Physical and Digital Infrastructure for Vulnerable Road User Protection

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***Abstract*—Smart roads and Intelligent Transport Systems (ITS) are introduced to enhance the traffic quality and reduce potential incidents. One important application of utilizing the ITS is the Vulnerable Road Users (VRU) protection, which could be achieved through complementing the road pilots capabilities with road infrastructure. (1) Background: An architecture for a VRU protection system is proposed, in order to detect and identify VRUs at risk of collision with road pilots. (2) Methodology: The VRU detection system provides a platform of Digital Map, wherein information about VRUs could be exchanged between Connected Autonomous Vehicles (CAV) and Road Side Units (RSU).**

***Keywords*—PDI, C-ITS, RSU, OBU, CAV, HD Map, V2X, CCAM, TMC.**

I. Introduction

For the purpose of increasing the safety and efficiency of the traffic, Cooperative, connected and automated mobility (CCAM) was introduced [1]. The bundle of CCAM technologies is a subcategory of Intelligent Transport Systems (ITS), which forms smart and connected corridors and highways. The first step of CCAM would be to provide the necessary Physical and Digital infrastructure (PDI) elements for large scale deployments [2]. The developed PDI is an essential component of the Cooperative ITS (C-ITS), which would enable road pilots to coordinate and orchestrate their interactions with other road users by sharing useful information with other road users, road infrastructure and Traffic Management Centers (TMC). The European Commission has launched multiple projects and initiatives targeting the C-ITS since 2005, which were backed by a list of services to be implemented by exploiting the deployed C-ITS infrastructure [1], [3]. Some Examples of services to be implemented are Emergency vehicle approaching, Slow vehicle warning and Adverse weather conditions [1].

The Vulnerable Road Users (VRU) protection has always been a primary focus as a CCAM service, for being considered as the main class of road user which suffers the most from road incidents fatalities and injuries [4]. The taxonomy of pedestrian safety could be: Infrastructure-based solutions, Vehicle-based solutions and Pedestrian-based solutions according to [4]. In this document, a hybrid PDI solution (integrating vehicle-based and infrastructure-based approaches) is proposed to meet the goal of VRU protection.

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II. Physical and Digital Infrastructure Solution

The vehicle-based segment of the solution is hosted in a Connected Autonomous Vehicle (CAV) which had a former version described in [5]. The Current setup of the CAV is equipped with new hardware such as an edge AI computing unit, RTK GNSS receiver, 5G-modem and additional power source, in addition to the existing Lidar, Camera, Automotive Radar sensors. Switching to the software stack of the CAV, it used to support safety functionalities such as emergency braking, semantic segmentation and object detection. Now the CAV supports a portion of new capabilities for the VRU protection such as Lidar-based autonomous navigation and localization, object detection and classification, communication links and HD Maps interface.

The core component of the PDI solution is the High-definition Maps (HD Maps). The HD Maps are part of the digital infrastructure which provides localization functionalities and supports perception, planning and control modules of the ego-vehicle (CAV platform) [6]. The HD Map could usually consist of multiple layers covering a spectrum of highly dynamic road features (e.g. road users) to static road features (e.g. lane counts and driving direction) [6]. A sample of the point cloud data of the static layer for one of our testing sites is shown in Figure 1.

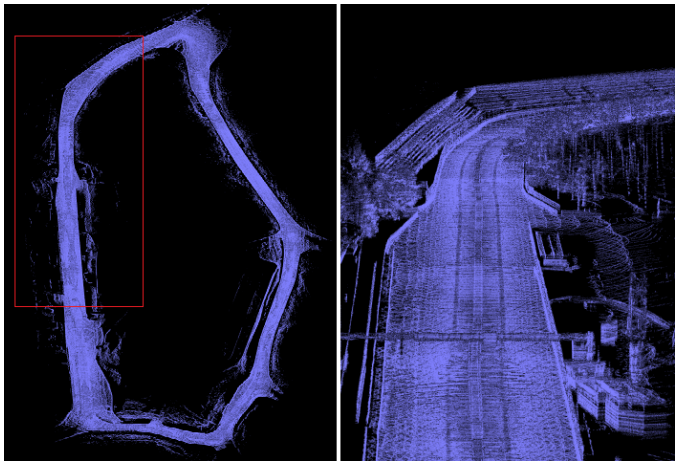

Fig. 1. 2D and 3D views of HD Map's static layer

The infrastructure element of this PDI solution is denoted as Road Side Unit (RSU). The RSU mainly has the capability of communication with road users (e.g. vehicles), central servers

