Implementation of modern approaches to development and testing of advanced driver assistance systems, including driverless systems

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Abstract. The paper describes FSUE "NAMI" competences in the field of on-board Advanced Driver Assistance Systems (ADAS) and driverless systems for automated vehicle driving. In recent years, FSUE "NAMI" has developed a number of prototype advanced driver assistance systems and vehicle driving automation systems. In order to comprehensively address the control automation tasks, the first SHATL prototype was developed, which was a demonstrator of capabilities of the fully digital control over the vehicle. SUE "NAMI" specialists conduct developments in three primary focus areas of computer vision systems evolution: visual recognition, radar technologies and lidar technologies. In modern technical systems, they are used cumulatively in order to increase the reliability and level of sophistication of computer vision systems, including the redundancy (reservation) principle.

1. Introduction

One of the most intense and dynamic trends in the automotive industry over the last 10 years is vehicle driving automation.

FSUE "NAMI" performs full-cycle developments, from scientific research and development of regulatory basis to technical examination, in the fields of transport engineering, which, of course, includes development of the vehicle model range within the UMP Project (Unified Modular Platform), driverless transport (SHATL, Driverless Vehicle, KAMAZ, ITS projects), advanced driver assistance systems (ADAS), and active safety systems. Also, there is evolving cooperation between FSUE "NAMI" and leading foreign engineering and production centers.

FSUE "NAMI" is challenged with a set of tasks related to implementation of advanced driver assistance systems (ADAS) and vehicle driving automation systems (DAS), as well as V2X systems based on modern approaches to development and testing of vehicle electronic systems.

2. FSUE "NAMI" driverless-vehicle-related competences

In recent years, FSUE "NAMI" has developed a number of prototype advanced driver assistance systems and vehicle driving automation systems.

First, the research works were performed based on passenger cars; then, the accumulated experience was transposed to trucks. In order to comprehensively address the control automation tasks, the first SHATL
prototype was developed, which was a demonstrator of capabilities of the fully digital control over the vehicle (see Figure 1).

The experience of the advanced driver assistance systems development was implemented in 2017 in a series sample of the passenger minibus.

One of the FSUE "NAMI" recent projects is the SHATL 2.0 development. It is a fully electronically controlled vehicle reworked in all aspects. The changes affected not only the styling design and structures, but also the computer vision systems, autonomous control algorithms and programs, and telematic systems. The developed variant of the platform is capable of level 4-5 autonomous driving.

The experience in creation of fully digital controlled vehicles was also applied in joint development of a cabinless truck electric digital platform.

![Figure 1. Some developments of highly automated vehicle control systems](image)

Since 2019, the research works in the area of autonomous driving were also focused on the control of group vehicle driving including the platoon driving.

Particular attention was paid to modernization of telematic systems and services, the importance of which is increasing every year.

At the same time, the advanced driver assistance systems (ADAS) of level 2 have reached series implementation in the AURUS vehicles.

Technological development of autonomous driving and computer vision took place in the following areas:
- new types of platforms with digital control;
- improvement of autonomous control algorithms;
- modernization of computer vision systems;
- advanced telematic services;
- implementation of systems in vehicles.

At the moment, FSUE "NAMI" specialists are working on industrialization and support for the products related to the advanced driver assistance systems (ADAS) in the vehicles of the AURUS family. Telematic systems for vehicles are also ready to be launched into production; they include functions of collecting information in the vehicle, special mobile applications and server software. Taking into account the experience of development of two versions of digital chassis for the SHATL-type vehicles, there are competences in development and manufacture of prototype samples. Also, for advanced driver assistance
systems, computer vision components are being developed to the level of production launch (together with partners).

Research and development works are carried out in all areas of work at FSUE "NAMI" in order to increase the technical level of the systems, develop and master new technologies.

3. Areas of interaction related to regulating documents and standards

For each area of activity, FSUE "NAMI" specialists develop a regulatory framework. This activity includes working with various regulations and resolutions on the ministerial level, working with international organizations on regulation development, working with technical committees in various areas, collaboration with the specialized organizations.

At the moment, intensive work is being performed in the field of regulatory document development for highly automated vehicles in the following areas:
- intelligent transport systems;
- ADAS;
- international regulations;
- artificial intelligence;
- computer vision systems;
- cyber security;
- automated control in transport;
- electronics;
- control systems designs.

4. Telematic systems

The success of development of intelligent transport systems, driverless and highly automated vehicles relies on the V2X technologies of vehicle interaction with other vehicles, infrastructure or other objects.

