Research of algorithms for road marking recognition in the lane departure warning system

A V Tumasov, D Yu Tyugin, D M Porubov, V I Filatov and A A Gladyshev
Nizhny Novgorod State Technical University n.a. R.E. Alekseev, Minin str., 24, Nizhny Novgorod, 603950, Russian Federation
E-mail: pavel.beresnev@ntu.ru

Abstract. The way to improve the safety of vehicles using ADAS systems has successfully proved itself in practice. The use of ADAS systems in vehicles is mandatory in many countries of the world and is accepted at the state level. One of the most widely used ADAS systems is the Lane Departure Warning System (LDWS). The paper describes the principles of operation of existing LDWS in the segment of light commercial vehicles (LCV). The algorithm and structure of the developed LDWS for the GAZelle Next vehicle are presented. The description and analysis of algorithms for recognition of road markings are given. The results and comparative analysis of virtual and road tests of the LDWS are presented. Conclusions are given on the operation of the system and the algorithm for recognizing road markings.

1. Introduction
The use of ADAS systems in vehicles is mandatory in many countries of the world and is accepted at the state level. One of the most widely used ADAS systems is the Lane Departure Warning System (LDWS).

The LDWS occupies a wide niche in the passenger car segment, with the exception of budget models, and also partially in the light commercial vehicle segment. Typically, these systems are offered as optional equipment and are available from many major vehicle manufacturers.

The Driver Lane Departure Assist System (LDWS) is a functionality designed to warn the driver that the vehicle is starting to leave the lane (if the turn signal is not turned on in this direction) on motorways, so that the driver is able to take the necessary corrective action. These systems are designed to minimize accidents by eliminating the root causes of collisions: driver errors, distractions and drowsiness. This paper is devoted to the study of algorithms for the operation of such systems.

2. Overview of LDWS
There are several systems currently on the market, most of which use a forward-facing video camera mounted behind the windshield. In rare cases, systems use infrared sensors or laser scanning technologies. Modern systems use different types of warnings: visual, audible or tactile, or its combinations.

The operation of the LDWS based on a video camera is carried out by assessing the current position and direction of the vehicle within the lane, by determining the road marking lines delimiting the lane from the incoming video stream or images of road sections taken by a camera installed on the front windshield of the vehicle [1-9].
Below there is a table with some LDWS from various vehicle manufacturers in the light commercial vehicle segment.

**Table 1.** LDWS of various vehicles manufacturers. Light commercial vehicle segment.

| Manufacturer      | Vehicle model | System name                                      |
|-------------------|---------------|--------------------------------------------------|
| Fiat [10]         | Ducato        | Lane Departure Warning System                    |
| Ford [11]         | Transit       | Lane keeping system                              |
| Mercedes-Benz [12]| Sprinter      | Active lane keeping assist                       |
| Volkswagen [13]   | Crafter       | Lane keeping assist system                       |
| Citroen [14]      | Jumper        | Alerte de franchissement involontaire de ligne (AFIL) |
| Peugeot [15]      | Boxer         | Alerte de franchissement involontaire de ligne (AFIL) |
| Renault [16]      | Master        | Lane Departure Warning                           |

All these systems are based on two successive stages:
- image processing from the camera located on the windshield of the vehicle in order to find the marking lines;
- the process of deciding whether to give the driver a lane departure warning.

The stage of detecting road markings can also include several sequential steps:
- pre-filtering of the image to suppress possible noise;
- detection of the road marking using the methods of technical vision and/or neural networks;
- post-processing of found lines to cut off false or incorrect responses.

The main situations are known that can lead to incorrect operation. Some of them are described in [17]:
- fuzzy lines of road markings (overlapping lines, abrasion of lines, contamination of lines, lines do not contrast well with the roadway);
- heavy load of the rear axle of the vehicle;
- abrupt change of lighting (entrance / exit from the tunnel);
- presence of several lanes;
- overlapping of road marking lines by other vehicles;
- sharp turns;
- damage or contamination of the windscreen in the immediate vicinity of the sensor.

