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The development of virtual road scene formation system for ground vehicles

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Abstract. The paper presents the analysis of existing lane keeping assist systems. It defines restrictions preventing the efficiency of such systems due to complex road climatic conditions of the Russian Federation. Besides, it reveals key parameters of a road scene, which shall be controlled to implement the developed system. The paper also provides a concept of a lane keeping assist system both in case of clearly visible road marking and in case of its absence. It gives testing results and assessment of the developed system.

1. Introduction

For many years the road safety, alongside with the improvement of technical and operational characteristics, remains the main issue of vehicle design and production. The accident prevention is the task of all car safety systems. Such systems control vehicles in critical situations. The most popular and already traditional safety systems are Antilock Brake System, Electronic Stability Program, Automatic Slip Regulation, etc.

However, thus far many car manufacturers are ever more engaged in the development and implementation of auxiliary safety systems (Assistants). These systems warn a driver on potential emergency and directly control the actuation mechanisms of a vehicle (steering control, brake system). The examples of such systems include the Parktronic System, Around View Monitor, Adaptive Cruise Control, etc. The most efficient secure-wise systems are the Lane Keeping Assistance Systems. This system is intended to prevent emergency situations bound to unintended change of the occupied driving lane. The majority of such accidents are caused by short-term carelessness or distraction of a driver. This, in turn, may lead to a vehicle deviating from the driving lane towards the oncoming lane or a roadside. The statistics confirms the consequences of such unintentional maneuvers.

Every year approximately 18 people per every 100,000 of the population die in road accidents in the Russian Federation. The majority of drastic consequences happen due to road accidents caused by entering an oncoming lane. The driver's experience, safe driver behavior and various safety systems installed in vehicles cannot guarantee 100% protection of a person against road accidents. Over 2018, the total number of road accidents already made 133,203, and the number of people that died in accidents amounts to 16,600 [1]. In EU countries, especially in Germany, entering an oncoming lane is the reason of about 17% of all serious road accidents with over 33% deaths.

According to experts, the use of auxiliary safety systems, such as the Lane Keep Assist system (LKAS) would potentially save over 5,000 lives and prevent nearly 40,000 severe injuries annually in

27 countries of Europe [2].

One of the first producers that serially equipped its vehicles with such auxiliary systems is the Mercedes Benz [3]. The video processing system sends data to the electronic control unit (ECU), which defines when a vehicle begins to leave the driving lane, respectively to the left or to the right. The system also assesses a driver's behavior to register intended or accidental change of a driving lane, i.e. for example, there will be no warning during passing or entrance to highway, etc. In case the system detects that a vehicle leaves a driving lane unintentionally, there is an activation of the electric motor therefore the steering wheel begins to vibrate – efficient way of immediate warning of the driver. The moment of action and time of vibration depend on a driving lane width, type of road marking, etc. The considered system operates at 60 to 250 km/h when it detects the marking lines and is disconnected when other safety systems are activated (ABS, ESP, others).

Another large manufacturer that serially equips its vehicles with LKAS is the Volkswagen AG. The Volkswagen Lane Assist [4] has functions similar to the above Mercedes system and is intended to assist a driver to remain within the intended driving lane. The system functions at over 65 km/h. Based on the information received from the camera and data on speed and trajectory of a vehicle the system calculates time and distance until expected crossing of the lane marking. When one or several indicators are lower the critical value, the Lane Assist System interferes, thus smoothly adjusting the steering control via the electric power steering. The torque value applied to the steering control is rather small and easily passable so that the driver always has the priority in driving. Besides, other large companies also designed simiar systems, including Lane Keeping Alert & Aid (Ford), Lane Departure Prevention (Infiniti), Active Lane Assist (Audi), Opel Eye (Opel), etc.

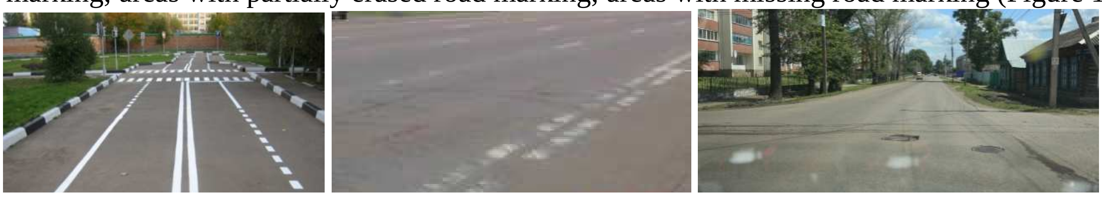
The main disadvantage of the above systems is their limited functioning in poor visibility (rain, fog, smoke, blizzard) and failure to operate with bad road marking: snow, dirt on a road marking, its damage or absence. It should be noted that the above operating conditions are the most common in the Russian Federation. Below, the paper considers the operating conditions of vehicles in general to define the road scene parameters to be controlled within the virtual road scene scenario.