(e.g. TMC) and other infrastructure units [7], in addition to performing dedicated tasks depending on the application. The RSU is mainly responsible for augmenting the CAV with information about the VRUs that are out of the line of sight (LOS) of the OBUs, utilizing the IR camera data as an input to a YOLO object detection model to distinguish the VRUs from other road users. Both RSU and CAV are exchanging the information about VRUs/road users through the HD Map over the available communication links between CAVs and RSUs. Data from both CAVs and RSU are aggregated, corrected and fused on the HD Map level. The communication protocol utilized by the RSU could differ so that it could meet the application requirements (e.g. latency), examples of communication protocols could be 5G Vehicle-to-everything communication (5G-V2X) or dedicated short-range communication (DSRC).

The proposed PDI solution in this document is based on an object tracking system. To obtain high quality information about the detected VRUs status (e.g. position and speed) proximate to the CAV, the object tracking system is based on a sensor fusion algorithm, which takes as an input the communicated information from the OBUs (On-board Unit) of road CAVs along with RSUs detections. The architecture of the entire system, including the CAV platform, RSU and their interaction with the HD Map is illustrated in figure 2.

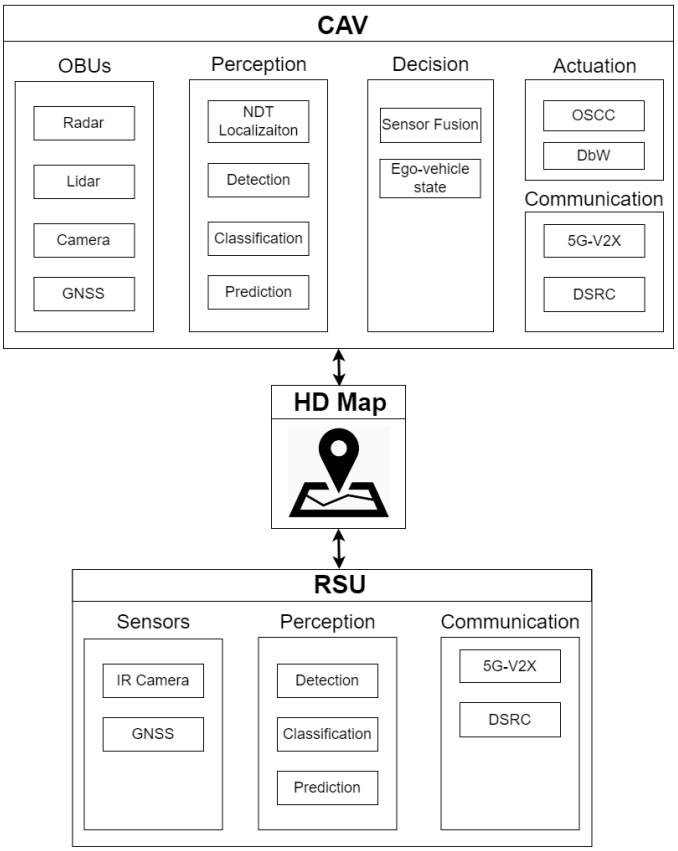

Fig. 2. Example of a figure caption.

III. Future plans

Up to now, some of the components for the PDI solution are already up and running, while others are still under development and/or testing as follows. The status of the main components are as follows:

- **Camera AI detection (OBU and RSU)** developed, under testing
- **RSU Hardware** not assembled or deployed
- **Communication** 5G-V2X deployed, DSRC is under testing
- **Dynamic layers of HD Maps** not built

According to the aforementioned list of the system status, and in order to deploy the road infrastructure, the AI detection and communication capabilities of the RSU will be integrated and go under continuous testing and enhancements until reaching its completed structure. The API(s) required for the representation of VRUs and other road pilots on the HD Maps will be combined with the current HD Map setup. The configuration of the tracking system of VRUs are still a subject of discussion, regarding the utilized algorithms and its structure configuration inside our system. In order to maintain our system and to test the newly integrated components, regular tests usually take place at the closed testing environment of Biķernieki Racetrack, while large scale tests are planned to be in the urban/suburban environment near the city of Ādaži.

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Abbreviations

The following abbreviations are used in this manuscript:

CCAM Cooperative, connected and automated mobility
C-ITS Cooperative Intelligent Transport Systems
PDI Physical and Digital infrastructure
VRU Vulnerable Road User
CAV Connected Autonomous Vehicle
HD Map High-definition Map
RSU Road Side Unit
TMC Traffic Management Center
V2X Vehicle-to-everything
DSRC Dedicated Short-range Communication
OBU On-board Unit
LOS Line of Sight

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