Techniques to Facilitate the Use of V2I Communication System as Support for Traffic Sign Recognition Algorithms

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***Abstract*—Solutions proposed in this work are related to development of vehicle-to-infrastructure (V2I) communication in the context of its support for Traffic Sign Recognition (TSR) algorithms used in advanced driver assistance systems (ADAS). One of the ideas of the application of the V2I communication, proposed in the literature, is to equip traffic signs (TS) with devices, capable of communicate their meaning to passing vehicles equipped with ADAS functions or autonomous vehicles. We propose grouping TSs and covering groups with single road side unit (RSU) devices. It will facilitate implementation and maintenance of the overall system. This will also reduce the amount of data sent over the network.**

***Index Terms*—Intelligent Transportation System, Smart City, V2I communication, ADAS functions, TSR function**

I. Introduction

In the automotive industry one can observe fast-growing requirements for systems from the, so called, active safety (AS) area. Advanced driver assistance systems (ADAS), which are the basis of the AS, offer more and more functionalities, evolving toward autonomous vehicles. All these functionalities require appropriate signal processing methods in real time [1]–[4]. One of the problems is the computation power, sufficient to process still increasing amount of data collected by vehicle on-board sensors [5].

An example function of this type is the traffic sign recognition (TSR). Systems of this type also evolve towards the possibility of recognizing an increasing number of road signs in various external conditions.

The number of different types of traffic signs (TS) that appear on European roads is equal to several hundred (Vienna Convention on Road Signs [6]). Currently used TSR ADAS functions usually recognize only selected signs (speed limits, end of speed limits, build-up area, end of built-up area, stop, etc.). In systems responsible for autonomous driving at SAE levels No. 4 and 5 [7], it will be necessary to recognize much larger number of TSs. The ultimate goal is to replace the driver who is assumed to respect most TSs, depending on the vehicle type. In this situation, relying only on methods based on the analysis of images from on-board cameras may become insufficient, which is due to several reasons, described below.

Even currently designed and used TSR systems are complex, despite recognizing only a narrow group of TSs. The problem is a high variability in the appearance of them, depending on weather, lighting (background) and other conditions, while these systems are expected to be highly reliable. In the future TSR systems adapted to fully autonomous driving, one should expect a further increase in the complexity of the used algorithms and thus a greater pressure imposed on hardware layer of the system, in which the algorithms will operate. Some of the road signs that will have to be recognized by autonomous vehicles in the future contain descriptive elements. It is so in Europe, although to a greater extent in North America. This may create additional challenges for the TSR systems.

In particular countries, appropriate regulations are available regarding the appearance of road signs and the way they are installed along roads [12], [13]. In reality, however, the signs may have a non-compliant appearance or be inappropriately arranged. Examples of such situations are shown in Fig. 1. The signs may be damaged, they may be mounted too low in relation to the applicable standards. Sign content may be ambiguous, and sometimes non-sign objects may look as TSs. Signs may be obscured by other signs or by natural objects (growing bushes or trees), or on a background that makes them more difficult to recognize. One of the solutions to this problem may (and should) be imposing some regulations that will enforce a proper appearance of the environment of road signs, in order to avoid the aforementioned situations. However, it is difficult to assure a full control over some (at least natural) factors.

Another problem, visible for example in Poland involves

Fig. 1. Road signs deviating in appearance from standards or difficult to recognize (own source)

a large number and large densities of TSs on the roads, especially in cities. Currently, this situation mainly causes degradation of the appearance of urban space. In the future, however, it may also negatively impact the functioning of the systems supporting autonomous driving.

The described problems cause, that in the literature it is considered to include road signs into future vehicle-to-infrastructure (V2I) communication systems, which would allow the TSs to send relevant messages to the vehicles passing by. In the presented work, new solutions related to these aspects have been proposed.

The paper is organized as follows. Next Section presents a state-of-the art related to the presented subject. Subsequently, the proposed solutions are presented in Section III. The paper is concluded in last Section.

II. State-of-the art study

This Section discusses several issues. First, it presents the solutions in the area of the application of the V2I related techniques in increasing the functionality of currently used road signs. The possible wireless communication technologies that in the literature are considered in this context are also briefly discussed in this Section.

A. Solutions for TSR systems based on V2I technology

In the literature one can find various suggestions for solving problems related to the visibility of road signs described in previous Section. One of the proposed solutions is an inclusion of TSs in a future system supported by V2I communication. This means equipping TSs with V2I communication devices (RSU) that will communicate with the vehicles. A proposal of this type of solutions is presented in [8]–[10].