### 3. Development of the LDWS

A group of researchers from NNSTU n.a. R.E. Alekseev is developing its own LDWS for use in the segment of light commercial vehicles, in particular, on the Gazelle Next vehicle. The approach was based on machine vision algorithms. The choice of this approach was determined by a number of its advantages:
- Simplicity and transparency of the solution: the algorithms [18 - 25] of this approach have been already developed and repeatedly tested.
- Performance: in general, the performance of algorithmic methods is higher than that of neural networks. This is an important advantage, since it is possible to reduce the cost of the entire system by choosing a less efficient computing unit, which will make the whole system more accessible.
- Adaptability: the whole solution is a set of sequential blocks. Each of the sequential blocks is dependent on the previous one in terms of input / output data, but the content of an individual block can be changed. For example, an algorithmic block for searching road markings in the future can be replaced...
by a block that uses neural networks. Then, to preserve the operability of the entire system as a whole, it will be sufficient that its output is the same as that of the algorithmic one.

Schematically, the main cycle of the system can be represented as follows:

![Diagram of the main cycle of the system](image1)

**Figure 1.** The main cycle of the developed LDWS.

The above work cycle consists of the following key methods:

3.1. **Canny operator [18] for borders detection.**
Applying this operation to a halftone image makes possible to select borders that correspond to the differences in colors (Fig. 2). In this case the markings have a color different from the asphalt, i.e. has a distinct color difference.

![Canny operator for borders detection](image2)

**Figure 2.** Canny operator for borders detection.

3.2. **Dilation [19] (expansion) of the found borders.**
The borders found at the previous step go through the dilation procedure (Fig. 3). This is a preparatory step for subsequent steps. The essence of this step is to simply expand the boundaries found in the image.

![Dilation of the found borders](image3)

**Figure 3.** Dilation of the found borders.

3.3. **Extraction of target colors in the image**
As mentioned earlier, the selection of borders using the Canny operator finds all the differences (gradients) of colors, however, they can refer not only to road markings. They can also be found on curbs along the road, or on shadows from objects on the road.
In order to cut off unnecessary borders, an additional operation is performed to select the desired (target) colors in the image (white and yellow). Color extraction is performed using threshold cuts of image pixel values (Fig. 4).

Before applying the clipping threshold, there is a need to apply the color distribution histogram equalization method, which improves the contrast of the image.

![Figure 4. Extraction of target colors in the image.](image)

3.4. Bitwise intersection of binary images
Canny operator, unfortunately, can distinguish not only the road marking lines, but also side edges. The selection of target colors in the image using threshold values is often noisy because thresholds have to be lowered in order for them to work in different conditions. Therefore, to compensate for the disadvantages of these two approaches, their bitwise intersection should be performed.

The input of this operation is the image from paragraph 2 (dilatation) and the image from paragraph 3 (selection of target colors). The resulting image (Fig. 5) is obtained by superimposing the input images on top of each other and includes only those pixels in which both images had a value other than zero.

![Figure 5. Bitwise intersection of binary images.](image)

3.5. Hough transform [20, 21] for finding straight lines
The binary image obtained in the previous paragraph is sent to the input of the Hough transformation. It makes possible to select the parameters of straight lines that could be on the prepared binary image (colored lines in Fig. 6).

![Figure 6. Hough transform [20, 21] for finding straight lines.](image)
3.6. **Initial filtering of lines by slope**

After the parameters of possible marking lines have been found, they are initially filtered by the slope. This stage is needed to immediately weed out horizontal and vertical lines, which obviously cannot be the road markings. Along the way, the lines are divided into left and right straight lines by the angle of inclination (Fig. 7).

![Figure 7. Initial filtering of lines by slope.](image)

3.7. **Combining close lines into groups (clusters)**

The filtered lines must be clustered (Fig. 8) since several parameters of the straight lines can be matched to the same marking line. Clustering is needed to average all these parameters and get one line. The DBSCAN algorithm was chosen as the clustering method [22].

