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Increasing cycling safety by an adaptively triggered road instrumented warning element in EU project XCYCLE

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Abstract

In urban traffic, cyclists are often exposed to high risks especially when being in interaction with motorized traffic participants. Objectives of EU funded project XCYCLE (http://www.xcycle-h2020.eu) are to improve and increase cyclists' safety. Focusing on urban traffic, the project addresses the use case of an intersection with right turning motorized traffic (especially HGV's) and privileged cyclists going straight on.
One of the main project activities lies in developing an infrastructural supported cooperative advanced driver assistance system (C-ADAS). Infrastructural detection and computations allow it to send situation and risk related information to the given road users (esp. the motorized traffic participant) using wireless communication standards like ITS-G5. As parts of the cooperative overall system equipped trucks and bicycles will also receive a warning. In this paper, the focus is on the concept, construction and triggering of a visual road instrumentation positively influencing gaze behavior of drivers of non-instrumented vehicles.

Keywords: cycling safety, bicycle crash prevention, cooperative ADAS, traffic conflict analysis, application platform for intelligent mobility.

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1. Introduction

In urban traffic, cyclists are often exposed to high risks especially when being in interaction with motorized traffic participants. That holds true for both the frequency of occurrence as well as the severity of consequences, especially for vulnerable road users like cyclists. According to Destatis (2013) in Germany about 350 cyclists are killed in road accidents and about 70.000 are injured. The percentage of injuries and fatalities according to collision with motorists has a share of 59% for injuries and 39% for fatalities. In comparison collisions with HGVs have a share of 5% for injuries and relative high amount of 20% for fatalities.
The objectives of EU funded project XCYCLE (http://www.xcycle-h2020.eu) is to significantly improve the safety of cyclists of all age groups and heterogeneous user types in their potentially dangerous interaction with passenger cars and HGVs. XCYCLE wants to develop "user-friendly, technology-based systems to equalize the treatment of cyclists in traffic and thus both encourage cycling and make cycling safer". One of these system approaches is the idea of a cooperative advanced driver assistance system (C-ADAS) that builds the envelope for the work presented in this paper.

1.1. XCYCLE cooperative system approach

The functional architecture of the cooperative system approach is displayed in Fig. 1.

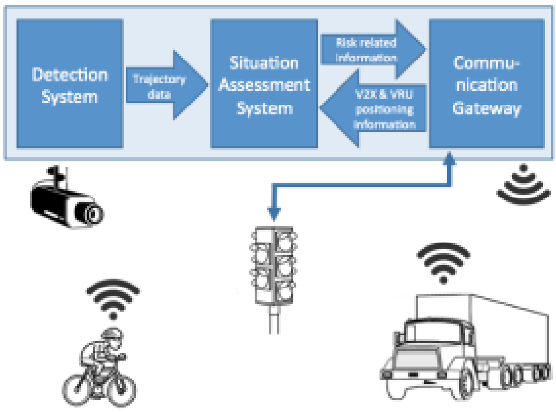

Fig. 1 Functional architecture of the cooperative system approach

Specific elements including traffic participants as well as infrastructural elements can be discriminated that form an integrated system network. One basic backbone of the system approach lies in an infrastructure-based detection system that is able to detect, track, and classify traffic participants under real-time conditions. The output of this detection system is so called trajectory data. This data includes spatial and temporal highly resolved information about the objects' positions, velocities and accelerations as well as an estimation of their dimensions and class (e.g. pedestrian, bicyclist, car, HGV). This trajectory data can be taken as primary basis for the online situation assessment system. This system processes all the given data to build up a situation representation of current traffic behavior. In addition, the system predicts near future development of the traffic events and derives potential risky situations. This risk related information is forwarded to instrumented traffic participants through a communication gateway. The traffic participants can integrate this information into their platform-specific ADAS systems. Technical communication can be used for information exchange. From the opposite viewpoint, traffic participants provided with communication instrumentation broadcast information about their current status e.g. via ITS-G5 Cooperative Awareness Message (CAM) specified by the European Telecommunications Standard Institute (ETSI) (2011). This information can be used to support and validate the given trajectory data.
Project XCYCLE makes use of the research intersection of test field AIM (Application Platform for Intelligent Mobility). Fig. 2 shows the basic features of this installation. Fig 2(a) shows different fields of detection that are covered by the sensor setup that is mounted on given light signal poles and XYCLE specific sensor poles, displayed in Fig 2(b) and (c). Though different sensor technologies are used in the facility, stereo video is the primary sensor technology utilized. Further information about is given in detail in Gimm et al. (2016).

