Development of the unmanned vehicle traffic control system with electric drive

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Abstract. The development of unmanned vehicle traffic control systems is a world trend. The development of the market of unmanned vehicles is stimulated by various contests and competitions. This paper presents the prerequisites and the first steps in the development of unmanned vehicle traffic control systems by the NNSTU n.a. R.E. Alekseev with the support of engineers from the United Engineering Center of the GAZ Group and specialists from PJSC GAZ. This system is developed for operation in difficult road-climatic conditions in the territory of the Russian Federation. As a chassis for installation of the system, an electrical platform was chosen. The component composition of the unmanned vehicle traffic control system is proposed, the location and coverage of the equipment are determined. The software modules of the unmanned traffic control system are implemented. Experimental studies of the system were carried out.

1. Introduction
The market sector of unmanned vehicle traffic control systems is new and rapidly growing both in the world and in the Russian Federation. Large automakers develop systems for unmanned vehicle traffic control based on ADAS (Advanced Driver Assistance Systems). Also, these systems are successfully developed by researches [1 - 5] and IT companies, such as Google (figure 1a), Nvidia (figure 1b), Baidu (figure 1c); and manufacturers of military equipment: DARPA [9]; Oshkosh Defense (figure 1d); Lockheed Martin [11] etc. (Figure 1).

Figure 1. (a) Google self-driving car, (b) NVidia self-driving car, (c) Baidu self-driving car, (d) Oshkosh unmanned ground vehicle.

To evaluate the efficiency and increase the level of competition among developers of unmanned traffic control systems the competition of unmanned vehicles has been organized with the support of the US government (DARPA Grand Challenge [9]). These competitions revealed all the shortcomings of unmanned vehicles and significantly influenced the development of the unmanned industry. It is worth noting that most of the participants were represented by relationship of big automaker, who has provided vehicle, and the university engaged in realization of unmanned functions on this vehicle.
In 2014, the United States approved the first national standard in the field of autonomous vehicles - SAE J3016 «Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems [12]». The standard contains definitions, terminology and classification of vehicle automation levels. The document under consideration is the basis for the subsequent development of standards and determines the level of interaction between the community dealing with automated and autonomous vehicles.

According to this standard [12], the highest level of automation of vehicles is reached by Google (Level 5 - Full Automation).

The main difference of Google's development from other developers of unmanned vehicles is that in the motion process the data obtained from LIDAR is verified with 3D high-resolution maps recorded earlier. Due to this, it is possible to detect an obstacle on the path by the comparison. Therefore, at this stage of technology development, the autonomous movement of the car is possible only in those areas where detailed three-dimensional maps were pre-recorded.

In the Russian Federation, the direction of development of unmanned vehicle traffic management systems is less successful, but there is a number of companies which have a big potential in the development of these systems such as Yandex [13], Cognitive technologies [14], FSUE “NAMI” [15], PJSC KamAZ [16], Avrora robotics [17] and others.

Among the Russian developers of unmanned vehicles, one of the most successful companies is Yandex [13]. The purpose of the development is the use of unmanned vehicles in the field of transportation services (taxi, trucking, etc.). To date, Yandex has developed two prototypes of unmanned vehicles based on the Toyota Prius and Kia Soul. The hardware consists of the following types of sensors. Inside the car there are cameras of the front and rear view, from which the recognition of cars, pedestrians, road signs and marking, as well as the boundaries of the carriageway, takes place. On the roof of the car there are LIDARs: Velodyne HDL-32 and Velodyne VLP-16. These sensors with the help of a laser emitter scan the surrounding space. Based on the information received, a three-dimensional map is compiled. With the help of this map, exact distances to certain objects around the vehicle are calculated. The vehicle is also equipped with sensors that determine its location, speed and direction of travel. These are GPS / GLONASS receivers, a block of inertial meters and sensors that measure the odometer data of the vehicle.

To reduce the gap in the technological development of unmanned vehicle traffic control systems, adapted to use in Russian climatic and road conditions, the staff of the NNSTU n.a. R.E. Alekseev together with the Joint Engineering Center of GAZ Group currently work on the development and implementation of unmanned traffic control systems for commercial vehicles of the GAZ Group.

2. Development of the unmanned traffic control system

As the chassis for installation of the unmanned vehicle traffic control system, an electric platform for commercial vehicles was chosen (Figure 2).
This choice is based on a number of advantages of electric transport over traditional types of vehicles such as the increase of safety and environmental friendliness through the use of modern technologies that ensure the use of electricity as the main source of energy. Almost all large automakers make progress in this area, and advanced countries, such as the USA, China, Japan, Germany and Great Britain - have long-term programs to support the development of electric transport and consumer incentives. Currently, support is expected from the government of the Russian Federation.