2. Vehicle operation conditions in the Russian Federation

Currently, the total length of Russian highways is over 1,396,000 km. Among them the federal highway system of the Russian Federation (RF) makes over 50,800 km [1]. The main roads are concentrated in the European part of the country. This figures increase with the development of a highway system and further development of the territory. The development of a highway system provides for more efficient transportation of passengers and freights on short and medium distances. At present, the percentage of motor freight transportation makes over 70%.

Among other means of transport the automobile transport is also the leader in terms of the road distance (28 mln km or 70% of the world highway system). According to [5], in order to ensure safety of passengers and freights all federal roads in the country shall have marking (road marking). The road marking sets certain traffic modes and patterns for vehicles and pedestrians. The road marking serves as means of visual orientation of drivers and is applied independently and in combination with other means to improve safety of traffic, increase vehicle speed and road capacity [5].

The quality of road marking may be roughly divided into several parts: areas with clearly visible road marking; areas with partially erased road marking; areas with missing road marking (Figure 1).



a b c

Figure 1. Quality of road marking: a – areas with clearly visible road marking; b – areas with partially erased road marking; c – areas with missing road marking.

The quality and functional durability of road marking depends on several factors. First of all, it is necessary to identify the following:

- quality of marking materials and items;
- type of marking technology and equipment;
- quality of road pavement;
- compliance with marking technology;
- operating conditions of a highway (street) and, respectively, marking.

It is clear that the quality of road marking also depends on territorial belonging (a residential area or a country road). Residential areas are mainly characterized by clearly visible road marking (Figure 2). This is caused by quicker access of road marking machines and relatively large number of road repair companies. According to the statistics, the correlation of areas with clearly visible and partially erased road marking is identical in the coutryside (Figure 3) [6]. First of all this is caused by far distance of such roads and complexity of continuous marking.

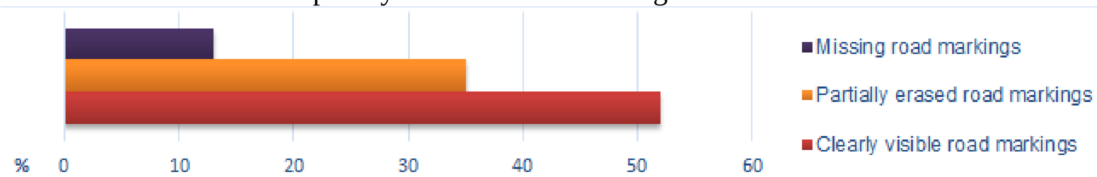


Figure 2. Percentage of road marking quality in residential area

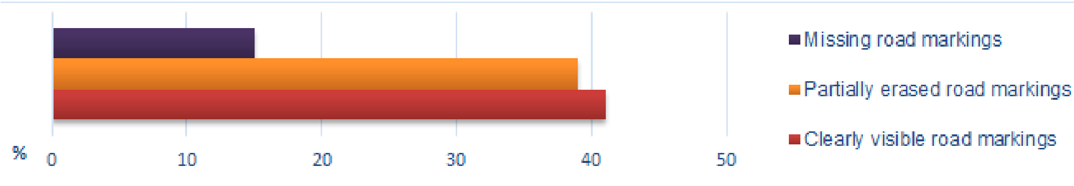


Figure 3. Percentage of road marking quality on a country road

The main feature of the Russian territory is a variety of road building climatic zones [6], which, in turn, also impacts the quality of road marking. Figure 4 shows road building climatic zones of the Russian Federation.

