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Autonomous electric commercial vehicle for difficult operating conditions

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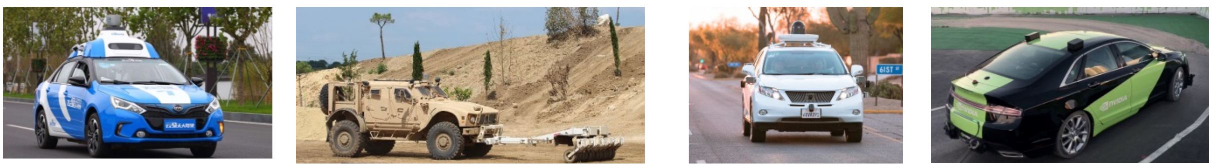
Abstract. Nowadays development of autonomous vehicle driving control systems is a global trend. The growing autonomous vehicles market is stimulated by a variety of competitions and awards. This article introduces the background and the first steps taken by the research team of Nizhny Novgorod State Technical University named after R.E. Alekseev (NGTU). The research is supported by GAZ Group's United Engineering Centre and by PAO GAZ experts. The control system in question is developed for operation in severe weather and road conditions of the Russian Federation. An electrical platform is used as chassis for the control system. The working components of the autonomous vehicle driving control system, its location and the area of operation are considered in the article. The software to operate every module of the system has been developed; the system operation has been tested.

1. Introduction

Autonomous vehicle driving control systems market is a relatively new and yet rapidly growing field both in Russia and globally. A number of large motor manufacturers including IT-companies, such as Google [6], Nvidia [7], Baidu [8], and military machinery manufactures DARPA [9], Oshkosh Defense [10], Lockheed Martin [11], etc. (Figure 1) are developing their autonomous vehicle driving control systems based on advanced driver assistance systems (ADAS). as well as some scientists [1,2,3,4,5], IT-companies, such as Google [6].



a b c d

Figure 1. (a) Baidu self-driving car[8] , (b) Oshkosh unmanned ground vehicle [10], (c) Google self-driving car [6], (d) Nvidia self-driving car [7]

DARPA Grand Challenge [9] autonomous vehicle contests sponsored by the US Government helped evaluate the performance and enhance competition in the autonomous vehicle driving control systems market. The contests revealed all the shortcomings of autonomous vehicles and influenced considerably the autonomous vehicles development. It should be pointed out that most of the contestants were represented by joint efforts of a large motor manufacturer, which provides a vehicle, and a university research team, developing an autonomous driving system for the vehicle.

In 2014 the US set the first national standard for autonomous vehicles SAE J3016 «Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems» [7]. This standard defines autonomous vehicles and provides the taxonomy for motor vehicle automation. The report lays the groundwork for further development of the standards and demonstrates high level of cooperation between the autonomous and automated vehicles developers.

The report states that Google has reached the highest level of motor vehicle automation Level 5 being Full automation.

The main difference between Google's and other companies' products is that Google immediately verifies the traffic data obtained by LiDAR while driving with 3D high resolution maps included in the system earlier. This allows comparing the data to detect any possible obstacles on the route. That is why for now it is only possible to follow the routes which have detailed 3D maps.

The Russian Federation cannot boast a highly successful development of autonomous vehicle driving control systems, however such companies as Yandex [13], Cognitive technologies [14], FGUP NAMI [15], PAO KamAZ [16], Avrora robotics [17] and others have given the field a good start.

Yandex [13] is one of the most successful autonomous vehicle driving control systems developers in Russia. The researchers aim to introduce self-driving cars into transportation services (taxi, haulage, etc.). Yandex has by now designed two self-driving car prototypes using Toyota Prius and Kia Soul as the base. The hardware includes the following sensors. Inside the car is equipped with front- and rearview cameras, which provide data to detect and identify any vehicles, people, traffic signs and road surface marking as well as the driveway borders. Velodyne HDL-32 and Velodyne VLP-16 are mounted on the roof of the vehicles. These sensors use a laser emitter to scan the environment. The obtained data then becomes the basis for a 3D map, which helps calculate the exact distance to the objects around the vehicle. The car is also equipped with sensors to identify its current position, speed and trajectory, like GPS/GLONASS, an inertial measurement unit and odometric sensors.