The control of the chassis electrical units does not require the installation of actuators as in the case of mechanical, hydraulic and pneumatic units. It increases the safety and reliability of the vehicle systems, as well as the speed and cost reduction of the various vehicle systems. 

This platform is the basis for the line of commercial vehicles of the GAZ Group, however, for the implementation of the unmanned traffic management system, the bus was chosen. The use of route transport as an object on which unmanned operation solutions will be applied is explained by a number of reasons: the main route of the vehicle has been determined in advance, the ability to move along designated lanes for public transport, the possibility of charging batteries at the final points of the route. At the first stage of development the hardware of the system has been determined (Figure 3).

**Figure 3.** The hardware of the unmanned traffic control system.

In order to collect and analyze information from various types of sensors of the system, an on-board computer with INTEL Xeon Processor E5-2690 V4 and three NVidia GeForce GTX 1080 Ti graphics cards is used.

LIDARs will be used to detect other traffic objects and obstacles along the route, as well as construct a virtual route map (Figure 4). Velodyne HDL-32 will be used to scan the space in front of the vehicle. This sensor has a wide vertical sector of operation (from +10° to -30°) and a range of up to 200 m. Since the sides and the back side are the least responsible, then for these zones will be applied LIDAR Velodyne VLP-16, having a vertical viewing angle from -15° to +15° and range up to 100 m. Also the planar LIDAR Sick LMS Pro 511 will be installed at the bumper level of the vehicle. The use of this sensor is due to its high scanning frequency of 75 Hz and a wide temperature range of operation from -30° C to +50° C. All LIDARs are connected to the on-board computer via an Ethernet connection. To implement the system for detecting objects of the road scene, the following software was developed: to detect objects on the video stream neural networks (modified architecture yolo v218) were used, to detect obstacles according to LIDAR data, cluster cloud algorithms were implemented as well as methods of linear algebra. All implemented modules for interaction with each other were integrated into the ROS infrastructure (Robot Operating System [19]).
An important aspect in the design of unmanned traffic control is the reliability of the entire control system as a whole. Especially this issue is relevant in extreme road and climate conditions. To improve the reliability of the obstacle detection system at the unmanned vehicle, in addition to the LIDAR system, a short-range and long-range radar system will be used. The most suitable by the characteristics are the radars Continental ARS441 and SRR510, operating at a frequency of 77 GHz. The ARS 441 radar has a range of up to 174 m with a horizontal operating angle of ± 10°. The SRR510 radar has a range of up to 70 m with a horizontal operating angle of ± 75°. With the on-board computer, these radars are connected via the Ethernet connector. The application of the radar system will allow to assess the situation in front of the car, to measure the distance to obstacles at long distances. The radar system operation is less affected by weather conditions, color of objects and illumination. Also radars have good resolution in range and speed, instant data processing, which is especially important for high speeds. It should be noted that systems with different types of radars are already being used by large automakers in the development of ADAS systems.

Compliance with traffic rules is a prerequisite for the operation of an unmanned vehicle on public roads. Recognition of the road scene participants, in particular, other cars, pedestrians, road signs, marking, etc. is carried out with the help of the system of technical vision, the hardware part of which is represented by video cameras Basler [20]. In the unmanned vehicle traffic control system, three video cameras are used, completely covering the front view.

To improve the efficiency, reliability and safety of the obstacle detection systems and other road users, the Titan 63221 thermal imager will be used, with a horizontal view of 90°, a vertical view of 65°, a temperature range from -60° C to 50° C. The thermal image, after processing by the computing complex, will improve the recognition of the boundary of the roadway, the estimation of the approaching turns and curvatures on the route in advance. It is worth noting that the thermal imager, unlike video cameras, operates even when the headlights of oncoming cars are illuminated, through smoke, dust, fog and rain.

In order to plan the trajectory of motion along the given reference points (in geo-coordinates) and recalculation of the trajectory parameters into the control commands of the vehicle actuators, a path planning program was implemented. The algorithm is implemented in the context of solving the optimization problem, which consists in finding the optimal control parameters of the actuators while minimizing the trajectory error and reaching the set speed. The program consists of the following blocks: the trajectory calculation unit, the navigation system data acquisition unit, the map data display unit, the route entry unit. The hardware consists of GNSS receiver OS-203-GSM, GNSS antennas AT330 and inertial block Xsens [22]. The system is implemented by a separate scheme for the integration of GNSS data of the receiver and IMU, i.e. they work independently of each other. Periodically, the IMU is updated according to GNSS data. The navigation complex provides high-precision geographic coordinates, speed, altitude, number of satellites and power of the satellite signal. It connects to the on-board computer via the Ethernet interface. The embedded software performs data processing, writes it to a database and associates measurement data with all sensors with geographic coordinates.