![Figure 8. Combining close lines into groups (clusters).](image)

3.8. **Averaging the parameters of straight lines over clusters**

After clustering has been done, the straight lines in these clusters are averaged (Fig. 9) so that for each marking line there is only one straight line.
3.9. Translating lines into bird's eye view format [23]
At this stage, the lines are converted from the original image to the bird's eye view format (Fig. 10).
This makes them more separable from each other and allows meaningful physical restrictions to be imposed on them (example: the distance between two adjacent marking lines cannot be less than one meter).

3.10. Multi-object particle filter [24, 25]
After the lines have been converted to bird's eye view, they are sent for processing to a multi-object particle filter. This makes it possible to compensate for the noise that may be present when selecting the parameters of the straight lines and to decrease the influence of outliers that occur due to various external
environmental conditions. In addition, this process for some time makes possible to restore lines that are no longer detected (Fig. 11).

**Figure 11.** Multi-object particle filter.

### 3.11. Decision making algorithm

After the road markings have been detected and filtered, the relative position of the vehicle within the lane is calculated. Further, depending on the fulfillment of the conditions, the system will decide whether a warning signal should be given (Fig. 12).

**Figure 12.** Decision making algorithm.
After the completion of the development phase of the LDWS, a series of tests have been carried out in order to test the developed modules and evaluate the performance of the LDWS in virtual and road conditions.

4. Tests
The system was tested in accordance with two main normative documents for the LDWS:

- UNECE Regulations 130 [26];
- Standard ISO 17361 [27].

All prepared and performed tests were directed to check the following points:

- Operation of the logical component of the system (switching on, activating, changing modes, etc.);
- Ability of the system to recognize road markings;
- Ability of the system to position the vehicle inside the lane;
- Ability of the system to issue a warning signal at the right time.

Testing was carried out by two stages:

- Tests of software part of the system in the virtual environment of the Carla simulator [28, 29];
- Tests of the assembled prototype at a test site with real road markings.

One of the important advantages of testing the system with a simulator is the ability to assess the performance of the system not only qualitatively, but also quantitatively. For example, to compare the distance to the marking lines, detected by LDWS, with the one that the simulator provides. This makes possible to quantify the positioning accuracy of the system in the lane. Below there is a demonstration of this assessment (Figure 13).

![Figure 13. Comparison of the distances to the road marking lines, which are detected by LDWS, with the one that the simulator provides.](image)

Testing the system with a simulator made it possible to detect a number of errors on the development stage and before assembling a real prototype.

After the tests with the simulator, a real prototype was tested on a specially equipped section of the test site.

As an example, here is a comparative test of the system in real and simulated conditions: unintentional departure from the lane.

Test conditions are:
• The vehicle moves in a straight line inside the lane at a speed of 65 km/h;
• Starting from a certain moment the vehicle starts to leave the lane;
• Turning lights are turned off;
• Leaving speed reaches 0.1 m/s;
• Distance of warning signal: 0.75 m from the corresponding lane markings in the lane, 0.3 m from the lane markings out of the lane.

Below there are graphs describing a part of the internal state of the LDWS, based on which the system makes a decision on possible warning of the driver about an unintentional departure from the lane.

We will start with a computer simulation of the test using the Carla simulator. In this example (Fig. 14) the vehicle leaves the traffic lane to the right side.

Figure 14. Testing the system operation when the vehicle departures the lane (computer simulation).
Here the graph “a” shows the distance from the right wheel of the vehicle to the right line of road marking.

The graph “b” reflects the fact that the vehicle has crossed the Warning Zone. It should be noted that the graph values correspond to the conditions described above.

The graph “c” shows the lateral speed of the vehicle (lane departure speed). Positive speed values mean that the vehicle is moving to the right, negative - to the left.

The graph “d” reflects the fact that there is a warning signal from the system. The signal is given only when the vehicle is in the Warning Zone, the lateral speed of the above-described threshold, as well as the direction of the lateral speed corresponds to the exit side.

