SIEMENS

Background Information

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Siemens Mobility on the way to an autonomous tram

While self-driving cars are still to come, automated train systems have been around for decades. Siemens Mobility has done pioneering work here and is thus enabling mobility operators to make their trains and infrastructures more intelligent and guarantee availability. Chicago has a fully automated airport rail system from Siemens, for example, and automated metro systems run in Paris, Taipei and Nuremberg. A Val system has operated in Lille since 1983, other cities followed, and a new fully automated Cityval system will be inaugurated in Rennes in 2020.

Automated operation is primarily suitable for closed rail systems such as metros and mass transit systems running on completely isolated rail lines. Autonomous operation in an open infrastructure, as is normal for urban trams, requires completely different technologies: an autonomous tram must learn to function intelligently and reliably in a highly complex and continually changing environment.

Since a mature infrastructure in urban areas can scarcely be altered, the technology must be installed in the tram itself. And the technology must be able to handle even the most complex traffic situations occurring with mixed traffic. The automobile industry also faces similar challenges and has been researching and developing self-driving cars since the 1980s.

Trams are in demand worldwide as an environmentally friendly, electrically operated means of transportation offering high transport capacity and great flexibility and requiring minimal space. Accelerating urbanization is driving the need for mobility. To satisfy this growing demand, tram technology must further evolve to be intelligent, closely networked with other road users and flexible enough to accommodate varying volumes of traffic – for example, by operating smaller units in

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the evening hours or running more frequently during peak times. New digital technologies – ranging from driver assistance systems to autonomous driving – are paving the way for this future.

On the way to an autonomous tram

Trams normally operate in a highly complex environment in which other rail vehicles, cars, buses, bicycles and pedestrians are constantly on the move. Traffic lights and signaling systems regulate traffic at critical points. Driving a tram basically requires driving on sight at prescribed speeds with scheduled stops along the line, carefully monitor the boarding and departing of passengers, and quickly dealing with any unusual situation or emergency. A tram driver must be able to handle at least 25 different tasks, many of them simultaneously. These range from reacting to car drivers, pedestrians and trams ahead, to maintaining set speeds and schedules under all weather conditions, stopping precisely at traffic lights, signals and passenger stops, coordinating connections, and responding quickly and appropriately to any problems that occur in the tram or along the line. In the end, the driver is responsible for the well-being of the passengers.

With experience, a driver can intuitively master most situations. A partially or fully autonomous tram, on the other hand, does not tire, can react faster than a human and has a more extensive field of perception. Sensors replace eyes and ears, and pattern recognition, basic behavioral patterns and reactions need to be incorporated into the tram control programs. However, human intuition and experience can be standardized only to a limited extent, and not every situation is predictable. The tram control system must be gradually programmed so it can react flexibly to each new situation. The software must learn to make decisions at lightning speed – or request support.

Development level 1: Avoiding collisions with the Siemens Tram Assistant

The development and training of an autonomous tram can only be done in stages. In order to offer transport operators quick benefits, Siemens Mobility is taking a step-by-step approach to development. Rear-end collisions are relatively common with trams and cause millions of euros in damages. Tackling this problem, Siemens Mobility has, as a first step, designed and implemented a collision warning system that combines data captured from radar and cameras. Siemens Mobility has equipped a Combino tram operated by Stadtwerke Ulm with this new assistance system. The Siemens Tram Assistant is based on automotive components supplied by Bosch.

With its sensors, the Siemens Tram Assistant monitors the space ahead of the tram and warns of impending collisions with other trams or cars and buffers. Three versions of the system intervene in the tram's control to a different degree. At the lowest level of integration, an audible warning is given, while at the highest level, automatic braking takes place if the driver does not respond to the situation. The driver can override the automatic braking at any time.

Twelve new Avenio M trams operated by Stadtwerke Ulm are already equipped with the Siemens Tram Assistant and ten older Combinos will follow. At the same time, 60 Avenio trams in Den Haag are also being retrofitted. The new Avenio trams ordered for Den Haag, Bremen and Copenhagen will also benefit from the Siemens Tram Assistant. Pedestrian reactions to this first extension of the system's basic functions will now be tested and evaluated.

Development level 2: Testing the first autonomous tram in Potsdam

ViP Verkehrsbetrieb Potsdam GmbH has been a customer of Siemens Mobility since the 1990s and has provided a Combino tram that has been equipped for autonomous driving tests with GPS, computers and several types of sensors such as cameras, lidar and radar scanners. The joint development project is studying the technological challenges of autonomous driving under real-life conditions in order to develop and test viable solutions. The world's first test vehicle was presented at InnoTrans 2018, but was not designed for commercial operation. Over the long term, however, a tram will be developed that can operate at the GoA 3 level of automation (accompanying driver to handle emergencies) or GoA 4 level (without accompanying driver).

