Study of Vulnerable Road User awareness

CAR 2 CAR Communication Consortium

About the C2C-CC

Enhancing road safety and traffic efficiency by means of Cooperative Intelligent Transport Systems and Services (C-ITS) is the dedicated goal of the CAR 2 CAR Communication Consortium. The industrial driven, non-commercial association was founded in 2002 by vehicle manufacturers affiliated with the idea of cooperative road traffic based on Vehicle-to-Vehicle Communications (V2V) and supported by Vehicle-to-Infrastructure Communications (V2I). Today, the Consortium comprises 61 members, with 11 vehicle manufacturers, 31 equipment suppliers and 29 research organisations.

Over the years, the CAR 2 CAR Communication Consortium has evolved to be one of the key players in preparing the initial deployment of C-ITS in Europe and the subsequent innovation phases. CAR 2 CAR members focus on wireless V2V communication applications based on ITS-G5 and concentrate all efforts on creating standards to ensure the interoperability of cooperative systems, spanning all vehicle classes across borders and brands. As a key contributor, the CAR 2 CAR Communication Consortium works in close cooperation with the European and international standardisation organisations such as ETSI and CEN.

Disclaimer

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Table 1: Document information

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02/02/2021	1.0	• Initial release of document	Release Management	Steering Committee

Table 2: Changes since last version

Table of contents

List of tables

Abbreviation

Table 3: Abbreviations

Abbreviation	Meaning
BiDiMoVe	V2X communication use to add several features to public transport e.g. VRU protection or prioritization at traffic lights
VRU Detector	Camera and Radar
CPS	ETSI-ITS Collective perception service
Cellular-V2X / LTE-V2X	Cellular-Short Range Communication (release 14)
Detector Loops	Vehicle & VRU Detector
INMOBS	Urban support for visible impaired people
LIDAR	Light Detection and Ranging
RFID	Radio Frequency Identification
Rx	Receive
Timon	Enhanced real time services for an optimized multimodal mobility relying on cooperative networks and open data
Tx	Transmit
UR:BAN	A communication bridge will be established between VRU and vehicles by means of the hybrid networks
UWB	Ultra-Wide Band
VRU	Vulnerable Road User
VRUITS	Improving the safety and mobility of vulnerable road users through ITS applications
Weather station	Environment Detector
Cellular-V2X / 5G-V2X (PC5)	Cellular-Short Range Communication based on network cells (release 16)

