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Design and Practical Evaluation of an Intersection Assistant in Real World Tests

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Abstract—**In this paper an intersection assistant, which is based on Inter-Vehicle-Communication, has been designed and implemented in a test vehicle. In addition to the development of the control algorithm and the definition of different technology layouts, diverse Human Machine Interfaces (HMI) have also been designed. Subjects with different age, gender and driving experience have been selected to evaluate the intersection assistant regarding safety enhancement, user acceptance and the assistance in the driver task as well as find out the most suitable HMI. Test results show that the system can assist the driver and improve traffic safety.**

I. Introduction

NOWADAYS, road traffic plays a more and more important role in human being's daily live and social economy. Due to the increasing traffic density and complexity, driving becomes also a stressful task. In order to relieve the driver's load and even to prevent traffic accidents, diverse advanced driver assistance systems have been developed in recent years.

Research results on traffic accident ([1] and [2]) have shown, that around 34.7% of all accidents in Germany occur in the range of intersections. Therefore a driver assistance system, which supports the driver at intersections, would have great potentials to increase traffic safety.

Because of the physical principle of the conventional sensors like radar, lidar or image processing system, other road users at an occluded intersection (caused by buildings, trees or other vehicles) cannot be detected. In these situations, the most suitable technology to detect other vehicles is the wireless communication. Inter-Vehicle-Communication (IVC) and Roadside-Vehicle-Communication (RVC) are two applications of this technology. Together with GPS or roadside measuring equipments, the detection of other vehicles in the range of an intersection can be realized.

In this paper, an Intersection Assistance (IA) system based on IVC is presented, which has been developed and implemented in a real test vehicle. It is designed to assist the driver in the situation assessments and also to prevent accidents in critical situations.

This IA can be applied in all intersections (especially the intersections without traffic lights) and to all kinds of vehicles.

When the vehicles approach an intersection, they exchange their positions, speed and other data by communication. The intersection assistant receives this information, processes it and takes corresponding reactions:

- provide it directly to the driver to inform him about the presence of other vehicles in the intersection (informing system)
- assess this information and warn the driver in case of a conflict situation (warning system)
- assess this information and intervene into the brake, if the driver does not react by himself (intervening system)

In the real world test, subjects with different age, gender and driving experience have been selected to evaluate this intersection assistant. The main aspects of the evaluation are the system performance, user acceptance, the influence of IA on the driving behavior and the preference of HMI.

II. Test Vehicles and System Architecture

For the practical evaluation of the intersection assistant in real world tests, the system, which consists of the algorithms as well as the Human Machine Interface (HMI), has been integrated in a test vehicle.

A. IA System Architecture

Fig. 1 gives an overview of the IA system architecture and the data communication of two test vehicles. In the test, the BMW 728iA is used as the main test vehicle (so-called subject vehicle), which is equipped with IA system (controller and HMIs), GPS receiver and communication device. The MB A170 is used as the principle other vehicle in the test. It is equipped only with GPS receiver and communication device.

In the MB A170, driving speed and turning signal are measured by the onboard sensors and are available for a Infineon C167cs based micro-controller in analogue format. This controller also collects the GPS signals from a GPS device and converts all necessary information into CAN messages. These CAN messages are sent to a WLAN CANbox and further transmitted to the WLAN CANbox in the BMW 728iA.

In the BMW 728iA driving speed and turning signal are already available on the vehicle CAN bus. Through an USB-serial adaptor GPS signals are delivered to the USB port

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of the IA controller, which is in this case a notebook-PC. In this way, all necessary input data of the IA system are available for the controller. After the calculation, diverse HMIs are activated according to the test layout.

situation assessment and HMI generation. Furthermore three sub-functions are included in the position determination block. These are the Gauss Krueger transformation of the GPS-position, road matching and position interpolation.

