

TESTING THE READINESS OF SLOVAK ROAD INFRASTRUCTURE FOR THE DEPLOYMENT OF INTELLIGENT TRANSPORTATION

LEHOCZKÝ Peter, JANEBA Matej, GALINSKI Marek, ŠOLTÉS Lukáš

*Slovak University of Technology in Bratislava, Faculty of Informatics and Information Technologies, Institute of
Computer Systems and Applied Informatics, Ilkovičova 2, 842 16 Bratislava, Slovakia,
e – mail: lukas.soltes@stuba.sk*

Abstract: In the recent years, we observe huge effort to develop new technologies for modern road vehicles in order to improve the level of safety for all passengers in the vehicle. Many of these systems are sooner or later becoming mandatory for the vehicles to be allowed to drive on the European roads. These are for example Lane Keeping Assistants (LKA) or Intelligent Speed Assist (ISA). Although there is huge effort on development and continuous improvement of these systems in the new vehicles, much less effort is put into the analysis of the infrastructure itself in the terms of its readiness for being used by these technologies. This study, in cooperation with the government authorities set as a goal an evaluation of sensoric readability of the horizontal and vertical road signs on the Slovak road infrastructure together with a public dataset to be released after the study will be completely done.

KEYWORDS: Intelligent transportation, ADAS, Automated mobility, Autonomous driving, CCAM

1 Introduction

Increasing road safety has become one of the most visible priorities across the EU countries, while this effort is being covered by “Vision Zero” initiative driven by European Commission (EC). This initiative set an ambitious goal to have zero fatal accidents on the EU roads by the year 2050. [1] In accordance with this initiative, many new regulations are coming to increase the road safety year by year. One of the most discussed regulations that are coming up in the very next years is the Intelligent Speed Assistant (ISA) which is to become mandatory for all new vehicles introduced to market since July 2022, and mandatory for all new vehicles sold in the EU countries from July 2024. [2] According to official information, that are present on the EC websites, “the ISA system is required to work with the driver and not to restrict his/her possibility to act in any moment during driving. The driver is always in control and can easily override the ISA system.” Generally, it is expected that this system will retrieve the data about the speed limit either by reading speed signs using the front camera, or by retrieving this information from the map source according to vehicle position determined by a GNSS sensor. Another highly discussed assistance system is Lane Keeping Assist (LKA), which is not yet mandatory by any EU regulation, but in the recent years is becoming a standard technology in all new vehicles in Europe. Speaking of LKA, it is not important if the system will be required by law, since this technology is essential if we want to deploy Level 3 of driving automation. [3]

While ISA is becoming mandatory independently from driving automation level with the primary goal of increased passenger safety, it will also become very important technology for the automated mobility in the future. If we want to speak about deploying Level 4 of driving automation, where according to SAE the vehicle will not require you to take over driving, the

vehicle itself must have a reliable technology to be able to drive within the correct speed limits on every road, where this level of automated mobility will be used.

To make all these systems work properly, it is not only a matter of the technology within the vehicle anymore. For both examples, ISA and LKA, an important variable affecting the reliability of this system is the quality of the road itself, or we can call it the readiness of the infrastructure for the deployment of intelligent transportation technologies. Both horizontal road markings and vertical road signs used on the European roads must be technically present, visible, readable, clean, and well-maintained, but also the information that will be gathered by car from these markings and signs must be clear to understand, without allowing car to have doubts about the meaning, or even worse, without being in conflict between two or more different signs. Last but not least, the temporary traffic signs which are being used i.e. during some reconstruction or during unexpected and potentially hazardous situations on the road must be chosen wisely and the workers must take care of maintaining the signs to be always up to date with what is happening on the given part of the road.

2 Related work

Main factors influencing the adoption of future autonomous transportation systems have been identified by the authors of [4]. They list four factors, i.e., technology readiness, infrastructure readiness, legal readiness, and user acceptance of the new technology. It is evident that adaptation of autonomous driving in the future is a complex process, and a wide range of issues need to be addressed.