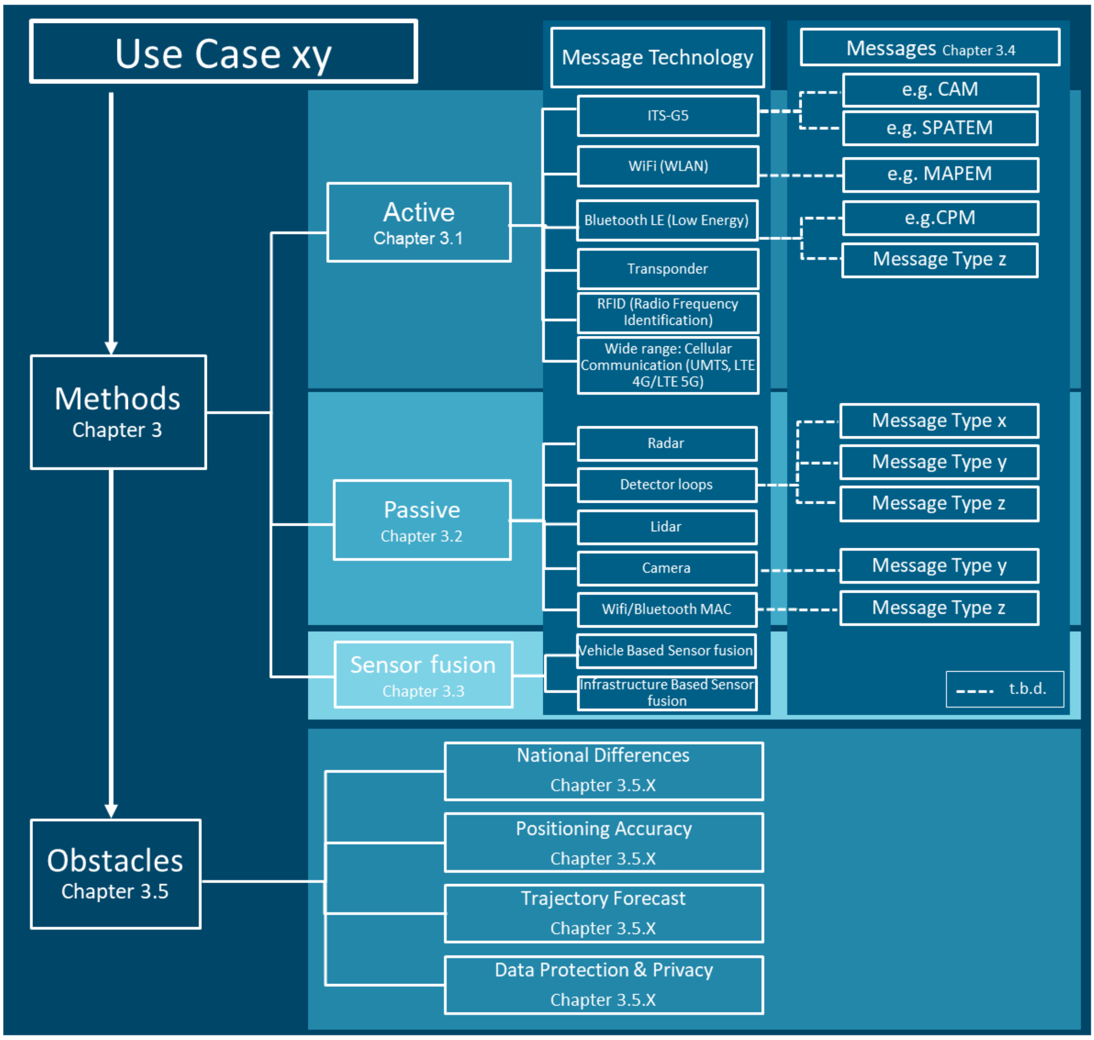
Introduction

The C-ITSs have been developed to enable an increase in traffic safety and efficiency, and to reduce emissions and fuel consumption.

As the focus now is shifting from vehicle safety to VRUs safety, it's important to highlight the impact of roadside infrastructure on enhancing the environmental awareness of VRUs **for next generation C-ITS applications** as well as for future cooperative automated driving, nevertheless harnessing the benefits of C-ITS regarding efficiency.

The document shows how using roadside infrastructure participates in protecting the VRUs in traffic environment and how more in time-data from roadside infrastructure can promise to mitigate safety risks and increase the system performance by optimizing the behavior prediction of all traffic participants relevant to a given traffic situation and thus to the collision risk analysis.

The **[ETSI TS 103 300-2 VRU]** describes two approaches for VRUs protection: an "active awareness" approach in which VRUs transmit C-ITS messages for awareness and a "passive awareness" approach where they are detected by vehicles and Infrastructure (collective perception).