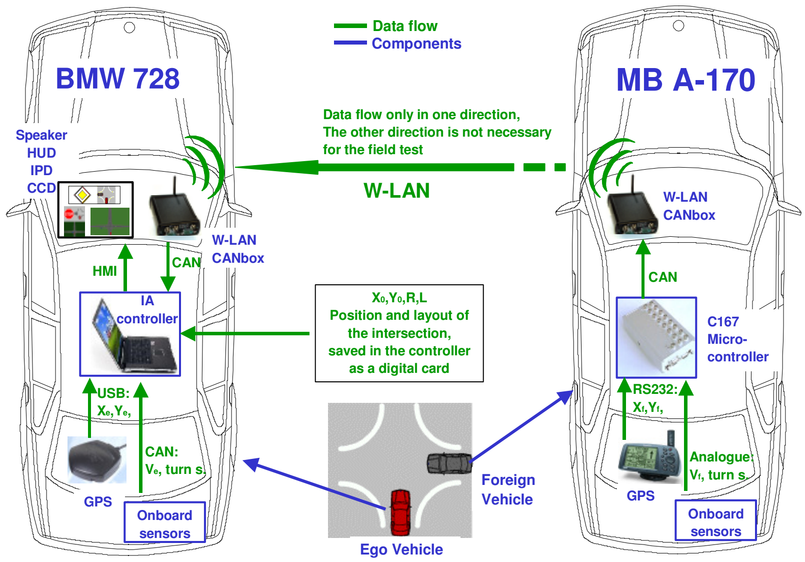

Fig. 1. IA system architecture

The position and the layout of the intersection (like the radius of the corners, the length and the width of the road) are saved in the controller as a digital map. This data is also used for road matching to improve the GPS accuracy.

B. *Test Vehicle BMW 728iA*

For the development and test of diverse driver assistance systems, this BMW 728iA is equipped with diverse environmental sensors, onboard sensors and actuators.

In order to utilize diverse add-on devices 5V, 12V, 24V and 230V are available in the car for the necessary power supply. A secondary private CAN bus is integrated, so that the CAN messages from the add-on devices can be collected together without influencing the original vehicle CAN bus.

For the purpose of developing advanced driver assistance systems, actuators for the regulation of engine and brake booster have been mounted in the car. In order to develop vehicle lateral guidance systems like parking assistant, lane keeping assistant, as well as lane change assistant, an active steering system is also integrated.

Numerous environmental sensors like 77GHz radar, infrared laser scanner, laser sensors as well as an image processing system are available onboard. All the information collected by these sensors is collected on the secondary CAN bus. C167 based micro-controllers have access to this CAN bus and can be used as controller for the driver assistance systems or as A/D converter for additional analogue sensors.

III. Intersection Assistant Control Algorithm

The intersection assistant consists of three main functions, which are illustrated in Fig. 2: position determination,

The controller reads the GPS signals and the CAN messages (vehicle speed, turning indicators etc. of the host and principle other vehicles) from the USB ports of the notebook. As the output the controller sends the video and audio signals to the corresponding HMIs.

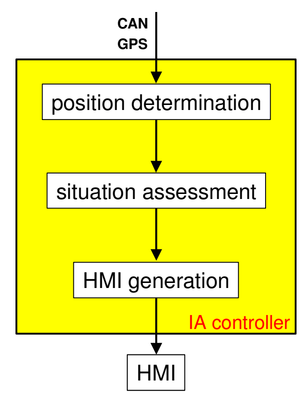

Fig. 2. Overview of the IA software structure

The function "situation assessment" is the core of the IA control algorithm. Here, GPS and W-LAN signals are processed together with the information acquired by the onboard sensors (such as vehicle speed sensor, turning signal sensor and etc.). The focus of the real world test with subjects is on a warning system. The warning algorithm, which has been developed in [3], is applied and enhanced. The flow chart of this algorithm is shown in Fig. 3.

IV. Design of Human Machine Interfaces

A suitable Human Machine Interface (HMI) is the

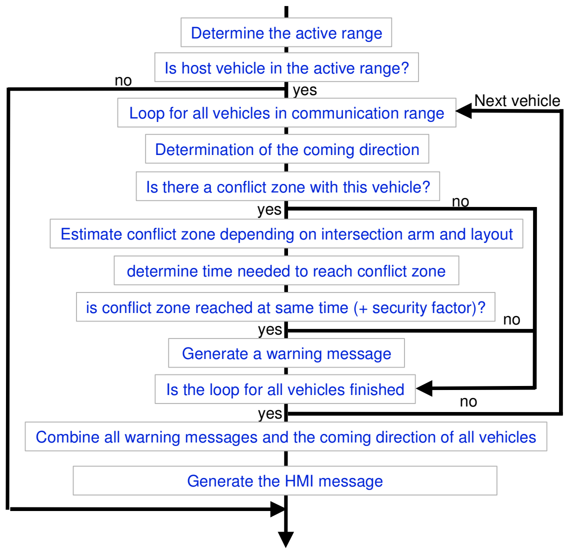

Fig. 3. Flow chart of the control algorithm

precondition for the assessment of user acceptance by subjects. The HMI for driver assistance systems can be realized by visual, auditory and haptical means. Because the information content provided by a haptical HMI is very limited, within this paper the focus is set on visual and auditory HMI.