One of the issues discussed in the literature is a selection of appropriate communication protocols and the standardization of the scope of the information provided to passing vehicles. Standardization works are already ongoing in this area (standard J2735) [11].

Another issue is the mode, in which the communication will take place. One of the proposed solutions is a constant broadcasting [9]. It may consist in sending information by a given TS in a continuous manner in all directions. The vehicles will have to recognize if a given message is directed to it on the basis of the content of the information. The reported solutions include providing, for example, the information on the meaning of the TSs, their positions in the global coordinate system (GCS), the road number to which a given TS is assigned (important at intersections, forks, etc.), the travel direction on a given road, etc. [10].

Another problem, which is basic while considering using the V2I technology in TSR systems, is to ensure a proper accuracy in determining the positions of particular signs in real time. This accuracy must be large enough so that signs can be distinguished even if they are located in a small distance from each other. The accuracy will depend on the used communication technology and technique. Various factors may impact it. In a dense urban area, signal reflections may appear. There may be a lack of full visibility of TSs (NLOS – non line of sight conditions), resulting from permanent overrides caused by infrastructure or other objects (e.g. vehicles). The impact on the localization accuracy will also have different heights, on which the signs and the accompanying RSU devices will be installed. According to the current standards, the TSs should be mounted at a minimum height of 2.2 m above the road surface [12], while a maximum elevation is not specified. The mounting height is one of the problems in this case. Another problem are natural terrain conditions (hills, pits), which may add additional values to differences in altitudes between the V2I communication devices in the vehicle (on-board units) and the RSU. One of the solutions proposed in this work, presented in next Section, refers to this issue.

The described problems may be of particular importance in a situation of high density of the TSs over a small area, additionally, in a situation where many roads are connected with each other. Example situations illustrating described problems are shown in Fig. 2.

One of the solutions, proposed in the literature, to the problem of precise positioning of the TSs on the roads, is equipping the TSs with GPS devices [10], [14]. Information about their location in relation to passing vehicles would be transferred to the vehicle by means of an appropriate V2I message [10], [14]. The solution based on the use of the GPS technology may face with several limitations, such as possible lack of precision, cost of GPS devices, relatively large energy consumed by such devices (supplying problem), etc.

B. Possible communication technologies for the V2I system

Various technologies may be used in the V2V and V2I communication [15]–[17]. Particular technologies offer different data throughput, different transmitter power and resulting communication range, etc. They are proposed in the context of various applications for the V2I system, including critical applications from a safety point of view, and those that do

Fig. 2. Compaction of traffic signs in a small area related to different movement directions and possible grouping of them (own source)