Study

Active awareness

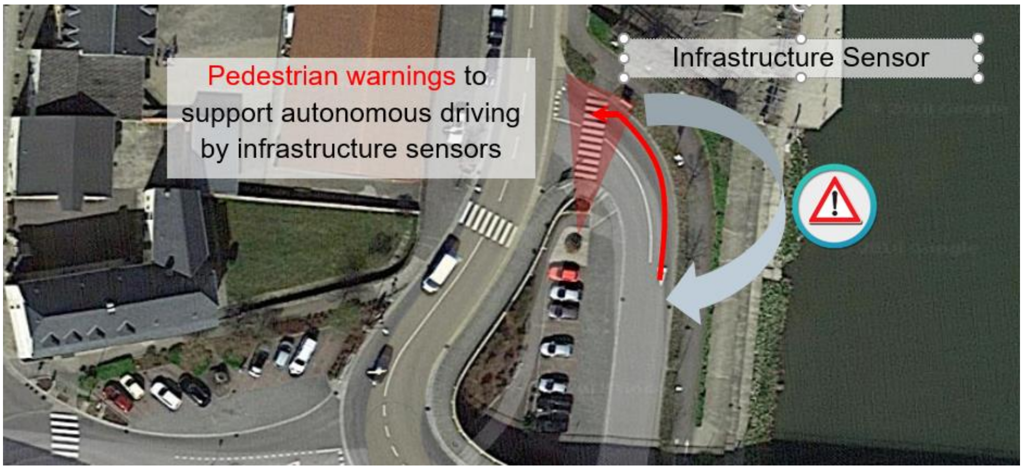
- The "active awareness" generation approach assumes that VRUs transmit periodic C-ITS messages, i.e. VRU Awareness Messages according to [ETSI TS 103 300-2 VRU], to inform the rest of the road users and the road infrastructure for them to be aware of their presence and behavior.
- The VRU is equipped with a VRU device (can be of any type Tx, Rx) which is transmitting continuously to the surrounding neighbor entities their status and dynamics (position, speed, heading, etc.), and more generally information that can be relevant for their protection.
- This approach depends on the fact that the VRU can communicate with different traffic contributors like vehicles, other VRUs and road side devices; also, the fact that the VRUs can be made aware of a dangerous situation and thus can be sometimes expected to act, depending on their VRU profile. For example, a bike user can reduce its speed, use brakes or change lane to prevent an accident.
- The expected communication technologies used are given bellow:

    - Short Range Technologies
        1. IEEE 802.11p/bd - ITS-G5/WAVE
        2. "Standard" Wi-Fi (WLAN)
        3. Bluetooth LE (Low Energy)
        4. UWB (upcoming technology in Cars and Smartphones)
        5. Cellular-V2X / LTE-V2X / 5G-V2X (PC5)
        6. Transponder for back packs
        7. RFID (Radio Frequency Identification)

    - Long Range
        1. Cellular Communication – UMTS, LTE 4G/5G (based on network cells and continuous cost)

Passive Awareness (Sensor based for collective perception)

- The "passive awareness" generation approach refers to the fact that VRUs are detected by vehicles and Infrastructure which in turn generate VRU awareness for the rest of the road users using the **C-ITS collective perception services (CPS)** according to [ETSI TS 103 324].
- In this second approach, VRUs are not actively making road users and infrastructure aware of their presence. On the contrary, awareness about VRUs is passively generated in that sense that VRUs just get detected by other entities, which in turn share via C-ITS information about VRUs presence.



Picture source: Siemens Mobility GmbH ©

- VRUs are detected by infrastructure equipment or vehicle sensors like radar, LIDAR, motion detectors and induction loops embedded in the road pavement. This allows VRUs without any communication unit to be recognized and included into the safety C-ITS procedures like CPS. The detection can be used for taking actions/measures in favor of the VRUs e.g. supporting VRUs by the traffic light for safe crossing.

- The necessary infrastructure-side technologies for creating VRU awareness through the passive approach are described below.