A. *Design Principles of HMI*

According to [4] and [5], the following aspects have to be considered, when designing a HMI for the application in a warning system:

- The warning must be noticed (e.g. visual warning should be introduced by a sound, otherwise the driver could oversee it).
- The warning must be read or heard (e.g. auditory warning should be louder than the surrounding noise level).
- The warning must be understood (e.g. the driver has to understand in case of an auditory beep, what is intended by this beep: collision waning, lane departure warning, seat belt reminder etc.).
- The warning must be accepted (e.g. there should be only few false alarms, otherwise the driver will get annoyed and not react to the warning anymore or shut the system off). This aspect is not only influenced by the HMI itself (e.g. if the kind of warning tone is annoying) but also by the system design (frequency of false and missed alarms).

B. *Visual HMI*

According to [6] and [7], three visual HMIs namely a Head-Up Display (HUD), a Center Console Display(CCD) and a Instrument Panel Display (IPD) are selected and mounted at the respective positions (see Fig. 4).

The HUD is mounted in the dashboard and it projects an image by means of mirrors on the windscreen. Because the image of the HUD is within the optimum field of view, only eye movement is necessary to watch it. The disadvantage of this position is the occlusion of the real scenery by the display. Therefore the image, which is projected on the windscreen, has to be half-transparent, which of course also reduces the quality of the image. In this application HUD has the task to show a warning sign and a schematic description of the traffic situation at the intersection.

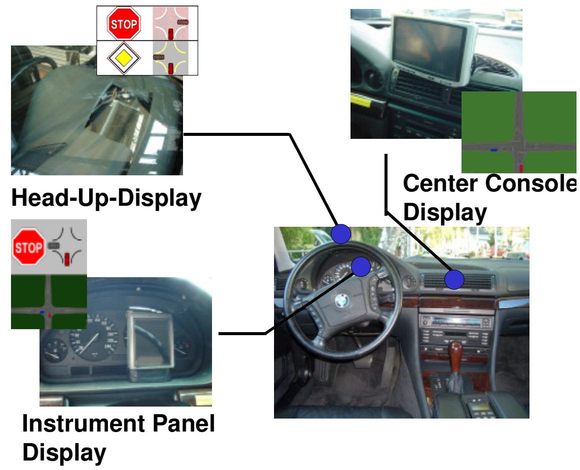

Fig. 4. The displays in the IA

The center console display (CCD) is mounted on top of the center console. At this position normally a display for navigation or for the infotainment system is installed in mordern vehicles. In the test vehicle, a 7” TFT display is used as CCD.

CCD serves in this intersection assistant only as a source of information to show the scenery of the intersection. When the subject vehicle approaches an intersection, the display is activated and shows a top view of the corresponding intersection by animation.

The Instrument Panel Display (IPD) is integrated in the instrument panel next to the speedometer. At this place usually small displays are integrated in modern vehicles. They are used for driver information systems like navigation and driver assistance systems like ACC to inform the driver about the current status of the system.

The image displayed on the IPD is divided into two parts. The upper part consists of a warning message and a description of the traffic situation by icons, which are also used for the HUD. The lower part shows a camera view as it also used on the CCD. That means it integrates both functionalities of the CCD and the HUD.

C. *Auditory Warnings*

Additionally to the above described visual HMI two types of sound are used as auditory HMI: Single beep tone and verbal message in forms of human voice.

The single beep tone is used as a notification sound to arouse driver’s attention at the activation of the HMI or when the situation changes.

Differing from the single beep tone the Human Voice (HV) includes more information and takes more time, e.g. "Beware, vehicle enters intersection, brake!". The human voice is not used as notification sound but as a warning message.