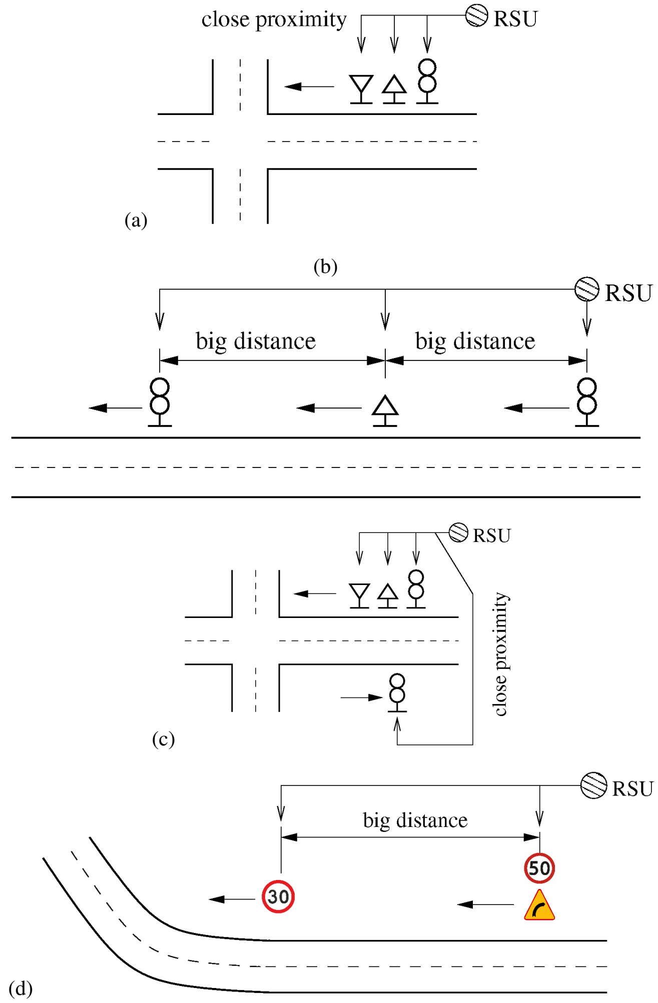

Fig. 3. Possible scenarios in arrangement of groups of traffic signs on the road, suitable for different described situations on the road:
(a) close proximity, the same direction,
(b) larger distance and the same direction,
(c) close proximity and different directions,
(d) some distances and TSs providing information valid at different distances from the RSU.

not substantially affect safety (e.g. for providing information) [22]. Depending on the target, one can indicate here data transmission functions (information exchange), as well as the abilities of the positioning of vehicles in respect to other vehicles or to road infrastructure.

One of the promising technologies that may be used for the positioning abilities, discussed in the literature, is the impulse radio – ultra wide band (IR-UWB) one [14], [18]–[20]. This technology offers several important advantages. As reported in the literature, it allows for a relatively high positioning accuracy of objects relative to each other. Depending on the distance between the communicating devices, the location errors theoretically should not exceed 10 cm [18]–[20]. Additionally, by applying appropriate numerical techniques, this accuracy may be substantially improved [21]. In the comparison with other communication technologies, the IR-UWB technology requires low power supply, comparable or smaller than in the ZigBee technology [14], [22].

The exchange of the information between vehicles and road infrastructure requires establishing some standards in terms of the communication protocols, for example the IEEE 802.11p [23] or the LTE-V2V [24], [25] standards. On the other hand, data exchange requires also standardization of the message formats and the ways how they are distributed over the network of connected vehicles, for example in the third-generation partnership project (3GPP) [26].

III. Proposed solutions to determine the positions of the RSU

The solutions proposed in this work concern mainly the situation, in which the positions of the TSs relative to vehicles are determined based on local data exchange (e.g. IR-UWB technology described earlier). However, they may also be used in other cases, including those relaying on GPS and other wireless standards.

As shown in previous Section, one of the most important features that should be offered by systems based on the V2I communication technology is the ability to faultlessly distinguish TSs from each other, taking into account the described negative factors. The accuracy of positioning may also depend on external conditions, such as the impact of ambient temperature on the operation of the RSU devices [21]. The susceptibility of the system to the possibility of making mistakes when distinguishing TSs will depend on how close they are located to each other in a given area. As shown in Fig. 2 (a), TSs intended for different movement directions may be located very close to each other, sometimes even on a single pole. Even with a very high accuracy of the wireless positioning system, this creates a risk of misinterpretation. For this reason, we propose solutions that aim at reducing the density of the V2I communication devices in a given area, while maintaining the number of required TSs in this area unchanged.

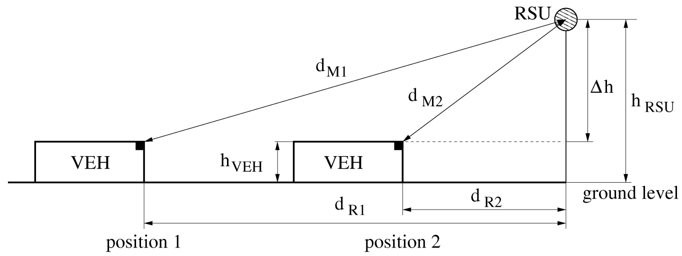

Fig. 4. Illustration of the calculation scheme of the distance between the vehicle and the RSU on the basis of measured distance, as well as the information on high over the road surface stored in the memory of the RSU associated with a TS or group of TSs.

It was shown above that the positioning precision may also depend on the height at which the TS is mounted along with the accompanying V2I communication device. Taking this into account, in this paper we propose a solution that can be helpful in solving this problem. Proposed solutions are described in following subsections.