Readiness of the road infrastructure is one of the key elements to support autonomous vehicles. Such vehicles form a mutual relationship with the road infrastructure. The authors of [4] conclude that new infrastructure will need to be built to fully support the requirements of autonomous vehicles. Despite the importance of changes in the current infrastructure, “very little research has been done on difficult questions relating to the readiness of the road infrastructure...” [5], including assessment of the current state of the infrastructure preparedness.

Communication is considered to be the most important capability of connected autonomous vehicles and also considered as the most important challenge [5]. It includes support for multiple types of connectivity to support various safety or navigation systems.

While V2V communication is sufficient to support safety services in some scenarios (e.g., emergency braking in platooning [6]), communication with infrastructure (V2I) or communication with any other entity related to traffic (V2X) is of vital importance in other situations like providing advanced collective perception. Such communication often requires high bandwidth and low latency which might be challenging to provide, especially in congested areas. Numerous solutions to prevent network congestion on multiple levels have been proposed, including filtering redundant sensor data in [7]. Methods with centralized control to better manage network resources and connected devices (e.g. [8]) have also been proposed.

In [5] and [4], the authors mention the requirements for road signage (e.g, good visibility in any weather conditions) and technology of roads, which is different from classical infrastructure. Although various physical road signs might be replaced with their digital versions in the future, classic road signs will still play an important role considering the costs of new or upgraded road components. Road surfaces for autonomous driving might also require better maintenance, for example to avoid potholes which might be dangerous for platooning vehicles in high speeds.

Authors of [9] assess the readiness of Greece to adopt autonomous transportation. They define multiple categories with specific criteria for evaluation. In category regarding infrastructure, they consider criteria similar to other works related directly to roads like quality of roads, but they also include quality of mobile internet or 4G coverage.

Since deployment of autonomous vehicles with higher automation levels is in very early stages, simulations can be used to investigate important aspects of autonomous vehicles and infrastructure before testing in a real environment. Authors of [10] study safety impacts using surrogate safety measure approach. According to their simulations, autonomous vehicles can reduce number of conflicts by tens of percent (according to simulated environments), but relatively high penetration of autonomous vehicles might be needed to get such improvements. Simulations modelling physical aspects of autonomous vehicles (including sensors) and roads in order precisely model specific situations has also been carried out by [11] or [12].

Test areas, constrained environments or simulated driving environments also help to evaluate abilities of current autonomous vehicles. However, trials carried out in such environments still cover only limited possible scenarios and same edge cases can still happen only in real traffic situations [5].

3 Experiment design

At first, key features for the data collection solution have been identified as follows; independent sensors as peripherals for the system, system independence from the vehicle, and time-aligned data from sensory peripherals stored in readable structured data format. Based on the conducted analysis, the solution was outlined as a roof box for vehicle which satisfied the need for a vehicle-independent solution. The box contains an embedded computer, which can be seen as a single onboard computer. The computer performs data collection tasks and aligns data into time-synchronized rows. To achieve task separation, data from sensors that need to process before storing are processed in separate computer; multiple Raspberry Pi computers were used in the case. The advantage of decoupling data processing and data storage is that more sensors can be used in the system without a big increase in the computation time and complexity of the solution. Therefore, sensors can be added or removed with ease. As the dataset output format, each frame from camera and lidar is stored in separate file, logically organized into folders with sensor identification. To keep track of the feature variables, the data are stored in a comma separated value file (.csv). The format is easy to understand and commonly used in the data science community.

To obtain valuable data sets, the data needs to be stored in lossless formats. For the camera data, the PNG format was chosen. LIDAR data is stored as Numpy Array file, which is a three-dimensional matrix. From the matrix, the point cloud of the surrounding area can be computed. The distance vector can also be computed. With the advantage of distance vector and data fusion, the distance to objects can be computed. Global Navigation Satellite Systems (GNSS) data was also stored. With the correction from the real-time kinematics service, GNSS positioning errors can be corrected and precise position can be determined. In terms of intelligent mobility, network connectivity and road infrastructure must be examined. Therefore, 4G and 5G network connection capable modem has been installed in the box, too. Qualitative parameters of the network such as delay and throughput have been measured.

To maintain high response of the measurement application, data store queues have been introduced. If the file cannot be stored now because there is another file already storing at the moment, the file will be stored afterward, when the need for compute power is lower. The

method increases the number of parallel camera and LIDAR sensors that can be used at the time. To keep track of each frame, only names of files are stored in the csv file as features.

