Real-time Locating Systems for Smart City and Intelligent Transportation Applications

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Abstract— **In this paper, we focus on practical issues related to the implementation of real time locating systems (RTLS) in the context of vehicle-to-infrastructure (V2I) communication. These emerging concepts are an important part of novel areas such as Smart Cities and Intelligent Transportation Systems (ITS). Some problems encountered during the development of these systems result from the limitations of technologies that are supposed to become the basis for these new applications. In our opinion, there is additionally a direct link between the development of the new technologies, the architectural planning, as well as regulations. An appropriate planning of surrounding of the road will facilitate the realization of V2I systems. On the other hand, technology limitations will provide guidance how to design the road environment. In this work, we focus, in particular, on the assessment of the localization precision of RTLS used in ITS. The precision to some extent will depend on the variation of physical parameters of the used circuits, e.g. PVT (process, voltage, temperature) variation → delay in answer → localization error → safety issues.**

I. Introduction

The whole globe has gone through a process of rapid urbanization over the past six decades. According to Revision of the World Urbanization [1], 54 per cent of the world's population is urban and it is expected to be more – the range of two-thirds is supposed to be reached by 2050. Unplanned and rapid urban growth threatens sustainable development, especially if the necessary infrastructure is not developed. Infrastructure is crucial for many aspects of the urban areas existence, such as prosperity, development and functionality. Considering the problem of poverty reduction and induce growth, roads, power and communication facilities, it is the Physical infrastructure, improve urban connectivity. Efficient transport networks and modern information and communication technologies (ICTs), a verity of new solutions introduced to modern cities, are very important [2].

That is why, urban spaces are turning into the smart cities. Because of the overpopulation on the globe, there is a need to develop a new, faster, much more safer, and above all most comfortable way of transporting people or things. The answer to this problem is the intelligent transportation system (ITS). Smart technologies and smart collaboration are the future of cities, which leads to the term smart city [3],[4].

Future development of the transportation system is usually understood as a development of autonomous vehicles that will enable traveling without human intervention. The purpose of the development of such vehicles is to improve road safety and ecological aspects. There are several essential problems facing such solutions. The surrounding of the vehicle is dynamically changing when the car is moving. Another problem is the complexity of the environment seen by the algorithms responsible for the vehicle autonomy. For this reason, the need for a support from the infrastructure and other vehicles is strongly emphasized. In this context, vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) types of the communication are increasingly discussed.

The V2I communication may be used in different ways in the transportation system. In its most advanced form, the devices located in the infrastructure will support building the, so called, model of the environment. In this approach, the model is created by the algorithms in the car that treat the V2I source of data as an additional sensor. Such application requires a development of efficient, high data rate, technologies supporting the V2X (V2V and V2I) communication, as well as techniques that will allow for a very accurate localization of a vehicle on the road.

Global positioning system (GPS) provides only coarse location information, which in the context of the possible application described above, is not sufficient from the safety point of view. To improve the accuracy, local facilities have to be used that will cooperate with onboard enhancement algorithms and sensors of the autonomous vehicle.

Real time locating systems (RTLS) are usually used in indoor or in other confined areas, such as buildings. In contrary to GPS, RTLS provides only a local coverage on a given, well-defined area. Systems of this type are usually composed of two types of devices, i.e. active markers (tags) and transponders (also called anchors). The markers are designed as autonomous specialized application specific integrated circuits (ASICs). Since these devices are portable, therefore an important issue here is to achieve its low energy consumption. Trajectories of the markers in the 3-dimensional (3D) space

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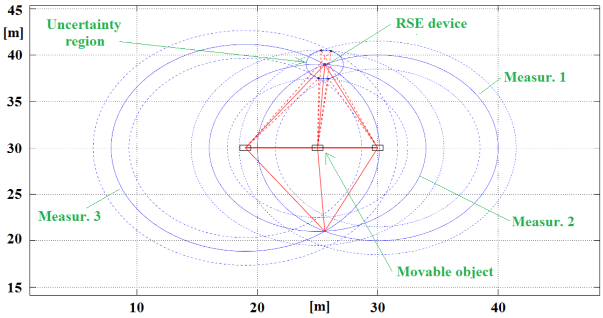

Fig. 1. Determination of the position of a stationary object on the basis of trajectory of movable object.

