Local Traffic Safety Analyzer (LTSA) – Improved road safety and optimized signal control for future urban intersections

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SHORT SUMMARY

Improving road safety and optimizing the traffic flow – these are major challenges at urban intersections. In particular, strengthening the needs of vulnerable road users (VRUs) such as pedestrians, cyclists and e-scooter drivers is becoming increasingly important, combined with support for automated and connected driving. In the LTSA project, a new system is being developed and implemented exactly for this purpose. The LTSA is an intelligent infrastructure system that records the movements of all road users in the vicinity of an intersection using a combination of several locally installed sensors e.g. video, radar, lidar. AI-based software processes the detected data, interprets the movement patterns of road users and continuously analyzes the current traffic situation (digital twin). Potentially dangerous situations are identified, e.g. right turning vehicles and simultaneously crossing VRUs, and warning messages can be sent to connected road users via vehicle-to-infrastructure communication (V2X). Automated vehicles can thus adapt their driving maneuvers. In addition, the collected data is applied to improve traffic light control depending on the current traffic situation, especially for VRUs. This abstract describes the LTSA system and its implementation in the German city of Potsdam. The current project state is presented and an outlook on next steps is given.

Keywords: Advanced urban traffic control with connected technologies, C-ITS applications, Multimodal traffic management, Traffic management/control in the presence of CAVs

1. INTRODUCTION

One of today's societal challenges is the transformation of our traffic system for a more sustainable world. To protect environment and climate, it is essential to change our mobility behavior. To push this change forward and ensure the mobility for everyone, we have to provide safe, efficient and sustainable infrastructure and mobility services. One key point of this transformation is to shift the modal split from private motorized transport to more sustainable traffic modes like the public and non-motorized transport. Especially the concerns of non-motorized road users – also called vulnerable road users (VRUs) – such as pedestrians and cyclists are moving into the focus of this discussion. In addition, the growing connectivity and automation of the mobility system plays a role, which leads to the expectation of greater efficiency. With regard to the upcoming lack of employees and drivers in public transport, automation is becoming even more important.

In order to strengthen the needs of VRUs in combination with supporting automated and connected transport in urban mixed traffic conditions, VITRONIC and the German Aerospace Center (DLR) are developing the Local Traffic Safety Analyzer (LTSA). This infrastructure system increases the safety of VRUs at intersections, particularly related to connected and automated vehicles (CAVs). In addition, the LTSA allows the traffic signal control at an equipped intersection to consider VRUs for its automated and traffic actuated decisions. This extended abstract describes the development and initial implementation of the LTSA system with a focus on the traffic control aspects.

2. LOCAL TRAFFIC SAFETY ANALYZER (LTSA)

The LTSA is an intelligent infrastructure system that observes the entire road space from an elevated point of view in contrast to the limited perspective that a road user or an automated vehicle has from the road's surface. It detects not only the presence, like most other systems, but also the movements of all road users (especially VRUs) in the vicinity of an intersection by combining the data from various sensors. Furthermore, the software of the LTSA processes the collected data, interprets the movement patterns (trajectories) of the road users and thus continuously analyzes the current traffic situation. Through intelligent data analysis, it identifies hazardous situations and sends warning messages to connected road users via vehicle-to-infrastructure communication (V2X communication). The LTSA extends the limited perception of connected road users and vehicles and thus contributes significantly to improving safety, especially of VRUs (Gimm et al., 2018), (Saul et al. 2018), in the future mixed transport system with CAVs and non-CAVs. As a result, accidents involving VRUs can be prevented as well as connected and automated driving is supported.