D. HMI Designs

Three reasonable combinations of HMIs are chosen and implemented in the test vehicle to be evaluated by subjects:

HUD + CCD: In this combination the HUD is used to show warning messages and a schematic traffic situation by icons, whereas the CCD provides a camera view of the intersection by animation, where the driver can see the intersection and the vehicles, which approach the intersection and are in the intersection area. Generally the activation of any HMI is introduced by a single beep tone to arouse the driver's attention to the displays. The single beep tone is also used, if the result of the situation assessment by the intersection assistant changes, while the HMI is activated (e.g. a new vehicle approaches the free intersection, so that driver has to stop, whereas earlier not).

IPD: In this case both icon messages (warning sign and traffic situation by icons) as well as the camera view of intersection are shown in this display. Again a single beep tone is applied, if the HMI is activated or the result of the situation assessment changes.

HV + CCD: The CCD is used as the single visual HMI in this case to show the top view of the intersection. A verbal warning message is given in addition to this visual information, if the driver has to consider the vehicles with higher priority (driver has to give right of way to other vehicles). A beep tone is not used in this HMI concept.

According to the experience, which was gained in a previous driving simulator study, where the system layout and HMI design of the intersection assistant have been analyzed [3], four kinds of single usage of the displays are also regarded in the test vehicle:

- IPD with only upper part (warning signs)
- IPD with only lower part (intersection animation)
- Only HUD (warning signs)
- Only CCD (intersection animation)

The single beep tone is also used in these four display concepts.

V. Evaluations of the Intersection Assistant

A. System Layouts and Specifications

Four possible layouts and specifications of this communication-based intersection assistance system have been studied in [8] and [9] with the traffic simulation tool PELOPS [10]:

- Low-tech "Simple IVC": Only IVC with available positioning system and digital maps
- High-tech "Simple IVC": Only IVC with for the future expected positioning system and digital maps
- Low-tech "Sophisticated IVC": IVC combined with RVC and available positioning system and digital maps
- High-tech "Sophisticated IVC". IVC combined with RVC and for the future expected positioning system and digital maps

The study showed, that the following two concepts can improve traffic safety significantly and have also necessary user acceptance:

- Low-tech "Simple IVC" with information about the right of way regulation
- Low-tech "Sophisticated IVC"

It cannot be expected, that the necessary high equipment rate for "Simple IVC" can be reached in the next future. For the first introduction of communication-based intersection assistant the "Sophisticated IVC" solution should be chosen, even if RVC is only used at some accident-frequent intersections. Although not all intersection accidents can be avoided by the RVC-based system, but a reduction of around 20 % of all car-to-car accidents is probable (for details see [8]).

To enhance traffic safety significantly the technology layout "Simple IVC" with a high equipment rate is required. For a better user acceptance, the right of way regulation in the intersection has to be implemented in the digital map.

B. Practical Evaluation with Subjects

16 Subjects with different age, gender and driving experience are selected out to take part in this field test. In the test, they are driving the test vehicle (BMW 728iA) in a pre-selected intersection with different situations (different speed, right of way, turning direction, coming direction and distance to the principle other vehicle, etc).

This field test focuses on the evaluation of HMI and the influence of the intersection assistant on the driving behavior. In addition to these two main test aspects, tests to timing of warning, warning threshold, IA performance at night, Low-tech "Simple IVC" with/without right of way information as well as the wrong usage of turn signal are also analyzed.

The assessment is realized by means of questionnaires. Subjects are asked to fill out a pre-questionnaire before the driving test, a set of questionnaires during the test (after each test item) and one post-questionnaire after the whole test. They are unaware of the test objectives before filling the questionnaires.

C. Test Results

In this section, the main results achieved in the field test are presented.

1) HMI

Fig. 5 illustrates the preference of the subjects regarding all HMI designs. HV + CCD is most preferred. Deeper analysis shows, that this combination is mostly preferred by male, older and experienced subjects. IPD is rated as second and is preferred mostly by female and inexperienced subjects.

Because the human voice warns the drivers directly, they do not need to look at the display to get the information about the traffic situation. Therefore the combination of HV + CCD is most popular. IPD locates in the instrument panel and shows both the warning signs and the intersection animation. But it is often occluded by the steering wheel or hands. Despite its drawback still four subjects prefer to this HMI, since all the necessary information is shown on it. Since HUD locates directly in the sight, there are three subjects preferring to it.