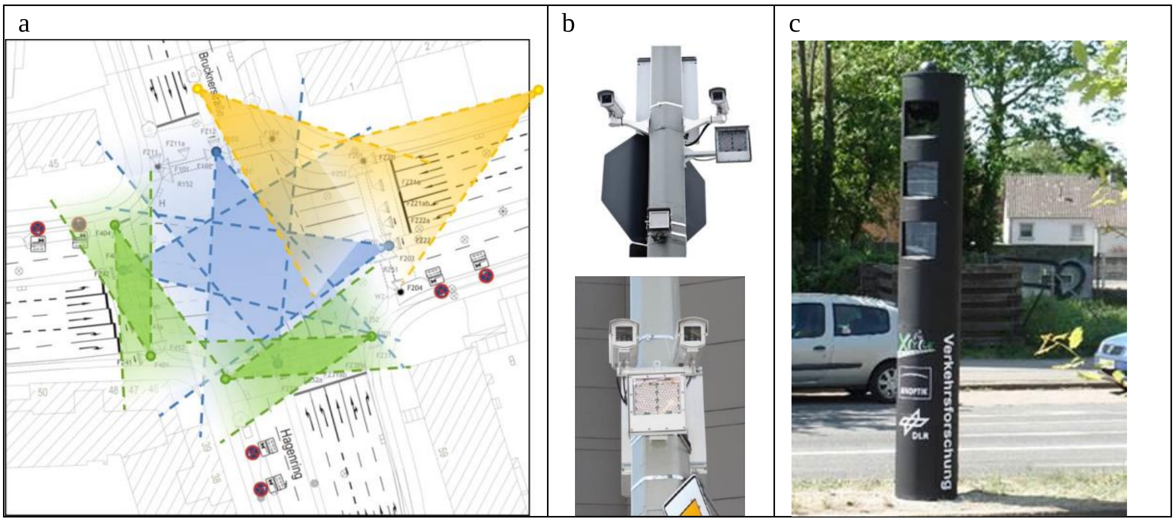

Fig. 2 AIM Research Intersection (a) detection ranges b) pole installations c) XCYCLE specific sensor poles

Fig 2(a) shows that substantial technical effort is necessary to cover all parts of the intersection. This is especially driven by general requirements of predicting potential critical events in the near future. This technical effort can systematically be reduced by only focusing on specific interesting types of use cases where technical support is really needed to improve safety. XCYCLE focuses on the use case turning right.

1.2. Use Case: Right-turning vehicles at Urban Intersections

One of the use cases, which are examined within the project, is turning right. In this respect, high numbers of accidents are still recorded, particularly in the case of HGVs like shown in Johannsen et al. (2015). Many examinations have been made regarding cyclist safety in crossroads. An overview is given in a deliverable from XCYCLE's sister project InDeV (2016).
Results of one exemplary study found in GDV (2013) are described in the following paragraph. Especially dangerous are conflicts between motorized vehicles turning and cyclists moving straight on. This type of accident is almost exclusively caused by the driver and ends in 80 percent of the cases with injured persons. At signalized intersections it turned out that separated cycle paths with a lateral offset of two to four meters from the road favor accidents. The most frequent reasons for conflicts are perceptual problems of the motorized traffic participant. Examples for this are a missing shoulder-check, looked-but-failed-to-see-errors and sight obstructions. An action catalog was derived on these findings and includes, among other things, an enhancement of turning assistants in motor vehicles to increase attention. The presented solutions are based on a sensor detection of the cyclist in order to address the problem that cyclists approach from the rear often with high speeds at simultaneous rather low turning speed of the motor vehicle.

