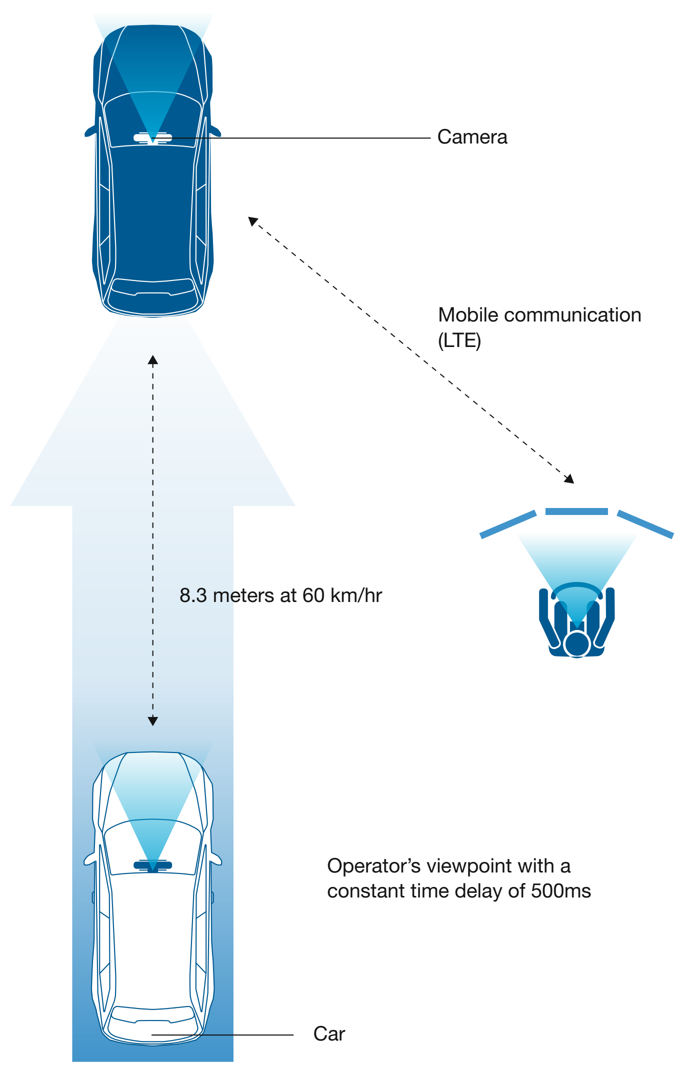
Camera systems record the front and side view from the cockpit. All images are transmitted via mobile communication to the operator, who controls the steering wheel and pedals.

bination of autopilot and remote control, the vehicle could continue driving by itself. Autopilot alone would not suffice here, since it could get stuck in tricky situations and truck drivers would not be allowed to intervene if they were on a break. Teleoperation, however, would be a real help. Diermeyer currently anticipates that teleoperated driving will initially be introduced in downtown areas – when looking for somewhere to park. The hunt for parking spaces alone is thought to account for 30 percent of traffic in major cities today. So it would be a significant relief if an operator familiar with the location could take over the car and park it. Close to the destination, the operator would then navigate to a vacant parking space via the shortest route. To ensure this functions smoothly, the remote command center would be linked up to a parking information system.

Eliminating jitter in the operator cockpit

Diermeyer and his colleagues have been focusing on autonomous driving since 2006, moving on to teleoperation in 2010: “Because it became clear to us that we’re going to need both. We are one of very few research groups to have this type of system up and running today,” underscores Diermeyer. The team has now been able to demonstrate its capabilities in several test drives. However, it was a long road to get there, with the researchers confronted by numerous technical challenges along the way. One of them was the time lag between camera images from the car reaching the control center and the corresponding commands being relayed back to the vehicle. Mute uses the rapid mobile communication standard LTE. Nonetheless, depending on reception and available bandwidth, the images and driving commands are always transmitted with at least a slight delay. The jerky effect this creates in the video stream is known to the experts as jitter. In the simulator cockpit, it meant that the car would sometimes seem to lunge forward and sometimes hesitate or even come to a complete halt. And this jitter quickly stresses even the most skilled or most experienced of operator. Hence, the TUM experts decided to incorporate an artificially fixed delay of 500 milliseconds into their signals. “That is the rough extent of the time lag we are dealing with,” explains Diermeyer. “So this now eliminates jitter and gives us an even data stream, albeit with a slight delay.”

This delay, though, presents the researchers with their next problem. The image in the remote control cockpit is now permanently 500 milliseconds behind, so never shows the precise position of the car at any given time. And the faster the car is moving, the larger the gap between its actual position and the image the operator sees. At 60 kilometers per hour, the car can travel a whole 8.3 meters in the space of 500 milliseconds. The researchers thought long and hard about how to give the operator an impression of the actual situation in spite of this – and came up with a surprisingly simple solution. The computer calculates the car’s real position, and this is displayed in the camera image as a simple square. Two small white spots are also visible, indicating the actual position of the front wheels. “Our tests show that the remote control operators adapt well to this after a short period of training.” Remote control always comes with the risk of the operator becoming disconnected from reality – resulting in “loss of situational awareness”, as psychologists call it. To avoid this effect, the researchers have a host of technologies in their cockpit to ensure that the simulated journey feels just like a real car ride. Loudspeakers are used to transmit the real background noise – including the sound of the vehicle on the road, as well as the horns of other cars. Driving on ice makes itself felt by a change in steering motion, and uneven ground by a shaker fitted to the seat. Operators also gain a sense of the car moving thanks to the camera image in the side windows imitating the natural blur of motion. ▷



An even data stream: Depending on the quality of the mobile network, jitter can occur in the video stream the operator receives. A deliberate time delay of 500 milliseconds ensures a constant video stream, albeit with a time lag that would translate into a distance of about eight meters at a speed of 60 km/hr. The computer calculates the car’s real position and displays this information in the operator’s console.