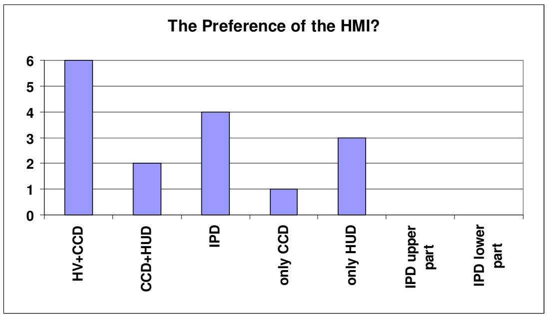

Fig. 5. The preference of HMI

2) Influence of the IA on Driving Behavior

Three situations as shown in Fig. 6 are used to find out the influence of the intersection assistant on the driving behavior. In each figure, the vehicle at the bottom is the test vehicle driven by the subject (subject vehicle). The arrow represents its driving direction. The driving speed of both vehicles is given in the circle.

For example in the situation 8 (S8), the subject vehicle turns left without right of way while a principle other vehicle is coming from right. The sight of the subject vehicle to right is occluded by a fence (illustrated as a blue curve in Fig. 6)

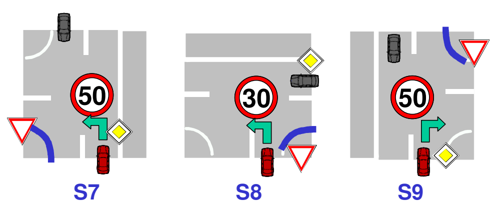

Fig. 6. Test scenarios of the influence of IA

An example of the speed course (driving speed over the distance to the intersection) is shown in Fig. 7. The driving behavior with IA is compared to the driving without IA.

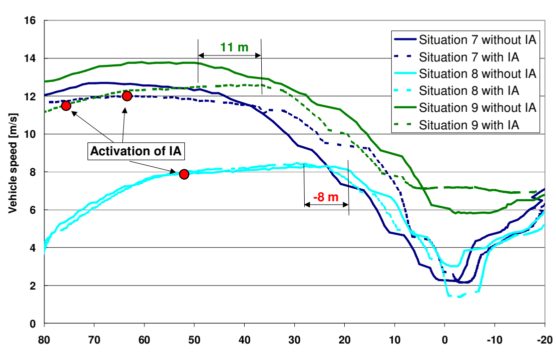

Fig. 7. Influence of IA on driving behavior

Like most subjects this female subject does not stop at the intersection. Because there is only one principle other vehicle, it is not necessary to stop, if the driver adjusts the speed in advance.

When the warning is given in situation 7 and 8, she does not brake immediately. There is no significant difference at the brake timing and driving speed through the intersection in situation 7 between the drive with and without IA. In situation 8, where she has to give way and cannot see the principle other vehicle, she brakes 8 m earlier and drives more slowly through the intersection with IA (between the distance from 5 m to –10 m). In situation 9, where she has right of way, she brakes 11 m later (it is not influenced by the slightly lower approaching speed, because an 1 m/s speed difference can not be perceived so precisely by a human driver.) and drives faster through the intersection with IA.

In Fig. 8 the results of this test item are summarized. The average difference distance between the braking point with and without IA is given. Negative values mean, that the subject brakes with IA earlier.

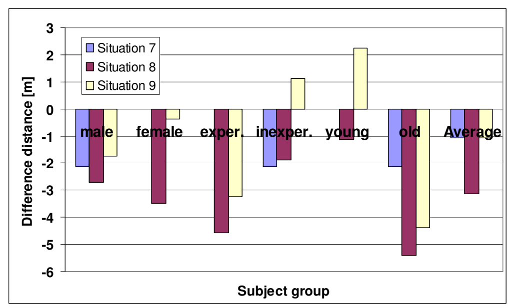

Fig. 8. Influence of IA on braking time

As shown, with IA the subjects brake normally in all situations earlier (average values). This effect is more significant when the sight is occluded and the subject have to give right of way (situation 8). Even in the situation 9, where the driver has right of way, the impact of IA on the driver behavior can be seen.