For the given intersection in Braunschweig (K047), the topological constraints and light signal operation cycles mostly separate the various traffic flows. Nevertheless the use case is also found at the AIM Research Intersection. Figure 3 depicts the described use case under research. It consists of motorists coming from the East (red) and turning right to the North (blue). The bicycle crosses the road from east to west creating a potential conflict zone. Motorists and cyclists have identical traffic light phases. Turning motorists need to yield to crossing cyclists. The cycling path has a variating lateral offset contributing to complex relations of the trajectories to each other. Depending on this relation the cyclist is hard to be seen from the perspective of the driver.

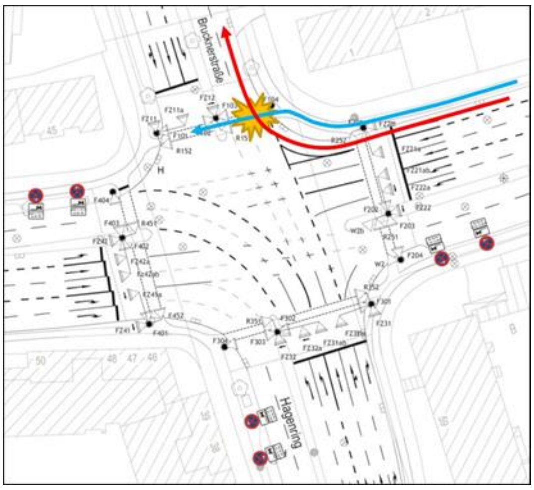

Fig. 3 Use Case “Turning Right” at K047 in Braunschweig

In this use case a field study based on trajectory data has been done in XCYCLE in order to analyze the interaction of motorists and cyclists. Results are shown in Dotzauer et al. (2017). Many encounters have been found which partially have a critical character. As a matter of this, specific measures have to be developed to make turning in the urban environment safer. As introduced above equipped motorists will be wirelessly warned in XCYCLE based on infrastructural computations. Nevertheless, the vast majority of vehicles are not equipped. Thus, they are not able to profit from the warning. The penetration of such systems in the vehicle fleet will also take a longer time. Due to this a general solution is needed: a road instrumented warning element.

2. Infrastructure-based ADAS-approach for unequipped vehicles

In order to incorporate unequipped motorists a road instrumented warning element shall be realized and be integrated in the functional flow of the overall system. A literature overview on available on-site warning systems is given in D2.1 (2016). The presented solutions are based on visual elements like light signals or sign elements to increase the driver’s attention. One example system uses inductive loops to detect bicycles and trigger LED lights located on ground of the street in parallel to the approaching vehicle. When XCYCLE project started to systematically identify demands and requirements of a possible technical solution with the municipality of Braunschweig, the discussion soon covered possible legal effects of our measures in case of accident events. Since the measures are to be implemented in real traffic conditions, this is an important factor to be incorporated. It was decided to make use of state-of-the-art solutions as basis for further development and investigations to reduce potential risks for the project.

In Germany, the state-of-the-art solution is a static flashing amber described in RiLSA (2015). It is used at hotspots with high potential for conflicts and accidents. The drawbacks of this solution are the following: first of all, flashing ambers are usually installed at the outer side of the bend in respect to the target lane to generally inform drivers of the right-of-way for VRU with right of way. Thus, drivers are given a signal in a field of view that pulls away attention from the relevant point of attention that would be on the right, since potential cyclists enter the interaction zone from this side (like shown in Fig. 3). In addition, flashing ambers are flashing with a fixed frequency, hard-wired with given traffic light cycles. They are not designed to show any adaptive characteristic which leads to well-known reductions in effectiveness due to habituation effects shown in Fischer et al. (2016).

In order to overcome this drawback, XCYCLE developments in detection and situation analyses are to be used to individually trigger the warning light. By this the flashing amber is supposed to only warn if a bicycle is really approaching. The concept for this adaptively triggered road instrumented warning element is presented in the following chapter.