The data detected by the LTSA cannot only be applied for VRU perception and CAV purposes but also for traffic signal control at an intersection (Halbach and Eggers, 2021). DLR's two patented VITAL approaches (Oertel et al., 2016), (Oertel et al., 2017) were designed for such use cases, where data from recently available sources, like the LTSA or V2I communication becomes available for traffic signal control. The VITAL approaches, which are extended within the project for improved VRU consideration, represent the traffic control component of the LTSA system. Common traffic light controls in Germany are mainly focused on motorized transport with mostly fixed and short or minimal green times for VRUs in order to have minimal impact on the remaining traffic flow. Typically, these controls either have no VRU detection or only use pushbuttons for phase requests. In comparison, the advanced VITAL algorithms process the automatically detected LTSA data, in particular the VRU data, to take the VRUs into account in their control decisions actively (phase request and duration). They are based on different concepts and degrees of complexity. The basic idea of the delay-based VITAL control (Oertel and Wagner, 2011) is to utilize delay times of road users for the adjustment of green times. The delay time of a road user is its additionally required travel time to move along a defined stretch, e.g. a vehicle lane or a bicycle passage, compared to a typical minimal travel time. Using these delay times as input and bounded by a minimum and a maximum permissible green time, a running green phase is prolonged as long as all road users with recorded delay time have been served. The cooperative VITAL control (Erdmann et al., 2015) goes one step further and combines an actuated green time adjustment with a GLOSA (Green Light Optimal Speed Advisory) application. Road users in the vicinity of an intersection are continuously tracked with their current positions and speeds, which are processed to predict their arrivals at the intersection's stop lines or passages. This prediction is done by the application of the microscopic traffic simulation SUMO (Simulation of Urban Mobility) (Lopez et al., 2018). The optimization algorithm takes all road users equally into account, including VRUs, and calculates an optimal distribution of green times for all of them. These calculated green times can then be broadcasted, e.g. via V2I communication, so that connected road users can adapt their movements accordingly. The optimization is demandresponsive and considers all road users, whereby various control strategies can be pursued depending on the boundary conditions (e.g. overall system optimum, prioritization of road user groups, etc.).

In total the LTSA integrates various technologies and functions to create a so far unique control and information system for optimizing traffic flow and increasing traffic safety at intersections. It focuses in particular on the support of VRUs, using the future potential of connectivity and automation in the traffic system. In the future, the LTSA (see schematic illustration in Figure 1) can be used as an additional infrastructure system at existing intersections to make them safer, more efficient and to prepare them for connected and automated driving.

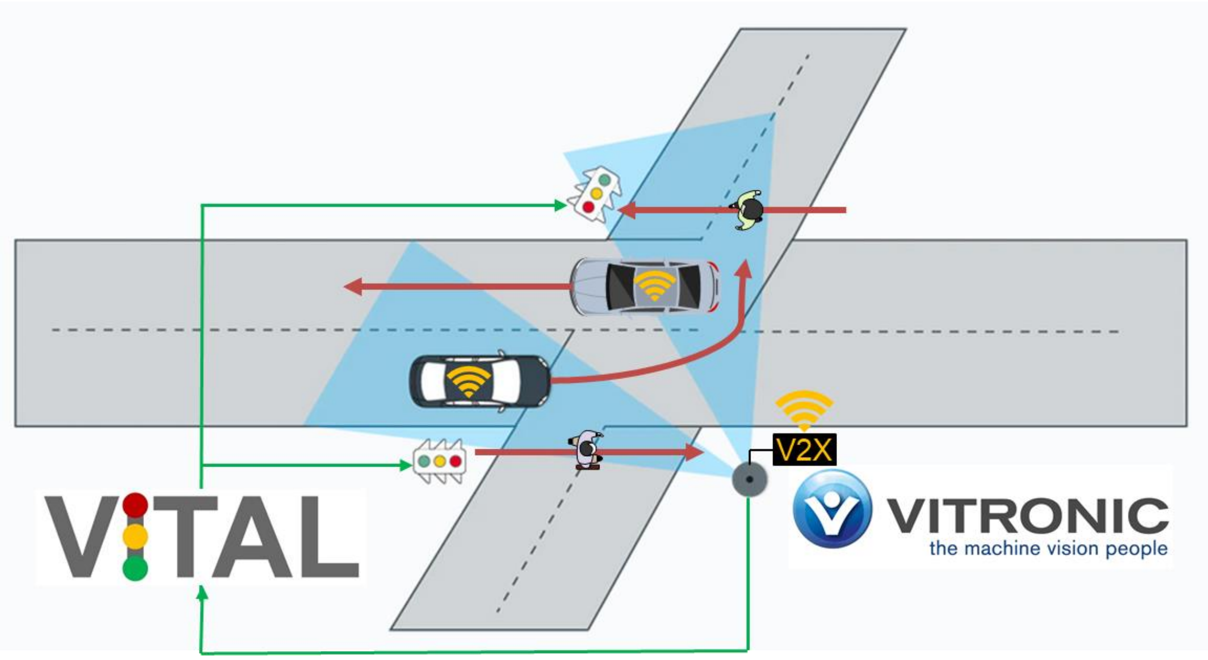

Figure 1: Schematic illustration of the LTSA

3. SCENARIO DEFINITION AND FIELD IMPLEMENTATION

As proof of concept a pre-version of the LTSA system was initially applied to a test intersection in Hamburg (Oertel et al., 2021). Based on this, VITRONIC and DLR have started a joint project for the development of the LTSA system. At the beginning of the development process, relevant situations and scenarios at intersections were identified with regard to the safety of VRUs and their active consideration in traffic signal control.