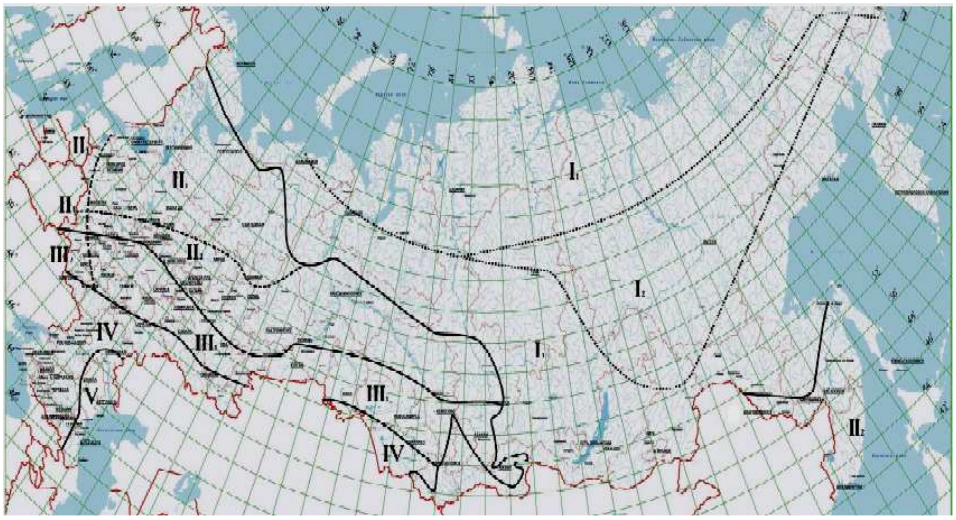


Figure 4. Road-climatic zoning

The majority of roads within the highway system of the Russian Federation are located in zones II1, II2, III1, IV, V and are generally characterized by a temperate climate. Zone I is characterized by abundant rainfall thus leading to full or partial loss of road marking. In turn, the temperate climate is characterized by wider temperature ranges (from –30 to +30), hail, blizzard, rains, and fog, which, undoubtedly, influences the quality of road marking and its chances to be detected by a driver.

According to the statistics, each climatic zone is characterized by available road marking. However, these data differ for residential areas and country roads. Figures 5 and 6 show histograms of road marking in different road building climatic zones in residential areas and on country roads.

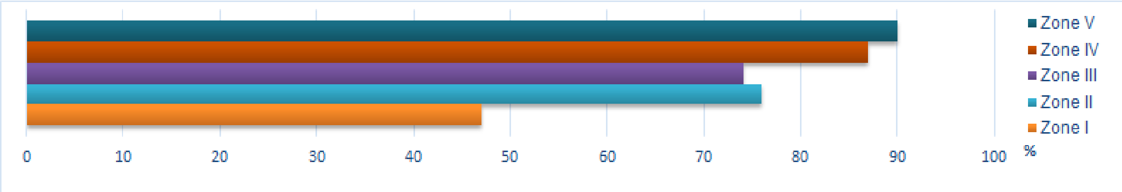


Figure 5. Road marking in residential areas in various climatic zones

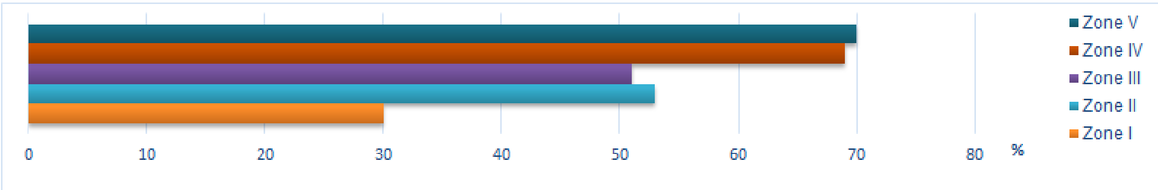


Figure 6. Road marking on country roads in various climatic zones

The above histograms show that the road marking is significantly lower on country roads than in residential areas. However, according to the statistics [6], the traffic flow outside residential areas (60% of major road accidents) is the most dangerous and thus requires extraordinary safety measures. Heavy rainfalls increase the risk of road accidents caused by the failure to quickly clean the driveway and the difficulty to drive a vehicle. The visibility of road marking (if available) is significantly limited under such conditions. Hence, if zone I has about 30% of road marking, then in case of emergency (snowfall, heavy rain, hail, etc.) situations this indicator will make approximately 10%, which, in turn, makes the traffic of vehicles extremely difficult.

The conducted analysis makes it is possible to conclude that throughout the long period of time in a year the roads of the Russian Federation had either no marking or its actual recognition by a driver was impossible due to weather conditions. The functioning of the above vision systems is also limited. It is caused by the absence of clearly visible road marking and by low efficiency of sensors (video cameras) in adverse climatic conditions. Thus, the above Lane Keep Assist can only be used in favorable weather conditions and with clearly visible road marking.

Hence, there is a need for systems capable to function in the absence of clearly visible road marking. To assess the current state of the matter the analysis of protection documents (patents) in the field of development of active and passive systems assisting a driver, including Lane Keep Assist, capable to function in adverse road climatic conditions, was carried out. Below the study presents the most efficient systems.