The challenge of time synchronization has also been addressed. In general, the problem can be approach in two ways, deterministic time intervals and non-deterministic time intervals for each row of dataset. In the deterministic time interval method, each row of the data set is stored periodically, if the deterministic timer runs off. The timer is reset to interval length, afterward. The non-deterministic time interval approach relies on the data from the sensor of the fastest refresh rate. The advantage of the approach is to keep the data as clean as possible and to avoid redundant data. The solution is not optimal in terms of data storage, event-stored data set could be more effective, but the data would not be stored in csv structured format. The pros and cons of the used solution were analysed and a solution that satisfies the requirements has been implemented.

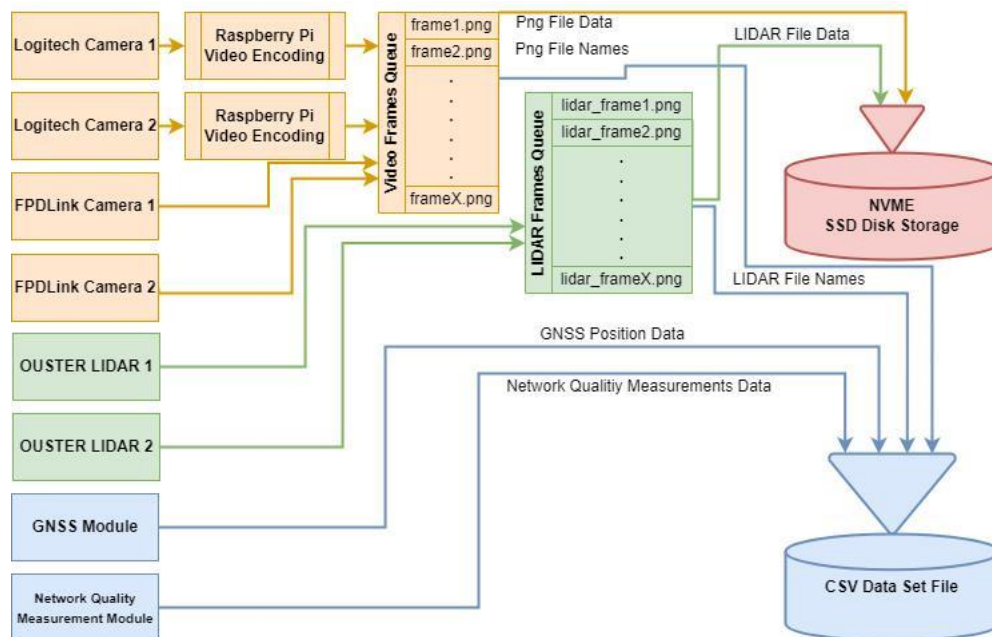


Figure 1: Data flow architecture for visual and telemetry sensors.

The data flow is depicted in Figure 1. In the diagram, orange represents the data flow of the camera data. The LIDAR data flow is described with green flows, and numeral or string values are depicted as blue. As can be seen, the CSV file stores only numeral and text values. As data storage, the NVMEA solid state disk has been used.

4 Preliminary results

During the first experiments, we started to observe huge differences in the quality of the road infrastructure in the terms of its readiness for intelligent transportation. There are newly reconstructed roads within flat terrain (see Fig. 2). On these roads, the stability of the data connection as well as the quality of the horizontal road markings (i.e., driving lanes) and vertical road signs is on the very high level making no problems to be identified in the image frames from the front camera. These are the places, where also currently present systems in the testing vehicle (LKA, Traffic Sign Recognition (TSR)) were able to provide correct results thus operated normally without any significant errors.



Figure 2: Ideal situation – newly reconstructed road II/503.

However, these drives identified several situations on the road, where state-of-the-art technologies would not be able to determine the result, that is expected as the correct one. Very common situation on the 3rd class roads in Slovakia is the state of the horizontal road markings. In most cases, the lanes and other markings are either not present, or very poorly visible (see Fig. 3)



Figure 3: Driving lanes marking not present or almost invisible.