  1.Radar (all VRUs)

  2.LIDAR (all VRUs)

  3.Camera (all VRUs)

  4.WiFi/Bluetooth MAC (Low Energy – used in Beacons)

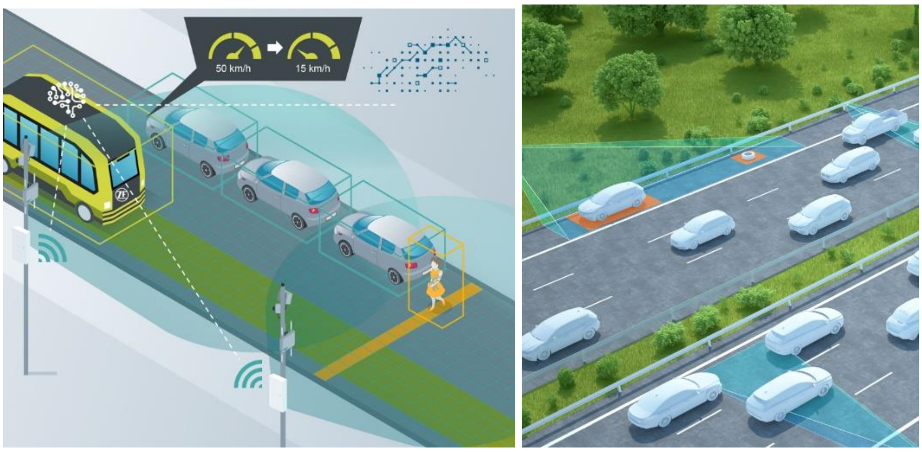
  5.UWB (upcoming technology in Cars and Smartphones)

  6. Passive radio localization with C-ITS

  6.Detector Loops (Bicycle, Scooter, Baby Buggy, etc.)

  7.Weather station (used by reduced visibility – fog, rain, smog, sand-/snowstorm)

In Urban and Interurban areas:



Picture source: Siemens Mobility GmbH ©

Data fusion technologies (Environmental conditions data to be augmented from the infrastructure side)

Vehicle-based VRU detection, described in the **[ETSI TS 103 300-2 VRU]** is based on 2D/3D detection. These methods are effective in detecting objects in the 2D plane; however, they lack the depth information which is crucial to retrieve the localization (elevation) and size of the object in the 3D space.

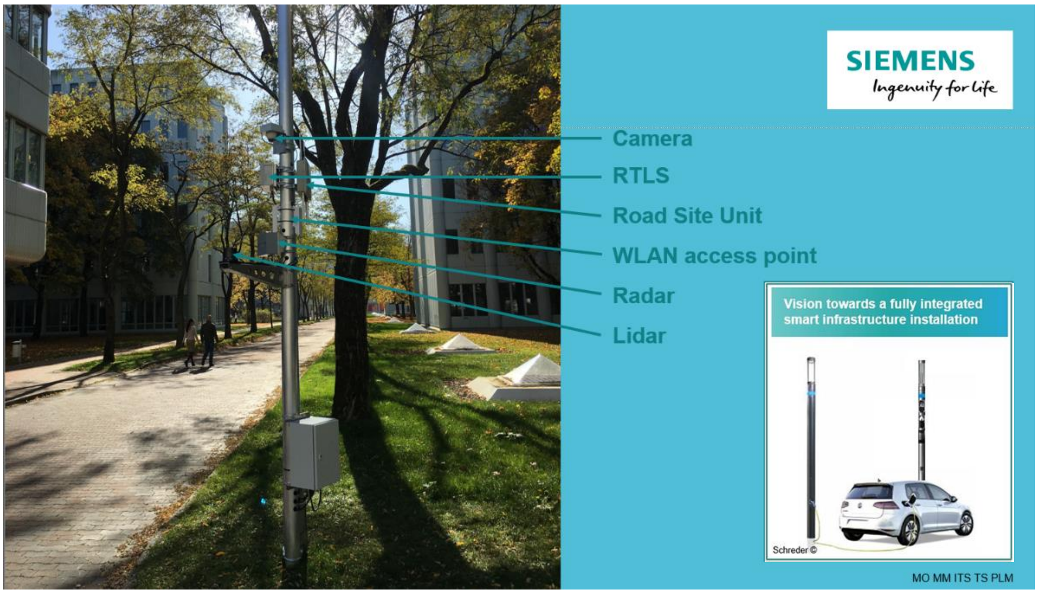
Hardly visible traffic areas can be identified in advance and monitored with appropriate sensors: this solves **shadowing/visibility obstruction problems**. The detection-**robustness** can be verified and a corresponding **level of quality** can be guaranteed. In contrast to simple trajectory estimation, computationally intensive algorithms such as **intention prediction** can be added to the VRUs via appropriate "computing power". **Intention Prediction** is especially important for VRUs because they can have an extremely high dynamic (change of direction, change of speed). Additional "soft parameters" can be extracted by a **longer tracking** of the road users and especially of the VRUs in the System of the infrastructure sensors: safety of movement of the road users, dynamic aggression, etc.