The LTSA is developed and scientifically tested in two living laboratories. The living labs are located in the city of Potsdam. Living lab 1 is an open space on the campus of the University of Applied Sciences Potsdam. That way, the required hardware and developed applications could first be set up and tested in a secured area. For this purpose, traffic situations were simulated according to the previously identified VRU scenarios. The focus in living lab 1 is on the testing and selection of suitable sensor technologies, the fundamental development of AI-based analysis and monitoring software (detecting traffic objects and interpreting their movements), and the identification and design of interfaces.

The findings from living lab 1 were transferred to living lab 2. Living lab 2 represents a real intersection equipped with traffic signals (see Figure 2). The aim is to implement the LTSA system for the first time under real traffic conditions. The previous work in living lab 1 made it possible to set up a sensor platform with suitable detectors as well as other required hardware. In addition, the designed interfaces for sending V2X messages and the connection to the VITAL controls were implemented. In parallel, the software applications on all system levels (detection, situation recognition, generation of safety warnings via V2X communication, extended VITAL approaches) were developed, enhanced or adapted. The software modules were also tested in simulation and laboratory environments. The test and evaluation of the system in living lab 2 will follow in the next months.

Figure 2: Living lab 2 – test intersection with traffic lights

4. CURRENT STATE OF VRU DETECTION AND TRAFFIC SIGNAL CONTROL

The LTSA's analysis and monitoring software was tested in living lab 1 with various sensor types: lidar sensors, thermal imaging and video cameras. Considering the best price-performance ratio, especially in case of VRUs, using the video cameras (see Figure 3) is the most reliable way to detect and classify traffic objects and to track their movements.

Figure 3: LTSA video camera in living lab 1

The data analysis model of the LTSA software is able to reliably distinguish between different object classes (cars, trucks, cyclists, pedestrians, etc.) in any situation. The application can also capture position, direction and speed with associated timestamps for each object, and derive trajectories and heat maps. The raw data is immediately and continuously converted into so-called Tracked Object Lists (TROL) for further use. The TROLs are also continuously overwritten to ensure that all data is handled in a privacy-compliant manner.

To identify critical traffic situations, the LTSA software relates the predicted trajectories of the traffic objects to each other. This enables the algorithm to perceive critical situations and conflicts. As an example, Figure 4 shows the case of a cyclist going straight ahead and a vehicle turning right from the same approach. The system detects and classifies both road users, calculates their trajectories and thus anticipates that the movement paths will cross.

To complete the situation detection, current traffic light data, provided by the VITAL controls (see also below), is also considered in the calculations. This way, a potentially dangerous situation can be identified even more precisely. If the LTSA detects such situations, Decentralized Environmental Notification Messages (DENM) are generated and broadcasted. These standardized V2X messages can be exploit by connected road users.

Figure 4: Warning in case of a critical situation between a cyclist (going straight) and a turning vehicle

With regard to the active consideration of VRUs in the VITAL signal controls, the LTSA data are processed on a parallel level. In addition to a reliable automated phase request, the objective is also to control the green time durations for VRUs. In order to this, the number of VRUs at the intersection has to be considered. In terms of reliability and efficiency of traffic control, the system must also detect whether a VRU wants to cross the intersection or is merely moving along the intersection. To cover these functions, the detection concept is based on request zones in the side space of the intersection and moving zones on the fords of the VRUs (see Figure 5).