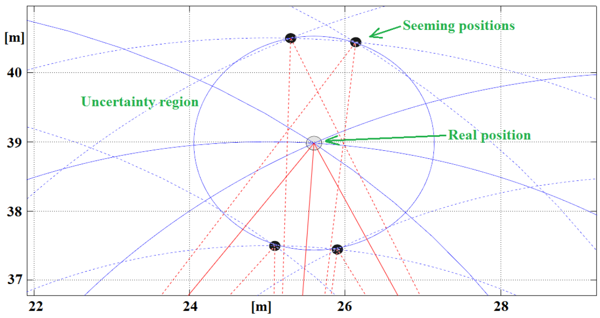

Fig. 2. Impact of the delays on the position of the RSU device.

are recorded by transponders. These devices constantly measure distances to the markers using, for example, the ultra wide-band (UWB) technology [5]. At current development stage, this technology provides ranging precision in the order of centimeters [6], [7] that is not achievable by other technologies. Additionally, one can observe a constant progress in this area [8]. The mentioned precision is achievable for a single pair of devices that communicate with each other in Line-of-sight (LOS) conditions. The precision may be enhanced by a cross-verification of measurements if they can be repeated. This technique will play a crucial role in a road environment, and therefore in this paper, we make a contribution to support these works.

II. Requirements in different applications

The ranging precision in the RTLS always depends on the application for which a given system is designed. In some medical applications, even millimeter level precision is required. Such situation appears in motion capture systems that aim at recording, with very high accuracy, the motion pattern of disabled persons [9]. A different situation is, for example, in warehouse applications that accept the precision at the level of 20-50 cm. An example RTLS of this type is offered by the Ubisense Company [10] with the reported localization error of 15 cm. This system was designed to operate on large areas. In the intelligent transportation system (ITS) the required precision will strongly depend on the function the V2X communication will play in the autonomy of the road vehicles.

Precision is not the only parameter to be optimized. For example, in the motion capture system, mentioned above, the most important problems are how to improve the ranging precision toward even sub-millimeter range, and how to miniaturize the markers to make them comfortable for examined persons. Since these devices are wearable, therefore energy consumption is also a crucial factor. On the other hand, since such systems are to be used in the indoor environment, in which temperature is at an almost equal level, therefore robustness to temperature variation (in a wide range) is less important. In typical systems of this type, the RTLS tags are affixed to moving objects and tracked by the transponders installed in fixed points of the environment, with precisely calculated and stored positions. The net of transponders may thus create a precise frame of reference for the markers. The transponders may have access to a power supply (or to be battery operated) and therefore a strong miniaturization is not required in this case. Prior to starting its work, the overall system has a sufficient time to be calibrated.

In case of the ITS, the situation is quite different. In this case, the network of devices will cover much wider areas than in indoor applications. The behavior of such systems will be different in cities and in suburban areas, mostly due to different density of the devices in each of these cases. In contrary to cities, in the suburban environment, we expect rather sparse networks, with a small number of devices in a range of sensors of a host vehicle. This creates some problems in terms of the localization precision, but in some situations can also simplify the communication scheme and thus the structure of the circuits supporting this system.

In sparse networks in the worst case scenario, even only one transponder may be available. In this case, the position of the vehicle will be additionally derived from the parameters of the trajectory of the car. For this reason, an essential problem will be the accuracy of which may be determined the difference between locations of a vehicle after a given time interval. An important role, in this case, will play the quality of onboard sensors (e.g. yaw rate sensor) of the vehicle.