A. Assigning single RSUs to groups of TSs

One of the proposed solutions consists in assigning V2I communication devices (RSUs) to groups of signs located close to each other (pairs of signs, triple signs or larger groups) instead of to particular signs, separately. This may apply to groups of TSs on one pole or signs at a certain distance from each other, as shown in Fig. 2 (b). It is also illustrated in Fig. 3, discussed below. Groups may be composed of TSs associated with a single travel direction (e.g. Fig. 2 (b) (group 1)) or with different directions (e.g. Fig. 2 (a)). This solution offers several benefits:

1) reducing the amount of data transferred wirelessly – instead of locating and then interpreting several TSs separately on the basis of the V2I communication, sending different identification codes from the same position, a given group of TSs will send its own single code, interpreted then by the vehicle. This will reduce the amount of data transferred over the network,
2) reducing the costs of devices associated with the V2I communication – instead of several independent communication devices intended for each TS separately, a single RSU device will be used for the overall group,
3) possibility to standardize the height on which the RSU is mounted – in the situation, in which several TSs are mounted on a single pole, a single RSU device can be located at the top of the pole. The mounting height has an impact on the visibility. The installation of the RSU at the top of the pole will increase the communication range under the LOS (line of sight) conditions. Regardless of the installation height of particular TSs belonging to a given group, this solution will allow to apply equal calculation scheme, and consequently will return equal position of all TSs on a given pole,
4) simplification of the assembly procedure of the V2I communication devices – such devices may be factory installed in the poles (a standardized design), and then programmed for specific groups of TSs that will be mounted on particular poles,
5) reducing the time required to identify TSs by particular vehicles – in cities where many vehicles are close to each other, each of them will cyclically attempt to locate and interpret road signs nearby. In the solution in which particular TSs would have their individual codes, the number of V2I communication sessions will be equal to a number of vehicles in a given area multiplied by the number of TSs in their field of view. In case of a large number of TSs and vehicles in a given area, there may be a problem of the capacity of communication links and the appropriate hierarchy of queries directed to nearby traffic signs. When using proposed aggregate codes for groups of TSs, the number of required localization sessions will be strongly reduced.

The proposed approach may also be applied to solutions based on GPS, presented in [10], [13]. If it is necessary to program TSs so that they contain an appropriate set of information, the use of group codes will facilitate this process and shorten the programming time. A single RSU device will be programmed for the overall group, instead of separately for each TS.

One of useful data stored in the memory of the RSU devices may be the elevation, at which the device is mounted above the road surface. Heights may differ substantially, as shown in presented Figures. Such information will have a meaning in case of using RTLS techniques for the determination of the position of the TS. In this situation, the transmission of the information about the height will allow to calculate a proposer position of the TS by the use the triangulation algorithms [18]. It is illustrated in Fig. 4. The measured distances are denoted as d_{M1} and d_{M2}. On the basis of the assumed known heights h_{RSU} and h_{VEH} it is possible to compute the $h_{\mathrm{RSU}} - h_{\mathrm{VEH}}$ term. The real distances d_{R1} and d_{R2} may be easily calculated in this case.

B. Ways of creating codes for TSs and groups of TSs

One can propose several ways to create unique codes for groups of TSs. The applied method may depend on the number of distinct types of TSs covered by the V2I communication, and the number of single TSs present in a single group. In general, the objective is to obtain the shortest possible codes, so that the amount of data necessary to transfer is as small as possible. Investigations reported in the literature show that the amount of data transferred in packets affects the transmission time [27]. On the other hand, the flexibility of the overall coding system is also important, as the ease of creating various combinations of groups of TSs and information accompanying them is important here. The following approaches may be considered:

1) the most flexible solution, but also the least economical consists in creating a code for a group by combining codes for particular TSs shifted by an appropriate number of bits, as follows:

$$C_{\text{group}} = C_1 << n_1 + C_2 << n_2 + \cdots + C_3 << n_k \quad (1)$$

The "<<" operation means shifting all bits in the C_k code of a given, k^{th}, TS by n_k positions to the left (multiplication by the 2^{n_k} factor). The values of particular n_k factors are calculated as follows:

$$n_k = b \cdot (k-1) \quad (2)$$

where: b depends on the number of distinct types of TSs. For example, if the number of TSs is less than 256, then b=8.

2) another possibility is to determine all possible distinct groups of TSs and assign separate normalized codes to them (for EU, NA) or codes normalized for particular countries. In this situation, particular signs would be numbered from 1 to n, where n is the number of single TSs covered by the V2I system, and the group of signs from $n+d$ to $n+d+r$, where d is the number of reserved codes for country-specific signs, or reserve codes for possible new signs in the future, while r is the number of distinct combinations of TSs.
3) a combination of two approaches described above. This approach may be relevant to groups composed of more than three TSs. In this case, a TS and groups of TSs (e.g. up to three TSs) would be identified with single codes as in case (b) above. If there are more TSs in a single group or there are small groups located close to each other, then the code for a larger group would be created using method (a) above, where the C_k codes could contain also codes for small groups. Determining the required values of the parameters d and r as in (b) needs a study of the variety of situations that can be encountered on the roads. The goal is to get the shortest resultant codes, on average.