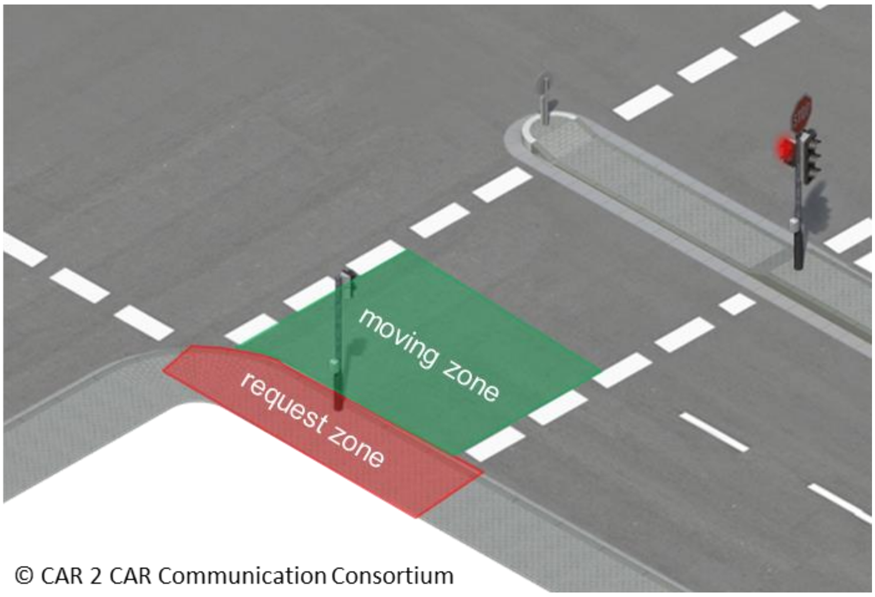

Figure 5: LTSA detection concept with request and moving zones

If a VRU enters a request zone, a logic checks whether the VRU wants to cross the intersection based on the movement path. In this case, the request is set within the signal control. It is also possible to prioritize the VRU. The moving zones cover half a ford each and are used to control the green times for the VRU, which must cover a minimum duration and can be prolonged e.g. according to a high VRU demand. Overall, compared to today's traffic lights, the LTSA system allows the traffic control (especially VITAL) to take the needs of VRUs into account depending on the current situation.

The components of the LTSA system have been implemented in living lab 2 for test operation under real traffic conditions. The setup consists of a server (see Figure 6, left), a central control cabinet with a computing unit for executing the software modules, and additional equipment (e.g. routers, aerials, etc.). The sensor platform consists of several decentral mounted detectors (see Figure 6, middle and right). For testing purposes, a 3D radar detector was also installed in living lab 2. A road side unit (RSU) has been set up to send and receive V2X messages (see Figure 6, left). The RSU is used in particular to send out the DENM (standardized V2X message) in case of hazardous situations detected by the LTSA.

Figure 6: LTSA server with RSU (left) and video cameras (middle, right) in living lab 2

The LTSA server in living lab 2 has a wired connection to the VITAL components and the intersection's signal controller. The server provides the detected data via this connection as input for the VITAL approaches. Figure 7 shows an aerial view of the request and moving zones that are captured by one of the installed video cameras (green dot).

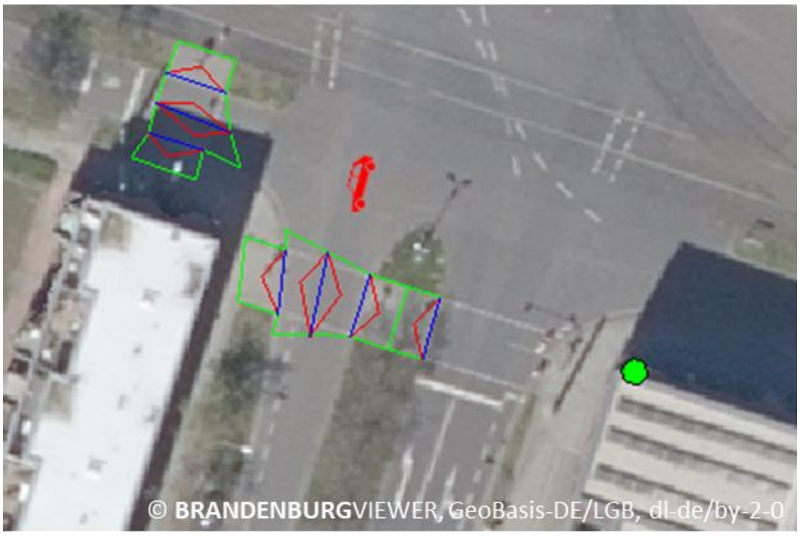

Figure 7: Part of LTSA detection zones in living lab 2

The VITAL modules supply current signal status information as standardized SPAT and MAP messages via the same interface in the other direction. These are used by the LTSA as additional information for situation recognition and are also broadcasted directly by the RSU. The system structure of the LTSA in living lab 2 is shown in Figure 8. For a better overview, the VITAL modules including the traffic light are only shown as a DLR logo.