The space ahead of and to the sides of the tram is captured by an array of cameras. The system's analytic software is trained with methods of artificial intelligence to recognize countless objects and people with every shape and in every position. Among other things, the special algorithms recognize traffic lights, signals and signal conditions, pedestrians, other vehicles such as cars, trucks, buses or bicycles, and objects and obstacles on the tracks ahead. Camera images are analyzed and stop the tram when traffic lights or signals block further movement. When the light or signal changes to “go”, the Combino automatically resumes its journey.

Information from the cameras is continually combined with data from the three radar detectors. The reflected radar waves identify, for example, metal objects such as cars and other trams, and enable the speed, distance and direction of these objects to be precisely calculated. Three lidar scanners, operating as digital eyes, scan and capture a 270° image of the space around the front end of the Combino. They scan horizontally and vertically, and can detect people, measure their speed and position, and calculate their movement in a stylized three-dimensional image of the surroundings.

Complex algorithms running on powerful computers are the “brain” of the tram. They analyze the momentary traffic situation, predict its further development and make the right decisions that are then carried out by actuators for the Combino’s bell, drive system, control electronics and braking system.

The route must first be learned by the tram. Test runs have been conducted in Potsdam since May 2018, accompanied by a driver who intervenes only in case of danger. Information processed in real-time from data provided by the cameras and sensors is displayed on a large monitor in the test tram. The test route has been extended from an original six to 13 kilometers and now runs from the ViP depot to the final stop at Marie-Juchacz-Straße. Buses also travel along an 800-meter-long roofed and fenced stretch where various scenarios can be tested.

On all test routes, the tram stops precisely at each station platform and resumes its journey on its own when allowed by the signal. People approaching the track are quickly warned by the tram bell. The tram reacts to cars crossing the tracks just like a driver would. There are no jerking movements, no sharp braking ahead of curves and no leisurely acceleration indicating that the tram is operating autonomously. Testing on the extended route and on automated depot runs serve to prove that the autonomous control system can be used successfully with the skills it has learned.

Development level 3: Test findings and future challenges

The ability to recognize obstacles and signals should soon be so advanced that the system can be used in normal tram operations. Since there are at present no approval procedures for autonomous rail vehicles, the Association of German Transport Services and Siemens Mobility are working together even at this early stage to define the necessary safety and legal framework for the new technology.

The sensors used on the test tram have come from the industrial and automotive sectors. Different conditions for pricing and durability apply in those areas and for the specific operating conditions of a tram.

Although Siemens Mobility is drawing on existing automotive technologies, it is adapting the basic pattern recognition and signal processing algorithms to the requirements of tram operations. Automotive sensors, for example, record many more objects in front of and alongside a car than are relevant for a tram. To correct this, stationary objects like power masts, fences and street markings that are no danger to the tram must be filtered out in the data processing. Deriving appropriate warning and action strategies poses another challenge. Although the components have useful algorithms for recognizing people, only a specialist can develop algorithms that recognize when a person presents a danger. In pedestrian zones and at tram stops, for example, people move very close to the dangerous space of a tram but must be assessed completely differently than in a car.

Side effects of the autonomous test tram

Testing the autonomous tram on the Potsdam tram network under real environmental and traffic conditions has shown that the technologies and their perspectives are promising. However, many hurdles remain until these trams can be used completely reliably in normal traffic. After all, the tram and its control software must learn to accurately recognize and analyze any kind of complex traffic situation and combination of individual scenarios and be able to draw the right conclusions and make the right responses. This requires an immense learning process and the development of countless algorithms that will keep developers busy for years.

Over the short and medium term, however, results from the project tests will be successively flow into new series-ready functions for driver assistance systems like the Siemens Tram Assistant, which already benefits customers. With a “Speed

Assistant," for example, it would be possible to prevent a tram from entering a tight curve too fast, or from accelerating or braking unnecessarily. Another application could provide data on temporary speed restrictions in construction zones or special notices about the route in real time. This would help the driver, increase safety and reduce wear – for example when accelerating out of curves.

In addition to such new functions for the Siemens assistance systems, the first intermediate levels of automated operation will be achieved in the next few years. The first commercially useful step – automated depot operation with autonomous driving into the parking facility – is already conceivable. Since the depot is largely separate from the normal public transport system, this simplifies technical controls and eases approval from authorities. The same is true for sections of tram lines with tracks separate from streets. Here, partial automation to relieve the driver will be possible soon without the need to master more complex mixed traffic scenarios. By 2020, partial automation of the depot operations will be tested in Potsdam in order to promote depot automation as a commercial application.

Since the sensors in the tram precisely register the tram's surroundings, they can also be used to monitor the condition of the infrastructure for maintenance purposes. Automated procedures can continuously check the clearance gauge and condition of the tracks and overhead lines and warn of fallen trees or other obstacles on the track. They can also monitor the integrity of signals, points and balises and see where vegetation is intruding into the tracks.

In all cases, the new technology helps the driver and provides greater safety, higher availability, improved passenger comfort, punctuality and energy savings. Fewer accidents, less wear and tear and lower repair costs also reduce operation costs and ensure an increase in value sustainably over the entire lifecycle.

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