To reduce the gap in the technological development of autonomous vehicle driving control systems designed specifically for Russian weather and road conditions NSTU research team and GAZ Group United Engineering Center are developing and installing autonomous vehicle driving control systems on GAZ commercial vehicles.

2. Autonomous Vehicle Driving Control System Development

We use an electrical platform for commercial vehicles as chassis to mount the control system on (Figure 2).

Figure 2. An overall view of the electrical platform

A number of advantages of electric vehicles over traditional ones have influenced our choice, the important one being a higher level of safety and environment friendliness of an electrical vehicle due to the use of electricity as the main source of power.

Most of the largest motor manufacturers are carrying out research in the field, while the most advanced countries like the USA, China, Japan, Germany, and the UK are engaged in long-term programs to support electric vehicle manufacturers and encourage the consumers. Right now the Russian Federation is about to introduce a program to boost the field as well.

Electrical units unlike mechanic, hydraulic or pneumatic units of the chassis do not need actuators or any drive gears to operate, which makes the vehicle systems safer and more reliable, and at the same time reduces their costs.

Although this platform is the base for a wide range of GAZ commercial vehicles, we chose a bus to implement our autonomous vehicle driving control system. The choice of a public transportation vehicle is driven by the following reasons: a preplanned path for the vehicle, following the special lane for public transport, an opportunity to recharge the batteries at bus terminals.

At the first stage of our development we defined the working components of the system and the coverage of the sensors.

The system uses an onboard computer based on INTEL Xeon Processor E5-2690 V4 CPU with three NVidia GeForce GTX 1080 Ti graphics cards to collect and process data obtained from different sensors.

LiDARs are to be used to detect any other moving objects and obstacles, as well as to create a virtual route map. Velodyne HDL-32 scans the environment in front of the vehicle. Velodyne HDL-32 is a wide vertical field of view sensor (from +10° to -30°) detecting targets at up to 200 meter range. The less important rear and lateral views are covered by Velodyne VLP-16, with vertical FOV from -15° to +15° and up to 100 meter range. Besides, the system is equipped with a planar LiDAR Sick LMS Pro 511, mounted at the bumper level of the vehicle. The choice is based on a high scanning frequency of the sensor (75 Hz) and ambient operating temperatures ranging from -30°C to +50°C. The LiDAR data is passed to the onboard computer over an Ethernet connection. We developed software for object detection: we used a modification of YOLO v2 [18] network for real-time object detection on the video stream, and point cloud clustering algorithms along with linear algebra methods for LiDAR data based object detection. All the modules are integrated in ROS (Robot operating system) [19] to ensure their smooth interaction.

In autonomous vehicle driving control system development reliability of the system as a whole is essential, especially for extreme weather and road conditions. To increase the reliability of the obstacles detection system we equip autonomous vehicles not only with LiDARs, but also with long- and short-range radars. And we suggest that Continental ARS441 and SRR510 operating at a frequency of 77 Hz are the best fit. ARS 441 operates at up to 174 meters range with a horizontal FOV of ± 10°. As for SRR510, it operates at up to 70 meter range with a horizontal FOV of ± 75°. Both of them are connected to the onboard computer through Ethernet. The system combining data from several radars allows a more detailed evaluation of the traffic situation in front of the vehicle and long-range measurements of the distance to any obstacles. Radars are less affected by weather conditions, color of the objects and light. Radars boast a high range and speed resolutions, immediate data processing ability, which is particularly important at higher speeds. It should be pointed out, that different types of radars based systems are already widely used by some of the large motor manufacturers to develop their ADAS.

It is mandatory to obey the traffic regulations while operating a self-driving car on public roads. We use a vision system and a Basler [20] camera as the main working unit to detect any road users, such as vehicles, pedestrians, traffic signs and road surface marking, etc. Our autonomous vehicle driving control system includes three cameras fully covering the forward view.