C. Case studies – the ways of creating groups of TSs

In this point we present selected ways of creating groups of TSs and assigning particular TSs to them, depending on the road situation. There are several typical situations on the roads that may be distinguished:

1) type / group A – all signs in a group refer to the same travel direction and are located close to each other, on a single pole or in a direct proximity. The direct proximity is understood as a critical distance below which there may be problems with distinguishing particular TSs, assuming the worst case scenario when using a given localization technology. It is illustrated in Fig. 3 (a). See also Group 2 in Fig. 2 (b).
2) type / group B – all signs in the group refer to the same driving direction / the same traffic situation, but are far away from each other. It is illustrated in Fig. 3 (b). See also Group 1 in Fig. 2 (b).
3) type / group C – TSs are located close to each other (below the critical distance), but concern different travel directions. It is illustrated in Fig. 3 (c). See also Fig. 2.
4) type / group D – TSs are relatively far from each other and concern different travel directions, or different situations. For example, two TSs are located relatively close to each other, but provide the information valid at different distances. It is illustrated in Fig. 3 (d).
5) the classification of groups of TSs to A, B, C and D types is not always straightforward. This means that a real group of TSs may belong to different types. In this case, it may be useful to rearrange the location of the TSs so that to enable assigning a given situation to one of the groups A – D.

Depending on the described situations different are details concerning creation of particular groups:

1) type / group A – in this situation all TSs from a given group should be covered by a single RSU device, in order to avoid ambiguity in the positioning of particular TSs. In addition to the meaning of particular TSs from the group (appropriate codes), the corresponding RSU device may provide a unified remaining information (e.g. the distance at which this group is valid). If such a group is located before the intersection, then an information about a further travel direction of a vehicle is not required.
2) type / group B – all TSs may be covered by a single RSU device, located next to the first signs the vehicle passes, belonging to this group. In a specific situation, the group can be broken down into several smaller groups covered by separate RSU devices.
3) type / group C – in this case, a single RSU can also be used. The difference will be in the way the information is provided to vehicles. Due to different directions of particular TSs belonging to the group, broadcasting should cover all directions. The information corresponding to particular signs may then be accompanied by additional information about the road number, to which the sign applies. Vehicles, having planned routes, may distinguish between the signs intended for each of them. In this case the RSU may sent a personalized information valid for a given vehicle.
4) type D is presented here as a supplement to three previous scenarios. In this case, separate RSUs may be assigned to particular TSs, or one can form a group of TSs, in which together with the code of the TS is also provided a distance at which particular TSs start to be valid,

IV. Conclusions

In the presented work, are proposed solutions that aim at improving the efficiency of future traffic sign recognition systems, in case of a support for these systems from the side of the V2I communication. In the literature one can find proposals for the use of the V2I technology for recognizing road signs that rely on equipping TSs with wireless RSU devices. The novelty of the proposed work is how to apply this technology, so as to improve the effectiveness of the TSR system, especially in the urban areas or close to intersections.

In such areas one can expect relatively large densities of TSs and thus possible interferences between signals emitted by RSU devices associated with particular TSs. Such situation may be a source of errors in determining the positions of the TSs. In case if each TS will be equipped with a distinct RSU device, one can expect a large traffic in the telecommunication network. As a result, problems with the capacity of the communication links may appear.

A basic technique proposed in this work is to group traffic signs on a given area and to assign unique identification codes to particular groups of TSs, mounted on a single pole, close to each other or those that form a natural group (e.g. concern the same travel direction). Instead of assigning individual RSU devices to particular groups of TSs, a single RSU device may represent a larger group of TSs. As a result, a much smaller number of RSUs may be used in this case that would have a positive impact on the cost of the overall system, the energy consumption of particular RSUs on a given area, and the amount of data exchanged via the telecommunication network.

One of the problems discussed in this work is how to efficiently create groups of TSs, so as to minimize the number of RSU devices on the roads in the future. We also suggested to increase the scope of information stored in TSs with data allowing to increase accuracy in determining their positions. An example here is the information about the height at which the RSU device of a given group of TSs is suspended over the road surface.

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