Another problem here was, that in the urban areas of the small villages, quite often comes to a situation, where there is a car parked on the road, blocking almost one half of the road width. These might be considered as an obstacle of the driving lane, yet the lane itself cannot be determined properly, as there are no lines on the road, or just the center line is missing.

The scenarios where there was a direct sunlight just in front of the camera prior to sunset showed the requirement to perform the correct post-processing to the stream from the camera. On the raw frame pictures, the driving lanes and the road signs were very hardly recognizable. Nevertheless, after a given post-processing technique consisting of changing saturation, contrast and lightning, all the necessary information were present to be detected in the pictures. The difference between the raw image output and the postprocessed output can be seen in the Figure 4.

The most problematic situation on the road is, when there is a clear inconsistency between various markings and signs, or when the marking and signs are not up to date with the actual situation on the road. These can be illustrated on various observations during the experiment. For example, if there was a road construction that has already finished, but the temporary markings were not cleared, the situation for the LKA system becomes non-understandable, even though there is no actual reason for such a confusing situation on the given road. This was observed even on the 1st class road I/61, which is heavily used every day by thousands of

vehicles. Both full color and grayscale image frame of this situation can be seen in the Figure 5.



Figure 4: Visibility and recognizability of the road sign before and after post processing.



Figure 5: Outdated temporary lane markings on the road I/61 (color and grayscale).

Another situation that affected the correct operation of the LKA system was discovered on the highway, where one would expect the markings to be kept always in the perfect condition. On the highway D1, which is one of the most important road entrances to the Bratislava, capital city of Slovakia, there we two lines present, dividing two driving lanes. This was due to the change in the count of driving lanes, where there were originally two standard lanes and one emergency lane, separated from the standard lanes by the acoustic line. Then, the highway operator changed the emergency lane to a regular one by adding one more dashed line to the road surface, but the old acoustic one was not removed properly (see Fig. 6).

On the highway, there was another situation detected that happens quite usually on the Slovak roads, however, this example might be considered a little bit extreme. During the road works, there are common temporary road signs used to inform drivers how to pass the construction site or an obstacle. These are, according to Slovak legislation, signs Z4a, Z4b and Z4c, which are used to inform the driver if he must drive by the obstacle from the right side, left side or in between several obstacles. However, on the highway D2 in the direction from Bratislava, there was a construction site where these road signs were used randomly and inconsistently (see Figure 7). Such a situation may lead an autonomous vehicle in the future into the situation, where it would have to do a dangerous and useless manoeuvre, or it would have to come to a decision that it will ignore these detected road signs.



Figure 6: Confusing situation in driving lanes markings.



Figure 7: Example of incorrect usage of temporary road signs.

Another situation worth mentioning is the use of the digital road signs. These type of road signs are very popular in the recent years and are a good step towards intelligent transportation, as these signs can be changed dynamically reflecting the situation on the road. Here we must only be aware of the fact, that these digital signs sometimes use slightly different icons for the given situation, and these must be standardized across the vendors and countries in order not to confuse the intelligent ADAS systems in the vehicles. Also, we must be aware of the fact, that these signs use various refresh rate, which sometimes result in the camera frame, where the sign (i.e., speed limit) is not complete, thus unreadable (see Fig. 8). For the system such as ISA to work properly, we must consider multiple subsequent frames captured by the camera.

Another evaluation that we would like to present within these preliminary results is the evaluation of mobile network latency in the urban area of Bratislava. We are using an LTE modem with external antennas outside of the vehicle, and here we present the results for ping time to first hop (first gateway in the ISPs network) and ping time to six.sk, which is the main and most used peering centre of the Slovak internet networks. In the Figure 9 we can observe the raw data from a five-minute drive across the city highway with outliers present, the Figure

10 shows the same data on the Y axis fixed for the values between 10 to 60 milliseconds, thus most extreme outliers are trimmed here.



Fig 8: Example of unreadable digital signs in the single frame because of the sign refresh rate.