Besides, this detection must be extended with a stage for prediction of VRU intention **in real-time**, as considering the future actions of VRUs is crucial to drive vehicle application reactions.

Here it's worth mentioning that the perceived surrounding environment **based on the vehicular sensors** only, might be negatively/badly affected due to elevation, crowding and adverse weather conditions (lighting, fog, snow...) which in turn raises a lot of challenges when it comes to predict the behavior of all traffic participants that are or can **become relevant** to a given traffic situation as well as making decisions and thus can rapidly compromise the performance of the VRU System and the safety of diverse road users especially in urban, mixed traffic scenarios.

Restrictions due to detection robustness and limited scope of the **relevant** environment can be overcome by more comprehensive **data in time** from roadside infrastructure which extends the surrounding environmental scope in terms of data about **objects** and **events** beyond the scope of built-in vehicles' sensors. (see **figure 9 in [ETSI TS 103 300-2 VRU]**).

This can be achieved by a **smart roadside equipment (data fusion and computational device/s)** which captures/augments the information from road-side devices and road users' sensors (**active VRU and/or a vehicle**) in order to optimize the whole detection process as well as leveraging the learning algorithms for classification, evaluation, prediction and decision making.



Picture source: Siemens Mobility GmbH ©

Functional Safety: depends on the "level" of automated driving

Data quality (PoTI), reliable system, confidence (Page 31 fig 9, tr_10330001v020101p)

The quality of sensor data on mobile and immobile objects in traffic situation is further increased if areas **covered by vehicle sensors and infrastructure sensors** overlap in real time. Safety, performance and comfort of all road users of C-ITS services increase if they obtain these data with verified quality, fuse and interpret them correctly and in time in relation to the traffic scenario where the data of the different **mobile (vehicle) and immobile (infrastructure) sensors** has been originated.

The fusion of sensor information from different overlapping sensors require all stations and sensors to be accurately referenced, i.e. positioned, oriented and calibrated. Their perception uncertainty needs to be considered in the fusion process in order to obtain an overall confidence on the location of all road participants. As concrete example we take **figure 9 in [ETSI TS 103 300-2 VRU]**, where a car is approaching a non-signaled bridge with 2 road users one is under the bridge while the other is on the bridge. It suffices here to implement a presence detection for the direct proximity (e.g. 3 m) of the road crossing to solve the elevation problem and accordingly enhancing the service reliability by avoiding false positive warnings.

Another aspect to consider is the "**service acceptance**" from the vehicle driver's perspective when sending out information or alert for them. If they are warned e.g. by flashing icons and sound if at least one pedestrian is about to cross the intersection, this assistance system can become too annoying. Drivers will only accept systems that warn of road users that

a) are actually about to cross the intersection and b) that have been overlooked.

If a driver is warned even if he/she has already seen the pedestrian, there is a dictation. This counts especially for bus drivers (see project BiDiMoVe) where no driver want's a system that gives every bus passenger a conclusion that the driver has done something wrong, e.g. organizational and regulatory issues (e.g. data privacy).