Male subjects are influenced in all situations by IA, whereas female subjects only in situation 8. For experienced subjects the effect is higher than for inexperienced ones. Older subjects are influenced significantly, whereas the effect on younger subjects is lower. The older subjects react with IA in average up to 5 m earlier than without IA. Inexperienced and young subjects brake later in situation 9 with IA. This could be a hint that those groups rely more on the IA than the other groups.

The influence of the IA on the driving speed through the intersection is also analyzed. There is no big difference in 30 cases. But in 16 cases subjects drive more slowly through the intersection with IA. Only in two cases subjects drive faster. The differences between the three situations are not significant.

Fig. 9 illustrates the influence on the driving speed of each subject group in all three scenarios. Gender and age have no influence on this effect. Inexperienced subjects are influenced more than experienced ones. In around 40% cases the inexperienced subjects drive slower.

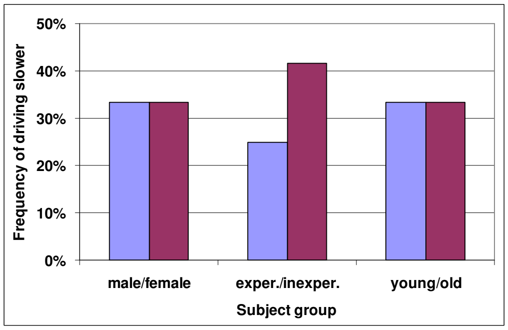

Fig. 9. Influence of IA on driving speed

3) Low-tech "Simple IVC" without ROW Information

In this technology layout, the right of way information is unknown to the IA system. Therefore the driver gets always a warning, even if he has the right of way.

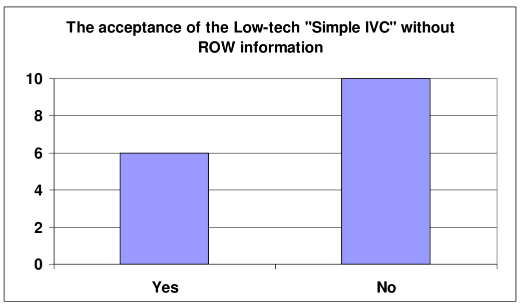

Fig. 10. The acceptance of the Low-tech "Simple IVC" without ROW information

The results of this test is shown in Fig. 10. This technical layout is rated as very unsatisfactory. Even in dangerous situations a warning in case of right of way is not accepted fully. 10 of the 16 subjects cannot accept a warning, if they have right of way. Female and younger subjects tend to be more open to a warning in this case.

4) General assessment

Fig. 11 shows that most subjects think the IA is meaningful (the average rating is around 4 and the standard deviation is around 1). The results of other questions show, that 13 of 16 subjects would have benefited form the IA in their daily life. The subjects agree that the intersection assistance can assist the driver and can reduce traffic accidents.

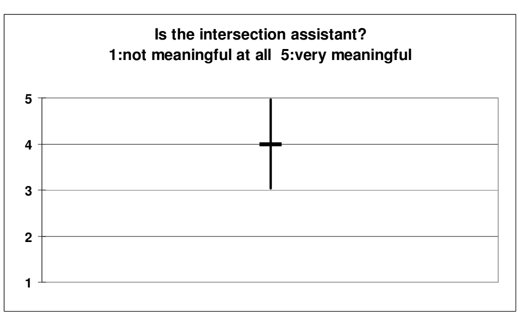

Fig. 11. General assessment of the IA

VI. Conclusion and Outlook

In the scope of this paper, a communication based intersection assistant as well as suitable human machine interfaces have been designed and implemented in a test vehicle.

The results of subject test show that HV + CCD provides most satisfying assistance, while IPD and HUD follow. Nearly all subjects agree, that this intersection assistant can improve the traffic safety and assist the driver, but they are also worrying about that people could rely too much on the system.

Besides this warning intersection assistant, another possible design is an intervening system, which is activated very late and only in case of danger. The requirements on information acquisition and situation assessment are very high, since false alarms have to be avoided. Otherwise it can be expected that the user will not accept the system.

The function of an intersection assistant can also be extended to:

- Communication with traffic light: using the system to prevent red light violation.
- Pedestrian detection: High requirements on sensors for pedestrian and bicyclists detection. Sensor requirements can be reduced by using digital maps with information about the location of zebra zones.
- Fully automatic driving at intersections: The vehicle approaches the intersection, waits until it is free and drives then through the intersection.

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