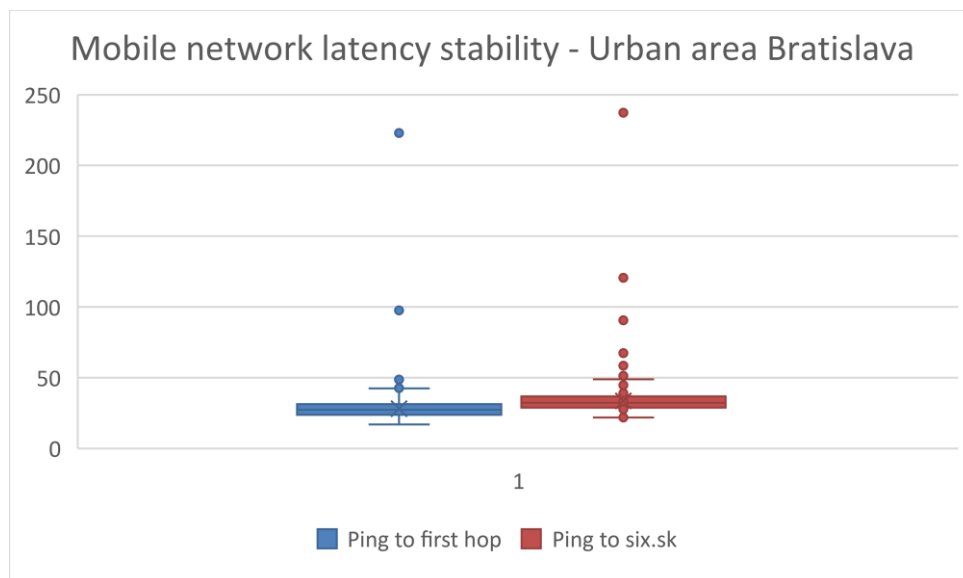


Figure 9: Mobile network latency stability – outliers present.

In these box plots we can observe that the LTE connectivity is very stable in the dynamic scenario of driving across the highway, so we can conclude the measured LTE stability and latency is sufficient for the time critical ITS applications.

5 Next steps

The results provided in this article are preliminary and used as an illustration of the objectives of this project. In the next weeks, we will continue with driving in various light and weather conditions on the roads selected for this experiment. We will continue with preparing the complex dataset with labelled data, and we are planning to evaluate the collected data in more complex manner, with projection over the map, with consistent analysis of the readiness of the Slovak road infrastructure to massively deploy intelligent vehicles in our environment.

We aim to summarize the complex set of recommendations for the infrastructure operators in the terms of keeping their infrastructure ready and safe for the daily use of all upcoming intelligent ADAS systems of vehicles on the Level 3 of automated driving and higher.

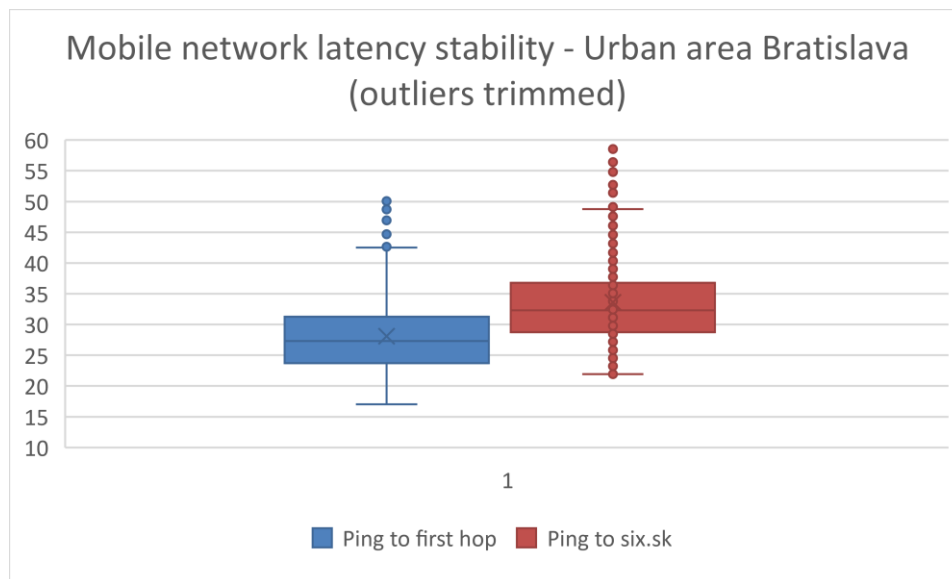


Figure 10: Mobile network latency stability – outliers trimmed.