Channel Congestion Control (overloading communication channels) interoperability and standardization

Support for pedestrians and disabled people

Often, pedestrians are hard to see by drivers as they are moving at a slower speed, are easily hidden by larger objects and are hardly visible at night. With the active and passive VRU awareness technologies, it is easy to identify pedestrians and warn drivers of unexpected pedestrians and thereby protect pedestrians in various situations from accidents.

Pedestrians can be characterized by

- their slow movement speed,
- unpredictable dynamics (very quick start and stop of motion, changes of direction),
- no special power supply (compared to vehicles or e-bikes), hence they are not good candidates for active VRU devices.

Following are some cases with respect to pedestrians and disabled people.

Pedestrians crossing the road at an intersection

Because there can be many pedestrians at urban intersections, a sensor based V2X information system should be planned wisely. CAMs as a surrogate could have too much overhead by means of packet header and packet count. Messages like CPMs seem to be more suitable.

Some projects for VRU protection (like BiDiMoVe) aim at calculating trajectories of such road users to anticipate collisions with vehicles. This leads to the following considerations for pedestrians:

- While there are concepts to equip VRUs with beacons, this is harder to achieve for all VRUs. Using the cellphone to communicate with vehicles directly is not a good idea (once the standardized V2X messages can be used there) as the GNSS receiver cannot give accurate positioning results in cases such as urban areas. A roadside unit with infrastructure positioning systems is a mediator (see project UR:BAN, converge, INMOBS) which could be used here.
- Pedestrians could change their direction or stop at every moment, e.g. if they are heading to a bus station right in front of the intersection. Thus, it is impossible to predict if they will cross an intersection, from a greater distance; infrastructure plays important part in this situation.

Because there can be many pedestrians at urban intersections, a sensor-based V2X information system can be used. Nevertheless, vehicles or roadside units to calculate trajectories and collision risks of every vehicle-pedestrian-pairing at an intersection. This sensor and detection equipment can turn very important in detecting and supporting VRU hidden from the sensors of a vehicle, e.g. a pedestrian, hidden by a bus or a larger immobile vehicle or perhaps a bad weather condition can be easily detected and supported on the infrastructure side by taking actions e.g. switching over traffic light from green to red for pedestrians; blinking yellow light to indicate.

Public transport stops are close to the intersection

Especially at intersections, it is hard for drivers to overview many other traffic participants. Additionally, many bus stops are located at intersections, which is causing an additional number of conflicting situations involving pedestrians. Passengers getting off the bus often intend to cross the street and suddenly occur from behind the bus. For drivers, it is often impossible to see these pedestrians. Therefore, it makes sense to install detectors at public transport stops at intersections and also using car/bus sensors in order to detect pedestrians who are not visible to drivers. The sensor matching has to be done on infrastructure side. Drivers then receive a warning in the car about unexpected pedestrians and can drive past and turn off at the intersection with special caution.

Overview of research projects on VRU

INMOBS (2010-2014)

Project title:

"Innerstädtische Mobilitätsunterstützung für Blinde und Sehbehinderte
(translation: Urban support for visible impaired people)

Link to project site

http://www.inmobs.de/
Remark APR: Link is no longer active anymore and rerouted to ITS mobility Homepage

Overview:

The mobility of visible impaired people is restricted due to many obstacles:

- Support of tactile and acoustic beacons is not almost available and not adapted to the needs to specific needs
- The action radius is reduced to well-known paths.
- The mobility is challenged based on different danger situations (e.g. crossings).