3. Concept for realization of the warning element at AIM Research Intersection

The next section gives an overview on the components before functional and design aspects for the realization are presented.

3.1. Components of the warning element

The outer appearance is designed in similarity to a traffic light facility (TLF) used i.e. at road construction works. In Fig. 4 an overview of the main components of the road instrumented warning element is given. At the upper end of the pole the signal stack (1) is mounted hosting the amber light. On the top of the pole the V2X-antenna (2) for the wireless connection is placed in order to reach best possible signal strength. The controller box (3) hosts the hardware components that are needed to process the warning like an application unit (AU) and a communication unit (CCU). A Wi-Fi router (4) allows internal network access wirelessly besides a physical connection via RJ45 network connector. The bottom of the system consists of a battery container enabling the system to perform independently of an external power supply which can be connected via an external power outlet (6).

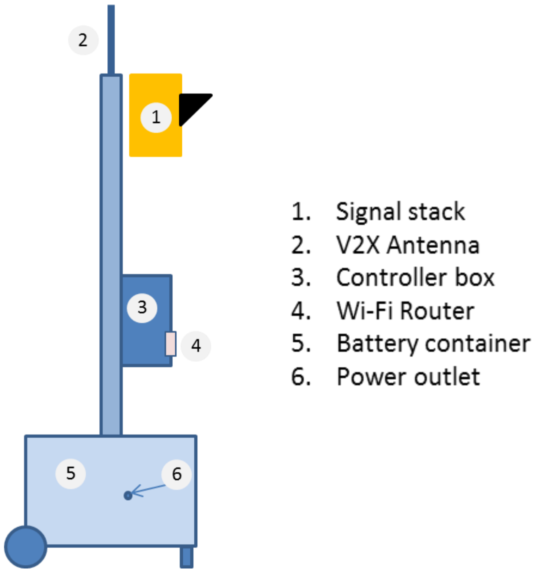

Fig. 4 Component parts of the early warning traffic light facility

3.2. Realization at AIM Research Intersection

In this section parts of the realization regarding functionality and design of the road instrumented warning element are discussed.
In the following the **triggering** of the flashing amber is described regarding **wireless connection**, the moment of activation and the frequency of flashing. A wireless connection is used to trigger the warning element. The existing AIM reference track described in Knake-Langhorst et al. (2016) is connected to the infrastructural situation and risk assessment servers of the AIM Research Intersection and is used to establish a link to the warning element. In the actual implementation the road side unit communicates via V2X-standard with the TLF. Nevertheless a local WLAN could also be set up. The warning elements default state is deactivated. Once in a second, the TLF sends a heart-beat message to the RSU informing about its state. So the availability of the warning element can be monitored. When the RSU wants to activate the TLF it sends an activation message every 100ms.
In order to prevent motorist-VRU crashes an early warning has to be given out to let the human driver react. Here the position of the vehicle in relation to the warning element is crucial. The **moment of triggering** is chosen before the motorist enters the conflict zone or rather passes the flashing amber. A warning is given out if a bicycle is approaching from behind and both traffic participants moving paths are predicted to enter the conflict zone at the same point of time. The developed algorithms for situation and risk assessment give out warnings to equipped motorists und bicycles. They will be adapted to also trigger the flashing amber.
Regarding the **frequency of triggering** multiple flashing modes are foreseen. Beyond a static flashing mode similar to existing state of the art warning elements, an adaptive flashing mode is foreseen in two stages. A basic frequency of 1 Hz is chosen. If the situation is predicted to be more dangerous, the frequency of flashing is increased to 2 Hz.

As **position** of the warning element a location at the inner curve of the right turning lane was chosen. The spot is indicated by the standing person marked with the green arrow in Fig. 5. The advantage of this spot is that it is not too far away or too close from the conflict zone in order not to warn to early or too late. Furthermore this position allows to positively influence gaze behavior. The driver is animated to have a shoulder check to the right to see approaching bicycles. Other positions that have been discussed were the outer traffic light poles or lamp post in the right of Fig. 5 in front of the ego vehicles position. They have been discarded being too far away of the conflict zone. A position on the traffic light pole directly in front of or behind the conflict zone would be too far away. It would distract the attention of the driver from the right liked described above.