A. *RTLS in ITS – Definition of the problem*

Development of the RTLSs based on the UWB technology, as well as improvement of its precision is the subject of interests of many institutions around the world. A majority of these works focus on indoor applications [11],[12]. However, there are also propositions to apply this technology in an outdoor environment [5], [13], [14], [15]. In the second case, due to high data rate this technology is also considered as a candidate for the communication standard for data exchange in the V2I systems [5]. One can find also propositions of the ap-

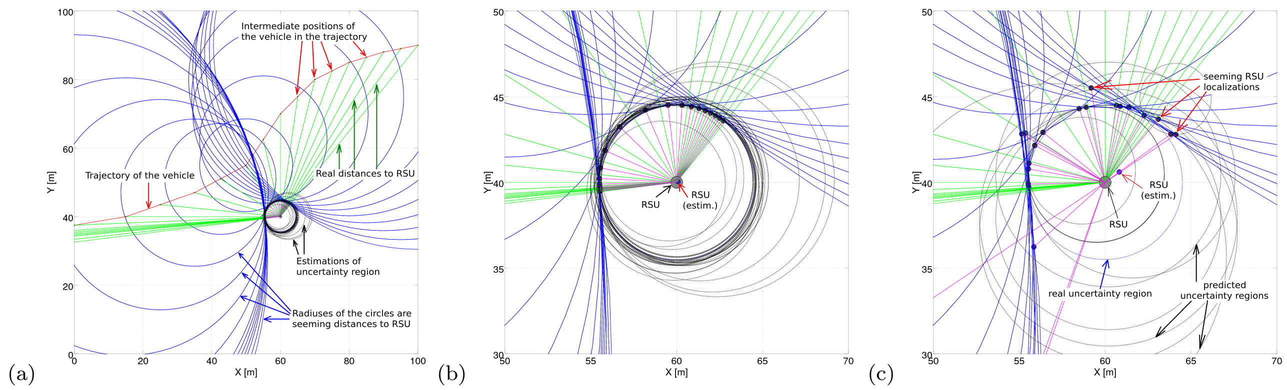

Fig. 3. Results for example trajectory: (a) and (b) without randomization of the distance measurements resulting from the noise or quality of the on-board sensors, (c) after the addition of the randomization at the level of 2 m. The circle of seeming points is well visible depending on the distance to the RSU and the trajectory shape.

plication of this technology in the localization purposes [13]. This may also include a direct support for building the model of the environment of the autonomous car.

The reported localization errors in indoor conditions are usually below 10 cm [16]. This is possible for relatively small distances below 10 m. For larger distances, due to noises, the precision may be additionally affected. Such situation is expected in case of the road conditions. One of the solutions may include a close cooperation of the RTLS with the GPS [15]. However, the overall system should be able to operate on its own in emergency situations.

As has been mentioned above, in sparse networks that are expected in suburban areas, in the worst case scenario, there will be only two devices communicating with each other. One of them will be an onboard unit (OBU) of a movable object. The second one – road side unit (RSU) – will be located in a fixed position of the road environment. The trajectory of the movable object may be known, with relatively good accuracy, on the basis of its velocity and yaw rate. A single communication session between the OBU and RSU will be quick enough to assume that during this period of time both objects are in still positions. This can be easily calculated from kinematic equations. If the distance between both devices is even at the level of 100 m, while the velocity is even 200 km/h (55 m/s), the movable object during a single communication session makes a distance not exceeding 50 μm, i.e. far below the safety margin and thus may be negligible.