A similar test has been carried out on a real prototype at a test site (Fig. 15). The only difference is that here the departure from the lane was made to the left. Otherwise, the test conditions are fully consistent with the conditions of computer simulation.

The system also gives a warning signal only when all the conditions described above are met.

Figure 15. Testing the system operation when the vehicle departs the lane (test site).
When carrying out full-scale tests at the test site, it was noted that the results coincided with the results of computer modelling. Testing was carried out according to the developed test plan, repeating the tests conducted with the simulator.

Below there is a demonstration of the system operation in areas with different types of road markings (Fig. 16 - 17).

**Figure 16.** Various types of road markings (a - broken white on the right side, b - broken white on both sides, c - solid and double solid white).

**Figure 17.** Calculation of the safe traffic corridor according to UNECE 130 and ISO 17361.
The tests also involved simulating inadvertent lane departure without the corresponding turn signal. Below there are the results of these tests (Fig. 18 - 19).

Figure 18. Departure from the lane to the right (warning signal issued in accordance with UNECE Regulations 130).

Figure 19. Departure from the lane to the right (warning signal issued in accordance with ISO 17361).
Also, during the tests, false alarms of the system were detected on:
- Shadow of the road barrier;
- Road barrier itself under direct sunlight (Fig. 20 a)
- Strip of bitumen mixture located along the road marking line (Fig. 20 b)

![False detection of road marking lines.](image)

From the point of view of the video camera, the shape, color, inclination and location of these structural elements fully correspond to the parameters of the solid white marking line.

Also, during testing of a real prototype, the performance of the system was tested. The data was collected during the LDWS start (on the Nvidia Xavier computing unit), and the result showed an average performance of 26 fps. The results of the speed of the main work cycle are shown below in Table 2.

| Processing stage                              | Time (ms) |
|-----------------------------------------------|-----------|
| Image pre-processing                          | 7,668     |
| Finding and filtering of the road markings   | 30,161    |
| Calculating the position of the vehicle within the lane | 0,00122   |
| Alert conditions handling                     | 0,001     |
5. Conclusions

The paper describes a few ways to improve road safety with active driver assistance systems using the LDWS. Also a few examples of existing LDWS of different manufacturers were given.

The algorithm and structure of the developed LDWS for the GAZelle Next vehicle were presented, consisting of preliminary processing of the video frame, search and filtering of road marking lines, calculation of the position of the vehicle within the lane and processing of the conditions for issuing a warning signal.

For this solution, tests have been carried out in two stages: testing on a simulator and testing a real prototype. Based on the results obtained during the tests the main advantages and disadvantages of the developed algorithm can be distinguished.

Advantages:
- comprehensibility and ease of implementation;
- high performance of the entire system;
- low requirements for computing power.

Disadvantages (described in [17]):
- sensitivity of the algorithm to the colors in the video frame, namely to yellow colors at sunset.
- faults with sudden changes in lighting;
- faults in the presence of glare surfaces in sunny weather.

Thus, the algorithmic vision methods used to recognize road markings and implemented in the LDWS are stable in good conditions, but false positives are still possible. The main reason for that is the sensitivity of this technology to ambient lighting conditions.

Setting up the system, modernizing the operation of algorithms and the interface to reduce the described system shortcomings to a minimum is planned to the future work.

Acknowledgements

This research has been performed with the financial support from Ministry of Science and Higher Education of the Russian Federation in the framework of the complex project “Design of a high-tech production of a range of GAZelle Next vehicles with a new electronic architecture of electronic systems” according to Agreement No. 075-11-2019-027 from November 29, 2019 (Governmental Regulation №218 from 09.04.2010).

The experimental research has been conducted with the use of measurement equipment of the NNSTU Centre of collective using “Transport Systems”.