In order to increase security and efficiency of the system we use a Titan 632 [21] thermal imaging camera for obstacles detection. The camera is characterized by horizontal and vertical FOV of 90° and 65° respectively, and ambient operating temperatures ranging from -60°C to 50°C. The thermal image processed by the onboard computer allows a better driveway borders detection, earlier evaluation of the upcoming corners and curves on the route. It is important that the thermal imaging camera unlike video cameras operates smoothly even when exposed to lighting of oncoming traffic, smoke, dust, fog or rain.

We developed a path planning software to set a path based on particular GPS coordinates and to process trajectory data into executive instructions. The software solves an optimization problem by assigning optimal executive instructions and minimizing any possible path and target speed errors.

The software involves the following modules: trajectory planning module, GPS data collecting module, data displaying module, path drawing module. The main working parts are OC-203-GSM GNSS receiver, AT330 GNSS antennas and Xsens [22] inertial unit. The path planner operates on separate integration of data obtained from GNSS receiver and IMU, meaning their performance is not dependent on each other. At regular intervals IMU is adjusted based on GNSS data. The navigation set provides highly-accurate GPS coordinates, an appropriate speed above the earth, altitude, and the quantity and quality of satellite signals. It connects to the onboard computer through Ethernet interface. Built-in software processes the data, manages the database and connects measurement data to any sensors in the system using GPS coordinates to operate.

The suggested vehicle is a kinematic model using model predictive control (MPC) schemes. A high-level logic manages the driving control during the start, while overcoming any obstacles on the route and when the target point is reached. Every step of the algorithm (meaning every time GPS receiver provides new data) solves a problem to assign optimal executive instructions to follow the path from the current location to the next preset point. Thus the system helps predict the vehicle's trajectory given the current position, speed and set of executive instructions. Optimal control parameters help specify the executive instruction set.

3. Autonomous Vehicle Driving Control System Experimental Tests

Before we mounted the vision system, which is responsible for traffic object detection, on the electric bus we tested it under real-life traffic conditions.

The tests involved detection and identification of vehicles, pedestrians, traffic signs and traffic lights. The system's software complex includes newly developed OCVStudio software based on OpenCV [23] database. At the input the complex receives an image from the optical sensor, which is then roughly processed over neural network and followed by neural network data output.

We used a YOLO v2 network modification to develop and fit the neural networks. During the development we made sure to avoid overfitting of deep neural networks, added screening layers, deepened convolutional layers and stretched fully connected layers.

The user interface of the complex displays real-time vehicles, pedestrians, traffic signs and traffic lights data. Refer to figure 3 to see some snaps from showing the testing process.

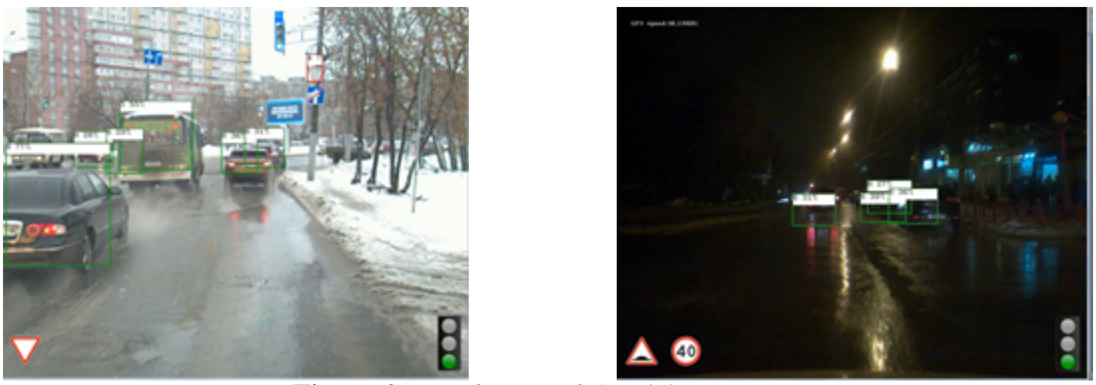


Figure 3. Test frames of the vision system

The benchmark of the proper system operation is accurate detection and identification of the traffic objects. The tests suggest that the system accuracy, showing how many of the detected traffic objects were identified correctly, goes up to 78%.