FSUE "NAMI" develops modern telematic systems, which include devices for vehicles and infrastructure, information display and exchange system, specialized applications, also for telematic servers (see Figure 2).

![Telematic systems for vehicles](image)

The following key areas for development in the field of V2X shall be particularly highlighted:
- creation of the proving ground for testing the vehicles equipped with V2X;
- standardization and certification of V2X systems.

5. Development technologies for computer vision systems

FSUE "NAMI" specialists conduct developments in three primary focus areas of computer vision systems evolution: visual recognition, radar technologies and lidar technologies. In modern technical systems, they are used cumulatively in order to increase the reliability and level of sophistication of computer vision systems, including the redundancy (reservation) principle.

The computer vision systems being developed (Figure 3) allow identifying static and dynamic objects of the road scene, specifically, people, vehicles, traffic lights and their current signals, road marking and roadway. They also allow tracking the identified objects (tracking their path of motion).
Radars for the automotive industry is a rapidly developing area. More and more vehicles are being equipped with assistance systems based on the use of radars.

Main parameters and functions:
- frequencies of 77 GHz or 24 GHz;
- range up to 250 m;
- recognition of static and moving objects.

FSUE "NAMI" has used the Continental ARS 4xx and SRR 2xx radars in its activities, and can also work with radars of other manufacturers.

The lidars, as well as the radars, are a dynamically developing area. Many modern problems of automation of control, cartography and navigation, obstacle detection are solved by means of lidars.

FSUE "NAMI" specialists carried out a set of works to form a data processing system, algorithms for implementation of functions required for the driverless control:
- creation of 3D maps;
- creation of vector maps;
- vehicle localization in space (SLAM / simultaneous localization and mapping) with positioning precision of up to 10 cm;
- detection and tracking of objects – up to 50 m.

6. Development of automated driving systems

Modern trends in development and testing of vehicle electronic systems comprise fully automated driving systems. Today, autonomous vehicles in Russia are already operated in closed territories and on the streets of some cities.

FSUE "NAMI" is developing and implementing automatic control systems taking into account vehicle lateral and longitudinal dynamics through application of mathematical models of vehicle motion, digital 3D road maps, and virtual motion simulation system.

There are algorithms and software being developed for the vehicle to drive along the route in the taxi or bus modes, to stop and go around obstacles, and to change lanes. All of this is done in full compliance with the traffic regulations.

At the same time, vehicle chassis control is ensured through digital interfaces (CAN, Ethernet). 

Figure 3. Examples of computer vision system operation
7. **Chassis robotization – digital motion control**

FSUE "NAMI" specialists apply modern approaches to implementation of comprehensive vehicle chassis systems control through digital interfaces (CAN, Ethernet):

- steering (lateral dynamics),
- acceleration, deceleration (longitudinal dynamics),
- control over transmission, hand brake, lighting equipment, sound signals, etc.

At the same time, special attention is paid to the possibility of takeover by the driver through direct (without additional buttons) input to the steering wheel, gas pedal, and brake pedal. The system automatically disables automated driving in a split second and gives control to the driver following the strictly incorporated input priority logic ensuring driving safety.

- Robotization of any type of vehicles (passenger cars, trucks, specialized vehicles)
- Additionally: development of a detailed mathematical model of vehicles.

8. **Evolution of vehicle dynamics control functions – digital motion control**

Based on the conducted works, FSUE "NAMI" specialists have presented a version of evolution of vehicle dynamics control systems, which shall be the next step forward for active safety systems:

1. Implementation of basic functionality for vehicle longitudinal dynamics control, including ICE torque control and pressure control in actuating brake mechanisms (VLC – vehicle longitudinal control).
2. Implementation of basic functionality for vehicle lateral dynamics control. At this level, vehicle lateral dynamics control shall be performed through steering equipment actuation (SDAS – steering driving assistant system).
3. Implementation of functionality for centralized lateral and longitudinal dynamics control. At this stage, centralized vehicle longitudinal and lateral dynamics control is ensured, which is the key for the vehicle dynamics control, while earlier (basic) functions provide the required background control (VGC – Vehicle Guidance Coordinator).
4. Implementation of basic functions for vehicle transient processes compensation. The distinctive feature of this level is resultant control recalculation and target parameters adjustment from the automated driving system (ADS) considering the control target (VTB – Vehicle Target Behavior).
5. The final functionality is forming such an interface of interaction between the ADS and the SRC (special robotized chassis) that will ensure complete safety of the vehicle and comply with the fifth principle of gradation (evolutionary development). Such interface shall possess the capability to make decisions independently and bring the vehicle into a safe state in case of evaluation of a threat, which can be caused by ADS operation (iVDC – intelligent Vehicle Dynamic Control).