To enable a sufficient localization precision, the delay introduced by the RSU should be normalized, and be independent on the physical parameters of the environment (temperature, humidity, etc.). Any spread of the response time of the RSU will impact the precision and may have an influence on safety aspects. The problem is briefly illustrated in Figs. 1 and 2. In Fig. 1 we see three intermediate positions of a movable object. The large circles drawn with solid and dashed lines illustrate real and seeming distances between OBU and RSU, respectively. For a single communication session, we get the information on the distance, without the information on the azimuth (thus a circle). Intersection points between two or more circles provide an estimate of both the localization and position of the RSU in respect to the movable object. The circle visible in Fig. 2 is an uncertainty region that results from a spread introduced by a potential delay caused by the RSU device.

In Time-of-Flight (ToF) approach the uncertainty in the response time of a device, that receives and then transmits the signal, impacts the assessed distance. The uncertainty at the level of 10 ns introduces a potential localization error of $\pm$1.5 m. If the RTLS is to be used, for example, to support recognition of traffic signs (TS) this may not be an essential issue if particular TSs are in sufficient distance to each other (in the sub-urban area). On the other hand, if the RTLS is to be used to support building the dynamic model of the environment, the localization precision will play a key role.

The problem may be defined as follows: Sufficient immunity of the RSU equipment for temperature (or other parameters) variation may not be assured, as well as sufficient accuracy of the onboard sensors of the car. Due to safety reason, we should even assume the natural variability of the parameters and try to immunize the entire system on it.

III. Possible solutions of the problem

One of the solutions to the problem defined above is enforcing some legal regulations concerning the road environment. One of the solutions for the ITS may be smart traffic signs (STSs) that will communicate with the car, informing about their meaning. Such STSs should not be located too close to each other, to avoid ambiguity during their V2I localization by the vehicle. In case if the TSs form a group in a single place, one can consider a separate V2I code characterizing such group.

Nevertheless, independently of legislation initiatives there still a need for improvement of the localization precision. The measurement accuracy of the position of the RSU may be improved if the measurements are repeated more than two times. As shown in Fig. 2 all "solid" circles resulting from real distances cross in a single point, while the "dashed" circles create different seeming positions of the RSU device. Note that independently on the distance to the RSU, if the delay error is constant, the uncertainty region forms a circle, whose radius depends on the value the error (discrepancy between expected and real delay). If this error is nonzero, the intersection points are located relatively close to this circle, as shown in Fig. 3, for two example trajectories. If the trajectory is smooth, the points create even very regular circle that may be identified. The center of the resultant circle is a predicted location of the RSU. The multiple dashed circles around the RSU, visible in both Figs., result from multiple predictions performed on the basis of only three points in each case. The obtained results are averaged, providing an estimate of the position of the RSU.

The results that are shown in (a) and (b) diagrams of Fig. 3 are for an idealized situation in which the delay error is constant whole the time. In this case, the localization error does not exceed 10-20 cm (radius of uncertainty region is 4.5 m). A problem occurs if we add some random variation that may result, for example, from the insufficient quality of the onboard sensors. Diagrams (c) of both Figs. illustrate a situation in which the trajectory estimation error is at the level of 2 m. In this case, the center of the uncertainty region may also be estimated, however, the resultant localization error of the RSU increased to about 1 m.

IV. Conclusions

In this paper, we have shown the problems that will accompany the development of the RTLSs for the ITS of the future. The localization precision of the devices in the environment will play a crucial role in this process. We identified possible sources of the localization errors and have shown a possible cross-verification method that can be used to correct them.

The results presented in this paper may be treated as preliminary. We performed investigations for different trajectories, sometimes even not realistic. The problems that have to be solved is an improvement of the identification of the circular uncertainty region, represented by circle . In this work, we used known methods, which may be insufficient if the noise influencing the measurements is large. However, on the basis of the location of the seeming points and the OBU, we initially narrowed the area in which the RSU was expected. This allowed us to filter out unrealistic results.

Given the uncertainty of the location of the RSU in the surrounding of the road, in the development of the ITS it will be necessary to regulate the organization of this surrounding in some situations. The goal is to facilitate the task of autonomous driving systems. Here the works of urban planners and city architects will play an important role. Cooperation with engineers is required.

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