At the same time we also conducted experimental tests on detection and identification of any obstacles on the route of the vehicle as well as on localization ability and path planning, which took place on GAZ Group's specialized test site. Figure 4 shows some snaps of the tests.

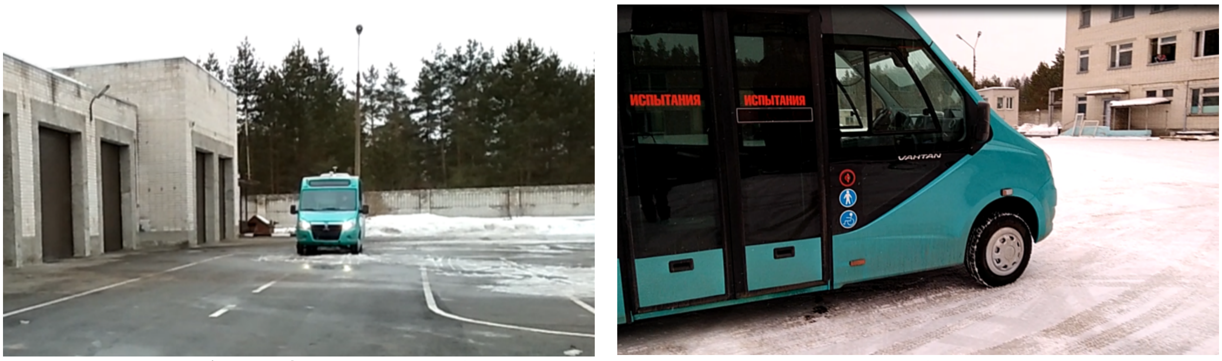


Figure 4. Experimental studies of the unmanned traffic control system

LiDAR tests help evaluate the ability of the system to detect obstacles and generate a point cloud for further localization these points. Figure 5 reveals some details of the tests.

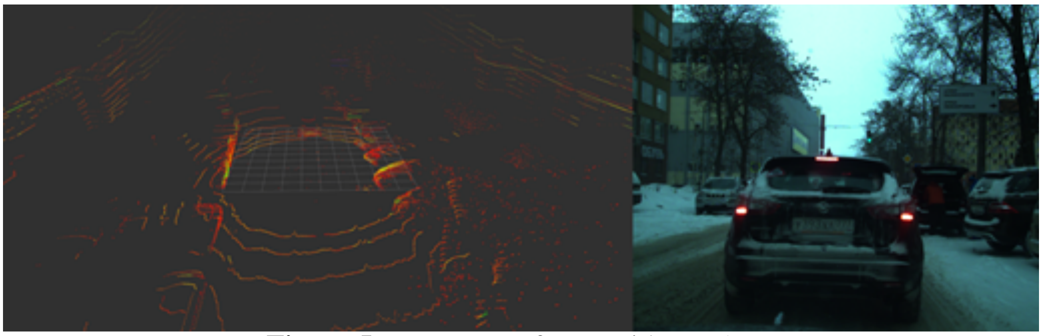


Figure 5. Fragments of tests with LIDARs

If an obstacle detected was higher than 15 cm or closer than 8 m, the vehicle was stopped. Driving was only possible with no detected obstacles in 9 m. Thus starts and stops upon an obstacle signal need a trigger to be completed, which helps avoid repeated signals if an obstacle on the border of detection zone.

The LiDAR tests reveal that obstacles are detected and identified both correctly and accurately. Besides, the tests justified the use of LiDARs to localize a vehicle. Our further step is to ensure LiDAR real-time map is compared to the preset map, which will allow localization of the autonomous vehicle in the relative coordinate system with LiDAR as a center.

The earlier mentioned GPS system data was the basis for path planning and trajectory control. A user draws a route over Tracker software interface. The vehicle follows the trajectory based on preset points and receives RTK corrections to the preplanned path from base b and executive instructions from MPC system through the GPS/GLONASS receiver. The vehicle took more than 50 rounds following the preplanned path, which simulated urban environment with buildings standing close to each other, metallic objects, farms and smokestacks. We evaluated the navigation system after every round by comparing data from GNSS receiver, IMU and preset trajectory, and by evaluating the signal quality. During the rounds we also evaluated the consistency and smoothness of the trajectory; the

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connection quality on the route; the connection between the executive functions control unit and the onboard computer; and the inertial unit performance. Figure 6 shows the details of the test.