The system for assisting a driver on multilane highways [7]. This system processes data on conditions of a road scene via a set of sensors and assesses potential hazards regarding other road users. The vehicle and the detected objects are correlated to driving lanes. The system generates a warning signal when the detected object is located at a critical distance and is potentially dangerous for the vehicle. The vision system consists of radars, LIDARs, ultrasonic and infrared sensors. This system utilizes a variety of functions due to a large number of sensors. The processing of a large volume of data obtained from sensors requires advanced computing capacity. This fact leads to the conclusion that the cost of this system is extremey high (in certain cases the cost of the system will be equal to the cost of a vehicle), which prevents serial production and market release due to potentially low consumer demand.

The driver alert system [8], which includes a camera, a radar, the LIDAR, and the GPS. The system is triggered by a computing block used for data processing and analysis of a road scene in real time.

Besides, it has a database containing information on earlier road situations and the program response to such situations. This system operates via the database containing records of already happened road situations and the response algorithms to such situations. Depending on the comparison results the system warns a driver on any potential danger on the road. It is worth noting that the efficiency of this system sharply decreases in case of unrecorded situations on the road. The hardware of this system is similar to the system of assisting a driver described above. This fact also leads to the conclusion on the high cost of this system and the impossibility to enter the market.

There is a vehicle control system [9], which includes a camera and the LIDAR transferring data as a 3D point cloud. The control unit processes data on the image obtained from a camera and data received from the LIDAR to detect other vehicles. This system is also equipped with the module ensuring information exchange with vehicles equipped with similar systems. This technical solution provides for automatic drive taking into account the movement of other vehicles, including via the signal from other vehicles. Compared to the above systems this system has cheaper hardware, however it is mainly intended for off-line control of a vehicle and bears a slightly different function.

The Russian Federation also has protection documents for the systems of driver's assistance. One of such systems is [10], containing different modules, in particular, visual representation of a road scene, current position of a vehicle, detection of marking sections of a road scene, control of boundaries of current sections of a road scene. This system allows detecting the position of a vehicle in relation to marking lines and warns a driver on any crisis situations. The hardware of the system includes several types of video cameras. It should be mentioned that along with traditional lane keeping assist systems this system is also ineffective in case of adverse weather conditions or in case of low-quality or damaged road marking.

The analysis of the systems capable to function in adverse climatic conditions irrespective of marking shows that there is an economic and social need to develop the low-cost lane keeping assist system capable to function in diverse climatic conditions of the Russian Federation. Such system will make it posible to increase the traffic safety, to reduce the number of road accidents and, respectively, the number of people injured in road accidents, inlcuding critical situations caused by adverse climatic conditions. Consumers of commercial and passenger transport face the greatest need for such systems. This is caused by the fact that unlike private transport, this type of vehicles spends much more time travelling thus causing risks of time and financial losses, and in case with passenger transport it is also caused by potentially large number of people injured in road accidents thus resulting in difficulties with insurance payments and compensation of damage. Hence, the designers of such systems shall lay emphasis on commercial and passenger vehicles.

3. Design of a virtual road scene system

The analysis of the operating conditions of lane keeping assist systems and vehicles in Russia resulted in key parameters of a road scene, the analysis of which will allow controlling the traffic flow within a lane. Such parameters are as follows: road marking according to [11], and if it is missing – carriageway edges (roadside).

It is suggested to utilize a specialized lane keeping assist system adapted to adverse climatic conditions to control these parameters, to overcome the above barriers related to service conditions of vehicles in the Russian Federation, as well as to improve the traffic safety in general.

This system will have the following functions:

- detection of road marking;
- detection of carriageway and development of a virtual traffic path in case the road marking is damaged or missing;
- warning of lane departure determined by the existing road marking or taking into account the carriageway boundaries.

The above functions require a complex visual system consisting of the visual road marking module, which includes a video camera as its core unit, and the road actual parameters determining module, which main device is the LIDAR. The processing of data received from sensors and the generation of command signals to actuation mechanisms are ensured through the electronic control unit representing a small-sized computing platform (NVidia Jetson TX2).

Figure 7 shows the algorithm of this system. Initially this system relies on data obtained from a video camera. If the road marking is successfully detected (its detection algorithm is described in [12]), the system tracks the position of a vehicle within a lane.