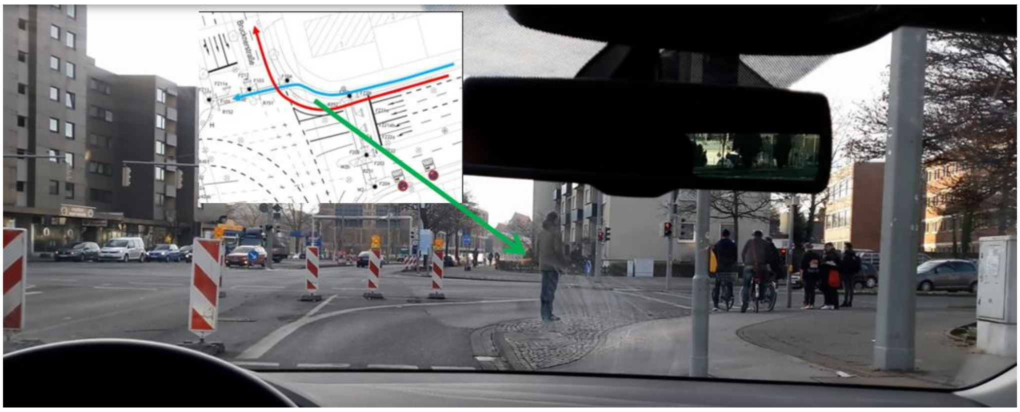

Fig. 5 Position for warning element from driver's perspective in right turning use case

The **orientation** of the amber light is chosen in a way to attract motorized traffic coming from east and turning right. To minimize the influence on approaching cyclists the orientation is changed a little in the direction of the inner field of the intersection away from the cycle path.

The **front of the flashing amber** will be equipped with the silhouette of a bicycle to make the intention of the warning directly clear for the motorist. Possibly an additional arrow is displayed showing in backwards direction to suggest that the cyclist is approaching from behind.

The **height** of the flashing amber will be around 1.70m. By this, medium height car drivers as well as truck drivers are able to see the warning. A more compact appearance as regular construction traffic lights will minimize sight obstructions.

Energy supply can be ensured for short-term operation with included batteries. A long-term operation will be granted by access to the local power network. As a matter of this earthworks are needed.

The amber light will have a **variable** character. The height can be changed, if the amber light is mounted in a lower position. Furthermore the orientation of the warning can be changed. The position might be adapted in a test phase with the rolls shown in Fig. 4.

To minimize the potential for **vandalism** battery container and controller box are locked. For unsupervised long-term operation a fixation on the ground is foreseen with an earth anchor. By this the position of the amber light can hardly be changed.

Due to intensive **public relation** works it is intended to inform the citizens of Braunschweig about further traffic research activities at the AIM Research Intersection which already belongs to the town picture throughout the years. One measure is to publish a newspaper article in the local press in close cooperation with the local municipality.

4. Conclusion and Outlook

Within the framework of XCYCLE, an infrastructure-based C-ADAS aimed at preventing motorist-VRU crashes using V2X-communication is realized. In this paper the concept for realization of an adaptively triggered road instrumented warning element was shown. The benefit is that unequipped motorists are addressed by this generic solution. The functionality of static blinking amber lights is outperformed by an adaptive approach.

The next project activities incorporate the implementation of the described concept of the road instrumented warning element. The integration into the infrastructure based system regarding situation and risk assessment is done. The test of the system is planned for first quarter of 2018 in two stages. First there will be local tests before the system will be installed for a longer period at the AIM Research Intersection in the field. The behavioral evaluation of the system will be done in before and after analysis. On the one hand questionnaires are analyzed regarding the perceived safety. On the other hand trajectory data is examined concerning the occurrence of unsafe encounters with the help of surrogate safety measures.

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