The motion is carried out by the kinematic model with prediction (Model predictive control - MPC). The traffic control functions are performed by the top-level logic when starting the route, an obstacle occurs on the route or the end point of the route is reached. At each step of the algorithm (with each new arrival of data from the GPS receiver), a solution is performed to find the optimal control parameters for
the actuators when moving from the current waypoint to the direction of the next point. Thus, the model allows to predict the trajectory of the vehicle path taking into account the current position, speed and set of control commands. Solving the problem of finding the optimal control parameters allows to define a set of commands for actuators.

3. Testing of the unmanned traffic control system

The vision system aimed to recognize the objects of the road scene, was tested in real traffic conditions before being installed on the electric bus.

During the tests, the system has performed the detection and recognition of cars, pedestrians, a number of traffic signs and signals of traffic lights. The software system of the vision system is implemented using the developed application OCVStudio, based on the OpenCV [23] library. The initial data for the system is a frame from the optical sensor. It is processed through the neural network.

In the development and training of neural networks, the modified architecture of yolo v2 was applied. Also the prevention of retraining in the extended neural network, addition of filter layers, increase in the depth of convolution and the size of completely connected layers have been performed.

The user interface of the complex displays in real time the information about the presence of cars, pedestrians, a number of road signs, as well as traffic light's signals on the roadway. The system test frames are shown in Figure 5.

![Figure 5. Test frames of the vision system.](image)

The criterion for correct operation of the system was the accuracy of recognition of objects in the road scene. The calculated accuracy, which shows the number of correctly recognized road objects in relation to the total number of recognized objects was 78%.

In parallel with the tests of the vision system, experimental studies were carried out in order to determine obstacles on the unmanned vehicle route, to perform the possible localization, and also to plan the route at a specialized polygon of the GAZ Group. The frames of experimental research are presented in Figure 6.

![Figure 6. Experimental studies of the unmanned traffic control system.](image)
In order to assess the possibility of identifying obstacles on the way and generating a cloud of points on the road scene for further localization of found obstacles in this cloud of points, tests has been conducted with the LIDARs. Fragments of the tests are shown in Figure 7.

The vehicle stopped when an obstacle in front of the vehicle higher than 15 cm and closer than 8 meters was detected. The motion began when there was no obstacle at a distance of 9 meters. Thus, movement and stopping on the obstacle signal is carried out through the trigger. This eliminates multiple trips to stop and move if the obstacle is located at the boundary of the detection zone.

Based on the results of the LIDAR research, it can be concluded that obstacles on the way are determined correctly and with high accuracy. Also the expediency of using the method of vehicle localization in space on the basis of LIDAR's data was confirmed. In the future, when driving an unmanned vehicle, the pre-compiled map will be compared to the real-time map, which is also formed with the help of LIDAR. Based on the results of this comparison, the localization of unmanned vehicle in the relative coordinate system will take place, where LIDAR is the center.

Planning and control of the motion along the trajectory of an unmanned vehicle was made on the basis of data from the navigation system mentioned above. The trajectory was entered by the user through the interface of the developed software "Tracker" with the display of the route of motion. The motion was carried out at given points with a feedback on the GPS / GLONASS receiver with RTK corrections from the base station (b) and control of the actuators via the MPC software. It was conducted more than 50 races on the route. The chosen route simulated an urban environment consisting of buildings close to each other, metal structures, trusses and pipes. The analysis of the navigation system was made after the test races and consisted of comparing the coordinates from the GNSS receiver, the IMU block and the reference pre-recorded trajectory, as well as monitoring of the signal quality metrics. The continuity and smoothness of the trajectory, the quality of the connection along the entire length of the route, the control of communication between the control units of the executive mechanisms and the on-board computer, the necessity and the quality of the inertial block operation has been determined during the races. A fragment of testing is shown in Figure 8.
The quality of tracking of navigation satellites along the entire trajectory corresponded to the norm. The only exception was the intersection with the iron trusses and pipes, which caused a delay in updating the trajectory for 1-3 seconds. The signal quality of the network was satisfactory, however, in some places (especially at the beginning of the route), breakdowns of communication (irregular) were observed. It should be recommended to use Wi-Fi to transmit corrective information from the base station to the vehicle with an additional backup link. The distance between the points for optimal operation was about 2 meters along the entire route.