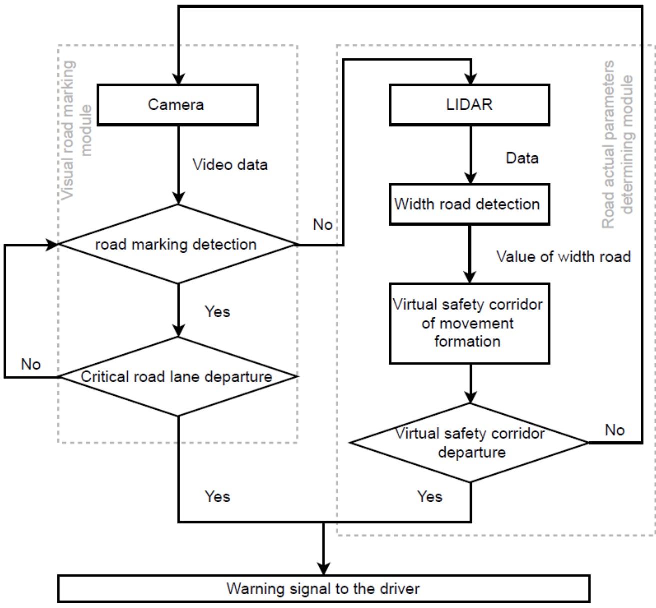


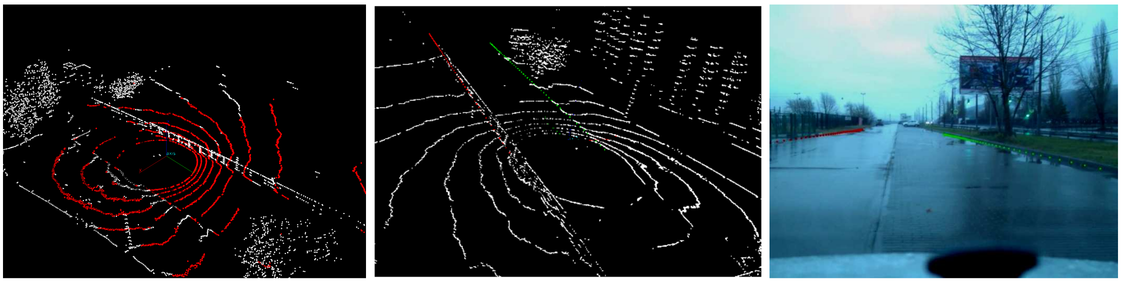
Figure 7. Algorithm of the designed system

Figure 8 shows the result of the visual road marking module, which receives the data video stream from a camera resulting in the value of deviation from a lane center. There are 3 warning zones: green – vehicle is in the lane center; yellow – deviation from the lane center from 0.2 to 0.3 m; red – deviation from the lane center by over 0.3 meters. The yellow zone is transition and it shows potentially critical situations to a driver. If the red zone is active the system generates a warning signal thus alerting a driver on a critical situation.

a b c

Figure 8. Visual road marking module: a – green zone, b – yellow zone (0.2-0.3 m deviation), c – red zone (over 0.3 m deviation)

According to the algorithm (Figure 7), if the clearly visible road marking is missing the system will activate the road actual parameters determining module, which will use the LIDAR information as the input data. Using certain transformations from a 3D point cloud it is possible to define the road plane (Figure 9a) and areas different from this plane representing the carriageway (Figure 9b). Figure 9c shows the image obtained from the road actual parameters determining module identifying the carriageway boundaries on a video stream. The safe virtual corridor of movement is formed on the basis of the carriageway boundaries, the vehicle width and the safety zone chosen in advance (around a vehicle). In case of a vehicle departure outside this virtual corridor the driver is alerted through audio and video signals. After each iteration, the system addresses the visual road marking module to check the road marking since the position of a vehicle within a lane along the road marking is the most accurate and safe.



a b c

Figure 9. Results of carriageway boundary detection using LIDAR

The road tests were carried out to assess the overall performance of the lane departure system in case of clearly visible road marking and in case it was missing. The vehicle equipped with this system moved along public roads at a rate of 45-60 km/h. The set maneuver – intended departure from a lane without direction indicators. It is considered that the system responded correctly if it generated a warning signal to a driver while changing the lane. According to the developed testing procedure, the efficiency of the system was estimated as the relation of true operations to the total attempts.

4. Conclusions

In 90% cases throughout the testing the system generated a warning signal informing a driver on lane departure. This result may be considered satisfactory with regard to the designed algorithms, however to introduce this system on serially produced vehicles there is a need to improve the reliability of the system thus reaching a higher level through software debugging. It is worth noting that at present the LIDAR, being part of the road actual parameters determining module, is rather expensive, however there is a tendency towards considerable cost reduction of this technology due to the development of the solid state LiDAR [13].

Active steering control to maintain a vehicle within a lane or in the virtual corridor of movement is further needed to improve the overall performance of the system thus ensuring the traffic safety. This will require the simulation modeling of the system with its integration into the electric power steering due to control over the electric motor. The simulation will make it possible to implement the system and to conduct its full-scale testing on a specialized testing track.

5. Acknowledgments

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