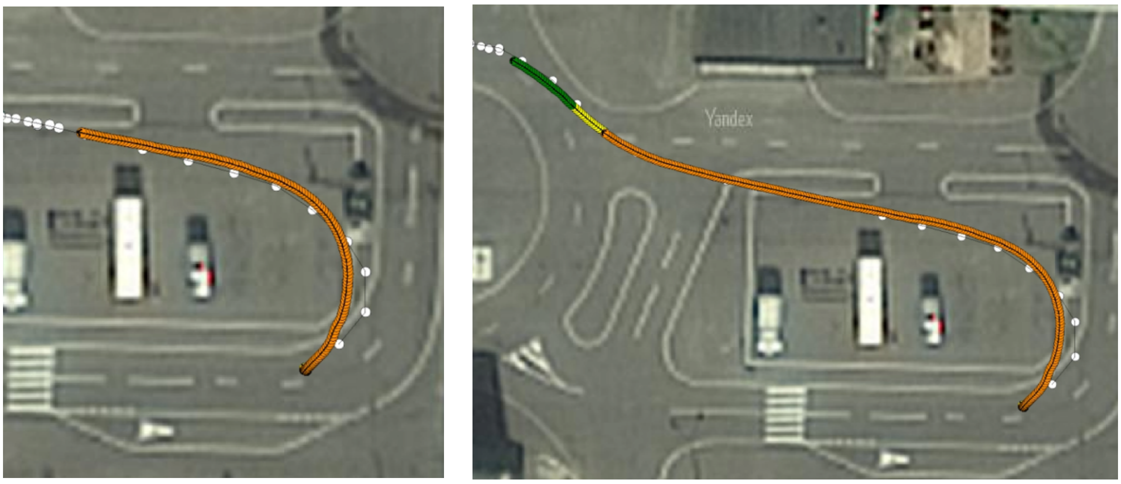

Figure 6. The user interface of the planning and traffic management program

Satellite tracking quality on the route complies with the standards, the exception being some metal trusses and smokestacks, which caused delay in trajectory update of up to 3 seconds. The signal quality was satisfactory, although at some points (especially at the start of the route) the connection could be unstable. We suggest using Wi-Fi to transfer updated data from the base to the vehicle with a backup communication channel. Optimal distance between the points along the route is about 2 meters.

It is important to note, that navigation trajectory is not an absolutely reliable source for vehicle positioning. The system performance is optimal in urban environment without tunnels or any other long-time disruptions of GNSS satellite connections. The tests reveal that INS trajectory deviation from GNSS trajectory never exceeded 3 meters, with deviation minimum being 1.334 meters, and deviation maximum being 2.647 meters. A big gap between the minimum and maximum values can be explained by a long-time GNSS connection disruption (more than 10 seconds) because of the metal trusses and smokestacks and low speed of the vehicle.

4. Conclusion

An autonomous vehicle driving control system was developed, and the working units for the system were designed. We drafted design documents for autonomous vehicle driving control system modules, for software and data communications networks, connecting all the subsystems into a single system on the onboard computer. We developed an electrical platform to mount the autonomous vehicle driving control system on. Experimental tests on different modules of the system were conducted, such as a vision system for traffic objects detection and identification, and an obstacle detection module. The tests revealed high performance of the tested modules.

We conducted experimental tests on path planning and satellite navigation trajectory tracking modules to evaluate the positioning ability of the system. The system performance is optimal in urban environment without tunnels or any other long-time disruptions of GNSS satellite connections. Our next step to increase the positioning accuracy is collaboration with diversification systems (vision system, laser scanning, etc.). A better quality of inertial unit output trajectory is needed as well. After all the necessary engineering follow-up more experimental test will take place to evaluate the corrections made.

This autonomous vehicle driving control system and the groundwork laid during the engineering development will give an impetus to self-driving public buses development. Autonomous public transport will cut transportation and time costs, increase economic efficiency and minimize road traffic accidents.

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