References

[1] Neumann-Cosel K V, Roth E, Lehmann D, Speth J and Knoll A 2009 Fourth International Conference on Software Engineering Advances pp 169–172
[2] Amditis A, Bimpas M, Thomaidis G, Tsogas M, Netto M, Mammar S, Beutner A, Möhler N, Wirthgen T, Zipser S, Etemad A, Lio M D and Cicilloni R 2010 IEEE Transactions on Intelligent Transportation Systems 11 617–629
[3] Deusch H, Wiest J, Reuter S, Szczot M, Konrad M and Dietmayer K 2012 15th International IEEE Conference on Intelligent Transportation Systems pp 270–275
[4] Jamaa A M, Ying H, Syed F U and Filev D 2017 IEEE International Conference on Industrial Technology (ICIT) pp 492–497
[5] Hamid U Z A, Pushkin K, Zamzuri H, Gueraiche D and Rahman M A A 2016 A survey. PERINTIS eJournal 6(2) 78–90
[6] Zeziulin D V, Tyugin D Yu, Porubov D M, Filatov V I, Tumasov A V and Groshev A M 2018 IOP Conference Series: Earth and Environmental Science 194(2)
[7] Beresnev P, Tumasov A, Tyugin D, Zeziulin D, Filatov V and Porubov D 2018 VEHITS 2018 - Proceedings of the 4th International Conference on Vehicle Technology and Intelligent Transport Systems pp 363-370
[8] Porubov D M, Groshev A M, Mishustov V P, Palutin Y I and Tumasov A V 2018 IOP Conference
[9] Porubov D M, Pinchin A V, Tyugin D Yu, Tumasov A V, Beresnev P O and Belyakov V V 2019 Proceeding of NNSTU n.a. R.E. Alekseev 2(125)

[10] Official site of Fiat. Retrieved September 20, 2020 from: https://www.fiatprofessional.ru/

[11] Official site of Ford. Retrieved September 20, 2020 from: http://www.ford.ru/Commercialvehicles

[12] Official site of Mercedes-Benz. Retrieved September 20, 2020 from: http://www.mercedes-benz.ru/content/russia/mpc/mpc_russia_website/ru/home_mpc/van.html

[13] Official site of Volkswagen. Retrieved September 20, 2020 from: https://www.volkswagen-commercial.ru/ru.html

[14] Official site of Citroen. Retrieved September 20, 2020 from: http://www.citroen.ru/index.html

[15] Official site of Peugeot. Retrieved September 20, 2020 from: http://www.peugeot.ru/index.html

[16] Official site of Renault. Retrieved September 20, 2020 from: https://www.renault.ru/vans/

[17] Forsyth D and Ponce J 2011 Computer Vision: A Modern Approach (Second Edition)

[18] Canny J A 1986 IEEE Transactions on Pattern Analysis and Machine Intelligence 8(6) 679–698

[19] Serra J 1982 Image Analysis and Mathematical Morphology

[20] Hough P V C. Method and Means for Recognizing Complex Patterns, U.S. Patent No. 30696541962

[21] Duda R O and Hart P E 1972 Commun. ACM 15 11–15

[22] Ester M, Kriegel H P, Sander J and Xu X 1996 Proceedings of the Second International Conference on Knowledge Discovery and Data Mining pp 226–231

[23] Carlbom I, Paciorek J and Lim D 1978 ACM Computing Surveys 10(4) 465–502

[24] Thrun S 2002 Commun. ACM 45 52–57

[25] 2013 Regulation No 130 of the Economic Commission for Europe of the United Nations (UN/ECE) — Uniform provisions concerning the approval of motor vehicles with regard to the Lane Departure Warning System (LDWS)

[26] ISO 17361 2017. Intelligent transport systems — Lane departure warning systems — Performance requirements and test procedures

[27] Mahler R 2007 Statistical Multisource-Multitarget Information Fusion

[28] Dosovitskiy A, Ros G, Codevilla F, Lopez A and Koltun V 2017 Proceedings of the 1st Annual Conference on Robot Learning pp 1–16

[29] Official site of CARLA Open-source simulator for autonomous driving research. Retrieved September 20, 2020 from: http://carla.org/