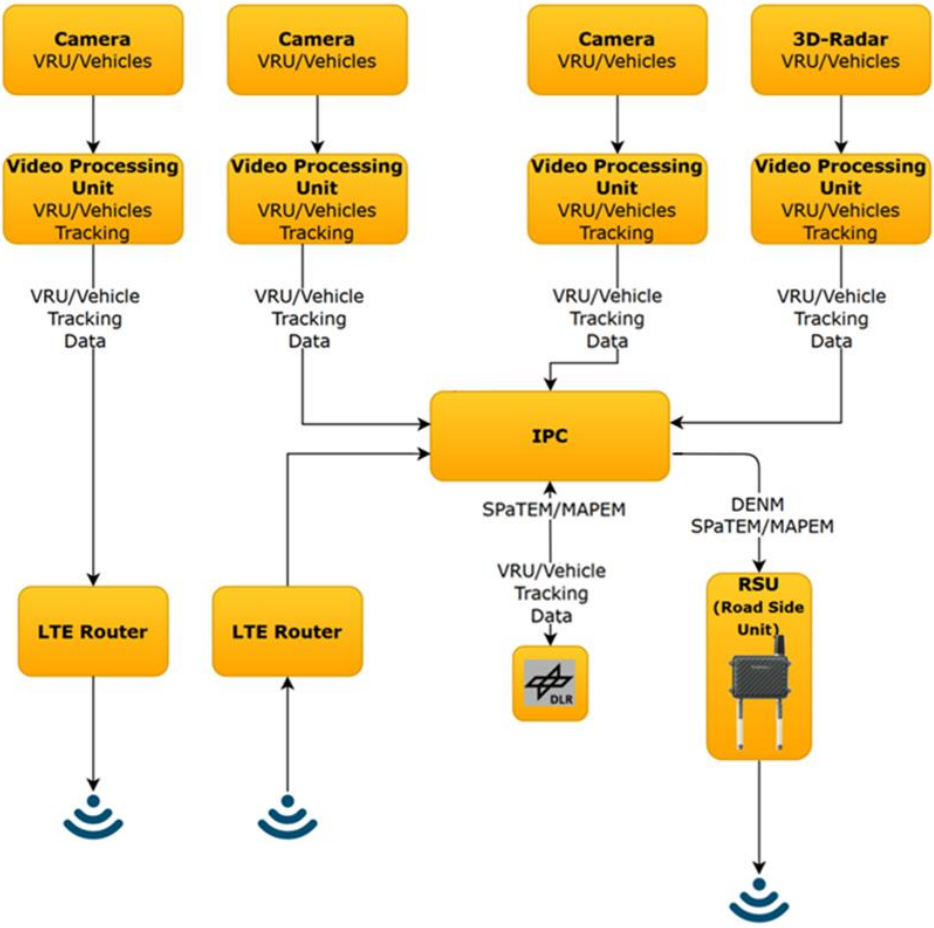

Figure 8: LTSA architecture in living lab 2

5. OUTLOOK

The system test and the evaluation (planned from October 2022 onwards) in living lab 2 will be under real traffic flow as well as induced scenarios. With regard to the traffic safety functions, the reliable identification of hazardous situations and the broadcast of safety warnings via V2X with lowest possible latencies will be the focus. Concerning traffic control, the detection reliability and the effects on the traffic flow (e.g. waiting and delay times) will be investigated, especially with regard to VRUs. Furthermore, the behavior of the extended VITAL approaches (with active VRU consideration) will be examined in comparison to the existing control approaches without LTSA. In the course of the evaluation process, the system components are to be optimized based on the findings. First results from the evaluation will be presented at the MFTS 2022 Symposium.

ACKNOWLEDGMENT

The project is funded by the European Regional Development Fund (ERDF) of the European Union (EU). The authors would also like to thank the University of Applied Sciences Potsdam and the city of Potsdam for providing the two living labs.

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