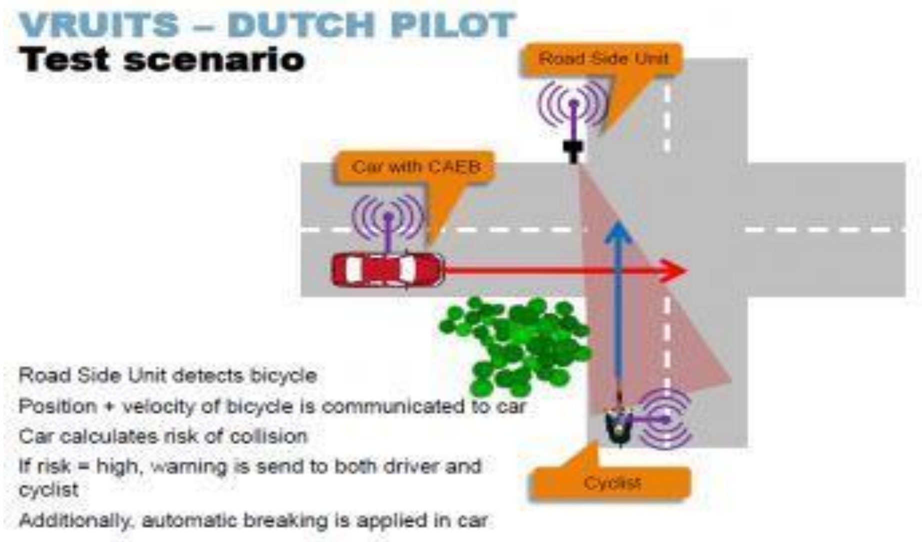
Objectives:

User oriented prototypal development and evaluation of personal assistant system for reliable navigation visible impaired people in public area with the focus on traffic light systems.

VRUITS (2013-2016)

Project title:

"Improving the safety and mobility of vulnerable road users through ITS applications".



Link to project site

http://www.vruits.eu/

Overview:

Vulnerable road users (VRUs), such as pedestrians, cyclists, motorcyclists and moped riders have not enjoyed the same benefits as vehicle occupants. The VRUITS project places the VRU in the Centre, aiming at actively integrating the "human" element in the ITS approach by incorporating the needs of all relevant stakeholder groups into the development and adaptation process of innovative ITS solutions to improve traffic safety as well as the general mobility and comfort of vulnerable road users.

Objectives:

- Assessment of societal impacts of selected ITS applications, and to provide recommendations for policy and industry regarding ITS in order to improve the safety and mobility of VRUs.
- Provisioning of evidence-based recommended practices on how VRUs can be integrated in Intelligent Transport Systems.

Timon (2015-2018)

Project Title:

Enhanced real time services for an optimized multimodal mobility relying on cooperative networks and open data

Link to project site

https://www.timon-project.eu

Objective:

A communication bridge will be established between VRU and vehicles by means of the hybrid networks. Services developed for VRUs will focus on assisting riders of powered two-wheelers and cyclists. VRUs will have access web a map depicting the current road traffic status and they will receive information on moving vehicles, vehicle collisions, as well as help in route re-planning for more efficient transport.

UR:BAN

Link to project site:
http://urban-online.org/en/cognitive-assistance/protection-of-vulnerable-road-users/index.html

Objectives:

- Addressing a much larger spectrum of use cases,
  i.e., VRU accident scenarios that were previously not detectable.
- Improving system availability through a range of weather conditions.
- Development of high-performance algorithms for sensor-based detection and classification, as well as modeling and prediction of behavior regarding vulnerable road users in all addressed scenarios and use cases.

BiDiMoVe

Link to project site:
https://lsbg.hamburg.de/its-projekte/12144506/its-projekte-lsbg/ (only in German)

Objectives:
V2X communication shall be used to add several features to public transport in the city of Hamburg: The first feature is a prioritization at traffic lights. Busses register at the next intersection according to their schedule to get a green light just in time. Second, sensors at intersections shall detect vulnerable road users and inform busses about their presence. An algorithm calculates collision potentials to warn drivers timely.
Such features are achieved via roadside units at selected intersections and on-board units in eleven busses. The VRU protection specifically aims at cyclists that approach intersections and could be overseen by bus drivers. The warning (together with traffic light information) could be realized via an HMI, flashing LEDs and sound. The VRU detection can be achieved via thermal as well as radar sensors.