“We are convinced that tricky situations will keep arising that driver assistance systems will not be able to resolve by themselves. In these cases, it would be helpful if an assistant driver could intervene from a remote command center.”

Frank Diermeyer

Graphics: ediundsepp, Picture credit: Eckert

Novel visual techniques

The TUM researchers developed another visual technique aimed also at ensuring a natural impression of the driving experience – namely data goggles. These show the outline of the car, precisely superimposed on the camera images of the surroundings displayed by the monitors. As experiments in Munich showed, any unsteadiness or slight discrepancies quickly lead to the user feeling unwell. As long as the driver looked straight ahead at the windshield camera image, everything was fine. But if they turned their head to the side, the system switched to the side window. The result was a brief time lag between the windshield and side-window images with each turn of the head – literally giving the operator travel sickness. Diermeyer's team thus decided not to transmit the various camera images separately, but to merge them within fractions of a second to produce a wide-angle image of the surroundings, which now stretches from left to right across all monitors like scenery at the theater. Since the view changes rapidly as the car drives along, the image data has to be computed extremely quickly. "The usual MPG-4 video standard would have been too slow for this," reveals Diermeyer. "We had to modify it and adapt it for our specific application needs."

Right from the start, Diermeyer's aim has been to develop an effective system for teleoperated driving that fulfils all the safety requirements necessary for use in real-world traffic situations. This also applies in the event of connectivity problems with the remote control center. Anyone who has made phone calls in a car knows that the connection cuts out in a dead spot with no signal – and of course this applies to remote control too. Teleoperation is primarily envisaged for downtown driving, however, and strong network coverage means minimal dead spots there. TUM's remote solution is currently designed for use at speeds of up to 60 kilometers per hour, which is quite sufficient for urban areas. If the network connection is ever actually lost, the car will come to a standstill – either gradually or by means of an emergency stop, depending on the situation. "At speeds under 60 kilometers an hour, putting the brakes on is the safest reaction in any case," emphasizes Diermeyer. But of course the aim is to prevent any interruption to the data connection if at all possible. With that in mind, the researchers have enriched their system with maps from mobile network operators, indicating the dead spots. This should enable the vehicle to bypass them – for instance by avoiding tunnels.

Meanwhile, Diermeyer and his colleagues have already been approached by several industrial companies interested in collaboration. Diermeyer hopes that Mute will have advanced sufficiently in three years' time to be able to drive around public streets all by itself, with no backup driver in the car. When you see how reliably it already steers its course, that seems entirely possible. As does the prospect of a future shaped not just by autopilot capabilities, but also by teleoperated driving. *Tim Schröder*

Dr.-Ing. Frank Diermeyer

Research dedicated to the elimination of road accidents

One thing is for sure: Germany does not have many researchers lecturing on motorcycle technology, so Frank Diermeyer is something of a rarity in that regard. And no wonder, since motorbikes are his passion. After many years riding sports models, he recently acquired his first touring bike: "In keeping with my advancing years," laughs the 41-year-old, describing his Honda CBF 1000 with 100 HP. "Ideal for cruising through the Alps – especially the Dolomites."

Diermeyer has always been a motoring enthusiast. In his leisure time, he rides his motorbike; at work, he researches cars. He started off working on the electronic stability control (ESC), primarily investigating vehicle rollovers. His task was to further optimize the ESP feature, and he wrote his doctoral thesis on this topic at TUM in 2008. "So it was just a small step from driver assistance systems to automated driving," he recalls, "since a really effective assistance system can only become reality if the car has the ability to drive itself." He thus moved on to researching autopilot capabilities in 2010.

"Vision Zero" remains Diermeyer's overriding aim; in other words, the elimination of road accidents. He is sure that automated driving has a role to play here, since driver assistance systems react faster than humans and cannot be distracted. Most accidents today occur due to driver error. For Diermeyer, autopilot finally brings Vision Zero within reach. When he first went into vehicle research fifteen years ago, passive safety was still the major concern, with technology such as airbags and seat belt pre-tensioners designed to protect the driver in a crash. Since then, however, active safety has become the number-one topic, with cars preventing accidents of their own accord by means of distance detection sensors and lane departure warning systems – and, in the near future, through automated driving. "Autopilot is the next big thing," declares Diermeyer – and that is very good news indeed from his perspective.

“We are one of very few research groups to have a system for teleoperated driving up and running today.” *Frank Diermeyer*

Picture credit: Eckert