It should be noted that the navigation trajectory cannot be considered as an absolutely reliable source of information about positioning. Thus, this navigation system can be used in urban conditions, but without the presence of tunnels and other long discontinuities in communication with GNSS satellites. Based on the results of navigation system research, the deviation of the INS trajectory from the GNSS trajectory did not exceed 3 meters. The minimum deviation is 1.334 m, the maximum is 2.647 m. The wide interval between the minimum and maximum values arose due to the loss of communication with GNSS satellites for a long time (more than 10 seconds) due to interference in the traffic area (metal trusses and pipes) and low vehicle speed.

4. Conclusions
The structure of the unmanned vehicle traffic control system was developed, the hardware part was selected. Development of design documentation for various modules of the unmanned traffic control system, software and data transmission network, which unites all subsystems in a single network on the on-board computer, preparation of the electrical platform for the installation of unmanned traffic control systems has been carried out. Experimental studies of the modules of the unmanned traffic control system, namely the vision system for recognition of the road scene objects and the obstacle detection module on the path of the unmanned vehicle have been conducted. Based on the results of these tests, these modules have confirmed their operability.

To assess the positioning of the vehicle in space, the module for planning and controlling the trajectory of motion through satellite navigation has been tested. It should be noted that this navigation system can be used in urban conditions, but without the presence of tunnels and other long-term discontinuities in communications with GNSS satellites. To increase the accuracy of positioning the vehicle in space in the future, it is necessary to ensure joint work with diversification systems to improve the reliability of the system (technical vision, work with laser scanners, etc.). Some work will also be carried out in order to improve the quality of the output trajectory of the inertial system, and repeated testing is planned. In the future it is necessary to improve the quality of the output trajectory of the inertial block, and also to ensure joint work with diversification systems.

The implementation of this unmanned vehicle traffic control system, as well as the skills collected during the development, will contribute to the development of unmanned buses for public transport.
routes. This, in turn, will significantly reduce the cost of transportation of passengers and time resources, increase economic efficiency, and minimize the number of road accidents.

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References
[1] Bojarski M, Del Testa D, Dworakowski D, Firner B, Flepp B, Goyal P, Jackel L D, Monfort M, Muller U and Zhang J et al 2016 End to end learning for self-driving cars *preprint arXiv* 1604.07316
[2] Chen C, Seff A, Kornhauser A, and Xiao J, 2015 *Deepdriving: Learning affordance for direct perception in autonomous driving*. In Proceedings of the IEEE International Conference on Computer Vision pp 2722–2730
[3] Krizhevsky A, Sutskever I and Hinton G E 2012 Imagenet classification with deep convolutional neural networks. In Advances in neural information processing systems pp. 1097–1105
[4] Hane C, Heng L, Lee G H, Fraundorfer F, Furgale P, Sattler T and Pollefeys M 2017 3d visual perception for self-driving cars using a multi-camera system *Calibration, mapping, localization, and obstacle detection. CoRR, abs/1708.09839*
[5] Zhang J and Sanjiv Singh 2014 *LOAM: Lidar odometry and mapping in real-time*. *Robotics: Science and Systems Conference (RSS)* July
[6] Autonomous car development company Waymo Retrieved May 10 2018 from: https://waymo.com/
[7] The Official NVIDIA Blog. Retrieved May 10, 2018, from https://blogs.nvidia.com/
[8] Baidu Retrieved May 10 2018 from: http://apollo.auto/
[9] DARPA. Retrieved May 10 2018 from: https://www.darpa.mil/
[10] Oshkosh Defense Retrieved May 10 2018, from:https://oshkoshdefense.com/
[11] Lockheed Martin Retrieved May 10 2018 from:https://www.lockheedmartin.com/en-us/index.html
[12] SAE International Retrieved May 10 2018 from: https://www.sae.org/
[13] Yandex Taxi Unveils Self-Driving Car Project. Retrieved May 10 2018 from: https://yandex.com/company/blog/yandex-taxi-unveils-self-driving-car-project/
[14] Cognitive Technology Retrieved May 10 2018 from: https://www.cognitive.ru/
[15] Central scientific research automobile and automotive engine institute «NAMI». Retrieved May 10, 2018, from: http://nami.ru/
[16] KAMAZ PTC Retrieved May 10 2018 from: https://kamaz.ru/
[17] Avrora Robotics Retrieved May 10 2018 from: http://avrora-robotics.ru/
[18] YOLO Retrieved May 10 2018 from: https://pjreddie.com/darknet/yolo/
[19] Robot Operating Syste Retrieved May 10 2018, from: http://www.ros.org/
[20] Basler the power of sight Retrieved May 10 2018, from: https://www.baslerweb.com/ru
[21] Pergam Retrieved May 10 2018, from: https://www.pergam.ru/
[22] Xsens Retrieved May 10 2018 from: https://www.xsens.com/
[23] OpenCV Retrieved May 10 2018 from: https://opencv.org/