VIDETEC (2020-2021)

Link to the project site:
https://www.bmvi.de/SharedDocs/DE/Artikel/DG/mfund-projekte/videtec.html

Objective: This project aims to evaluate the performance in the detection and tracking of VRUs in urban traffic scenarios using two radio-based detection technologies. On the one hand, a micro-Doppler radar sensor, which is able to capture detailed kinematic signatures of the objects, is considered. On the other hand, a detection of moving objects by evaluating the propagation effects of V2X signals originating from roadside units, such as reflection, scattering and blockage, is evaluated. Field-tests with different road users at an urban-like environment are planned in order to acquire the data needed for a first assessment of these technologies.

SUMM of the VRU Study

There is a big chance to reduce accidents and fatalities on roads by using connected sensor fusion technologies!

The question how to protect Vulnerable Road User is not only based on communication technology.

The question is how can existing technology and technology which is under research help to protect Vulnerable Road User.

The quality of sensor data on mobile and immobile objects in traffic situation is further increased if areas covered by vehicle sensors and infrastructure sensors overlap in real time. (false positives). In addition, for the infrastructure and vehicle devices a clear and regulated program of calibration and maintenance can be outlined to ensure that all deployed devices operate at their highest possible quality and that this quality is transparent to all sensor operator.

Detection must be extended with a stage for prediction of VRU intention in real-time, as considering the future actions of VRUs is crucial to drive vehicle application reactions. Detection means object and environment detection.

Intermodal communicating sensor based for collective perception from Vehicle and Infrastructure is today and also in the future the most efficient and legally protected way to get an acceptable result for protecting Vulnerable Road User!

Why?

1) The biggest issue is to locate the VRU's!
2) Who is responsible to protect Vulnerable Road User?
3) VRUs who accept the delta's regarding technology and system related issues

1) Technical Issues:

a) Problems with GPS Systems in Smartphones/Beacons devices in cities and other areas without an efficient GPS network coverage

b) GPS Systems are sometimes unprecise in case of military scenarios

c) Smartphone/Beacons devices must have enough battery capacity

d) Smartphone/Beacons devices must have enough process power

e) Smartphone/Beacons devices must have always updated APPs/Security (all operating systems must be included)

f) Smartphone/Beacons devices must have security protection system on board (e. g. Virus Scanner, Firewall and Encryption Keys)

g) Smartphones/Beacons must follow the standardized VRU rules (ETSI/SAE/C2C-CC etc.)

h) Smartphones/Beacons must follow the standardized data protection regulations (different regulations in different countries)

2) Things like societal or practical challenges which can't be made mandatory:

a) Smartphone/Beacons devices must always be worn

b) Smartphone/Beacons devices must always be switched on

c) Smartphone/Beacons devices must always be charged enough

d) Smartphone/Beacons Apps must always be switched on

e) Smartphones/Beacons must follow the standardized data protection regulations (different countries for these regulations)

3) Accepted deltas regarding technology and system related issues:

a) Visible impaired people accept the deltas regarding technology and system related issues because of the results which increase the percentage of reduction of dangers situation and accidents

b) Other groups of VRU who using beacons or other devices knowing the restrictions of the used technologies.

c) One of the location technologies could be UWB. UWB is designed to locate objects by scanning and triangulation of the position

! The sovereign responsibility for the protection of citizens/VRU's lies with state organizations and not with the citizens/VRU's themselves!

(Also, not at the Vehicle OEMs and Infrastructure supplier!)

Appendix

References

Symbol	Version	Title
[ETSI TS 103 300-2 VRU]	2.1.1	Intelligent Transport System (ITS); Vulnerable Road Users (VRU) awareness; Part 2: Functional Architecture and Requirements definition;
[ETSI TS 103 324]	0.0.19	Intelligent Transport System (ITS); Vehicular Communications; Basic Set of Applications; Specification of the Collective Perception Service