Conclusion

In this paper, we described the current progress of the project focused on testing the readiness of Slovak road infrastructure for the deployment of the intelligent transportation. All the activities during this project are aligned with requirements of Ministry of Transportation and Construction of the Slovak Republic, in partial cooperation with National Highway Company and Slovak Road Authority. This paper describes preliminary results and observations collected while working on this project by the research team as well as it identifies the most relevant challenges for the intelligent ADAS systems and intelligent transportation systems on the Slovak roads in general. We conclude that the effort that has been put into evaluation of the readiness of the road infrastructure readiness for the ITS deployment was not sufficient in the recent years, yet this kind of evaluation is crucial for the modern vehicles equipped with intelligent and mandatory ADAS systems to operate correctly and result in safer mobility on our roads.

ACKNOWLEDGEMENT

This work was supported by APVV-19-0401, APVV-20-0346 and KEGA 025STU-4/2022.

REFERENCES

- [1] European Commission – Mobility and Transport; Road Safety; “Vision Zero”; Available at: https://road-safety.transport.ec.europa.eu/index_en [Accessed: 18.9.2022]
- [2] European Commission – Mobility and Transport; European Road Safety Charter; “Intelligent speed assistance (ISA) set to become mandatory across Europe”; Available at: https://road-safety-charter.ec.europa.eu/resources-knowledge/media-and-press/intelligent-speed-assistance-isa-set-become-mandatory-across_en [Accessed: 18.9.2022]

- [3] SAE International; “Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles”; Standard J3016_202104; Available at: https://www.sae.org/standards/content/j3016_202104/ [Accessed: 18.9.2022]
- [4] Alawadhi, M., Almazrouie, J., Kamil, M., Khalil, K. A. “A systematic literature review of the factors influencing the adoption of autonomous driving”, *International Journal of System Assurance Engineering and Management* 11(6), pp. 1065 – 1082, **2020**.
- [5] Johnson, C. “Readiness of the road network for connected and autonomous vehicles”, RAC Foundation: London, UK, **2017**.
- [6] Sidorenko, G., Thunberg, J., Sjöberg, K., Fedorov, A., Vinel, A. “Safety of Automatic Emergency Braking in Platooning”, *IEEE Transactions on Vehicular Technology* 71(3), pp. 2319 – 2332, **2021**.
- [7] Delooz, Q., Willecke, A., Garlich, K., Hagau, A.C., Wolf, L., Vinel, A., Festag, A. “Analysis and Evaluation of Information Redundancy Mitigation for V2X Collective Perception”, *IEEE Access* 10, pp. 47076 – 47093, **2022**.
- [8] Emran, M., Thayanathan, V., Umair, M., Kotuliak, I., Qureshi, M. S., Qureshi, M. B. “The Handover and Performance Analysis of LTE Network with Traditional and SDN Approaches”, *Wireless Communications and Mobile Computing*, **2022**.
- [9] Mylonas, C., Chalkiadakis, C., Dolianitis, A., Tzanis, D., Mitsakis, E. “Assessing the Readiness of Greece for Autonomous Vehicle Technologies”, *arXiv preprint arXiv:2010.07297*, **2020**.
- [10] Morando, M.M., Tian, Q., Truong, L.T., Vu, H.L. “Studying the safety impact of autonomous vehicles using simulation-based surrogate safety measures”, *Journal of advanced transportation*, **2018**.
- [11] Długosz, M., Roman, M., Węgrzyn, P. “Virtual simulation environment of an autonomous A-EVE vehicle”, In *2021 25th International Conference on Methods and Models in Automation and Robotics (MMAR)* (pp. 168 - 172), IEEE, **2021**.
- [12] Lukáš, H., Ľuboš, M., Ján, D., Tomáš, M., Peter, K., Robert, S. “Simulation of Pedestrian Detection in Urban Environment”, *Strojnícky časopis – Journal of Mechanical Engineering* 71(2), pp. 121 – 130, **2021**.