9. **Modern methods for development and testing**

The modern methods of electronic systems development significantly rely on testing methods, which allow speeding up the process of the development itself as well as the tuning, calibration and testing processes.

The development and testing are performed according to the so-called V-shaped scheme.

- The upper level is the general/vehicle level.
- The middle level is the systems level.
- The lower level is the software level.

The following testing types are applied by FSUE "NAMI" within the research and development process:

- VIL (vehicle in the loop) – in-vehicle testing;
- HIL (hardware in the loop) – seminatural testing of units/systems;
- SIL (software in the loop) – software testing.

With such approach, international requirements for the process of system development are fulfilled, system quality and reliability are improved, and time required for the works is reduced.
10. Advanced driver assistance system test bench (ADAS HiL)

The HIL simulation complex for ADAS testing is designed for functional testing of modern advanced driver assistance systems consisting of an electronic control unit, vehicle radar of the 76-77 GHz frequency range and vehicle camera (Fig. 4).

The complex allows checking and testing the whole ADAS system as well as each of its components individually by means of environment simulation and input of simulated signals to the devices under test. This complex enables preliminary validation of the ADAS systems before the road tests. It allows simulating road situations which are not safe to be tested on the road.

The complex consists of three systems:

1) target simulation system for vehicle radars of 76-77 GHz frequency range;
2) system for projecting video to vehicle camera lens;
3) HIL simulation system for system electronic control unit.

Figure 4. Hardware-in-the-loop simulation complex

The HiL test benches are integrated into the process of electronic system development and testing. They allow accelerating the processes of development of control system algorithms, enable carrying out primary adjustments and calibrations of parameters and applying the automated testing processes and automated report generation. At the same time, a lot of firmware is available to the developers for adjustment and conducting of experiments, as well as convenient integration of new units, systems and cables.

The Labrig bench (Fig. 5, on the left) represents a structure with all the electric and electronic components installed – complete simulation of a real vehicle. The main purpose of the bench is functional software testing according to the test scenarios. Both single component tests and integration testing of various systems, communication tests, and system diagnostic function tests are performed on the bench.

The LABCAR simulation and physical modelling bench produced by ETAS (Fig. 5, on the right) was created for development and testing of software and electronic control units for the control systems. In particular, these are control units of the hybrid power train, transmission, etc.

The bench consists of a physical model made in the form of a rack with a set of units and modules simulating operation of sensors and actuators as well as a simulation model run on the real-time computer and used to control the bench physical model.
The modern methods for development and testing include one more aspect – testing on a Vehicle-in-the-Loop bench.

The main idea is to create a virtual environment for the computer vision systems of a real vehicle moving on an empty road, where the required driving conditions will be simulated. For example, urban area and moving vehicles.

The simulation bench equipment itself is located on the vehicle. One of the significant advantages of this testing type is using real control signals and real vehicle dynamics.

- Possibility of testing ADAS functions of all levels
- Possibility of creating different scenarios without the need to physically modify the proving ground
- Possibility of simulation of various weather and other conditions

This focus area is currently at the stage of development.

11. Proving ground equipped with intelligent transport systems (ITS) for highly automated vehicles testing

In order to carry out works on testing and calibration of vehicles with ADAS and automated driving functions, special test areas have been organized on two sites — FSUE "NAMI" (Moscow) and NAMI Proving Ground (Dmitrov).

The test area for driverless vehicles at NAMI Proving Ground is equipped with a V2X service platform, traffic light object control system, and also features marking, signs, traffic lights, pedestrian crossings, railway crossing, tunnel/overhead road, building model, roadway gates, etc. The test area elements are managed from the control center.

The variety of the test area facilities allows imitating the maximum number of scenarios, while the artificial lighting ensures round-the-clock testing. Mobile infrastructure elements allow changing the test area
configuration. There is a photo- and videorecording system with a possibility to store data. Proximity to the repair, laboratory and presentation facilities is also important.

The possibility of additional use of different types of closed roads with the total length of 115 km is also worth a separate mention.

12. Conclusion
For over 100 years, FSUE “NAMI” has been developing the most advanced units, mechanisms and systems for automotive vehicles, as well as regulatory documentation facilitating their implementation. The current stage of vehicle evolution is characterized by the most intensive development of electronic systems, for the creation, testing and improvement of which the institute has all the required potential, including the scientific, laboratory and testing capacities, as well as professional staff.

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