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The Analysis of Technical Vision Problems Typical For Driverless Vehicles.

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ABSTRACT

This paper presents formulation and analysis of tasks included in the common task to avoid collisions of driverless cars, which can be solved by using technical vision systems. The research was based on review of capabilities proposed by foreign automakers in the field of technical vision. The innovative alternative way to solve some of these tasks, traditionally assigned to technical vision systems, was also offered.

Keywords: active safety, driverless vehicle, recognition of the road scenes, technical vision.

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INTRODUCTION

The creation of a driverless vehicle is the scientific and technical goal which attracts vast attention of modern society. Leading foreign companies and domestic automakers are focusing considerable financial and intellectual resources on solving this problem.

Self-driving cars have some considerable benefits. Firstly, they gain the opportunity to significantly reduce the cost of passengers and cargo transportation as there is no need to pay salary to drivers. Another advantage is the elimination of a huge portion of accidents caused by driver errors, speeding and drunk driving.

The developers give positive predictions inspired by reliable functioning of aircraft autopilots and unmanned flying machines, which successfully solve, at first glance, more complicated problem of automatic stabilization of flight parameters in three-dimensional space, including takeoff and landing. Indeed, controlling a vehicle takes place on a two-dimensional surface. It greatly simplifies the task of roll, pitch and yaw angle stabilization, as well as angular velocities stabilization during rotation around three orthogonal axes.

However, the motion on the two-dimensional surface possesses many other features: the uncertainty of the road surface condition, the motion parameters of the obstacles and etc. The whole number of such parameters in the case of dense city traffic can be up to 11 units. Possible technical faults and driver errors during maneuvering should be added to the list of considered factors.

The advertising videos and the ringing reports of scientific supervisors can make the impression that plenty of safe driverless vehicles for various purposes will appear on the roads in the nearest future. However, for practical implementation of these ambitious projects a preliminary solution of the collision prevention problem in the most general formulation is required (Kuipers *et al.*, 2006, Buznikov, 2007, Beeson *et al.,* 2007).

RESEARCH METHODS

The study used research methods of system analysis, including methods of decomposition and optimization of technical solutions. Furthermore, methods of path planning, motion of the vehicle in space (the environment), was used. The method of artificial intelligence, set theory and mathematical logic were applied.

Main part

<u>The problem of dynamic stabilization</u>

The typical collision prevention problem was transformed to the problem of dynamic stabilization of the n-dimensional state vector X with limited control actions U:

$$x_{i\text{гр}}^{H}(X,U,t) \le x_i(t) \le x_{i\text{гр}}^{B}(X,U,t), 1 \le i \ \le n$$

When $U \in U_{perm}, where$

$$U = (U_1, U_2, U_3, U_4, U_5)^T$$

U_{perm} - a permissible set of control actions;
U_1 – gearbox stage;
U_2 – control action on the throttle valve of the engine;
U_3 – control action on the brake system;
U_4 – control action on steering wheel;
U_5 – control action on the clutch.

The set of state vector X components includes the following:

V_m – longitudinal velocity of the mass center;
a_m , a_q – longitudinal and lateral acceleration of the mass center;
ΔL_{m1} , ΔL_{m2} – distances to the front and rear passing obstacles on the lane;
ΔL_T – distance to the front stationary obstacles on the lane;
ΔH_m – deviation from the center of lane;
L_m – mileage from the starting point;
ψ_c – rotation angle of steered wheels;
$\Delta\omega_m$ – additional component of angular velocity of the mass center rotation when wheels skid and drift;
ψ_s – additional toe-in angle of steered wheels;
$\Delta V_{si}, 1 \le i \le 4$ – the longitudinal velocity of wheels at sliding;
$P_i, 1 \le i \le 4$ – air pressure in tires;
$T_i, 1 \le i \le 4$ – temperature of tires overheating;
$T_{Bi}, 1 \le i \le 4$ – temperature of brakes overheating;
$\Delta x_i, 1 \le i \le 4$ – misalignment of wheels and hubs;
$\Delta R_{Ki}, 1 \le i \le 4$ – tire cord wears.

The vector components of the upper $x^U_{i\,lim}$ and bottom $x^L_{i\,lim}$ dynamic borders includes borders of state X variables, which can be identify from the conditions of the r groups prevention of the typical collisions:

$$\begin{cases} x^U_{i\,lim} = \min[x^U_{i\,\mathrm{lim}1}, \dots, x^U_{i\,\mathrm{lim}\,r}]\,; \\ x^L_{i\,lim} \;= \max[x^L_{i\,lim1}\,, \dots, x^L_{i\,\mathrm{lim}\,r}\,]\,. \end{cases}$$

Modern functional level of foreign automobile active safety systems demonstrates the incompleteness of the solution. The collision prevention problem is reduced to the dynamic stabilization problem of the state coordinates of a controlled object with limited control actions at conditions of not fully observed state vector and its dynamic boundaries.

The uncertainty of particular components of the state vector and dynamic boundaries do not currently permit creating a fully automatic control system for a driverless vehicle.

The presence of an adequate driver (operator) in the cabin is necessary for performing the building up of the unobservable components of the state vector and its dynamic boundaries based on personal experience, intuition, predictive ability and other qualities. It is the crucial factor for more or less successful solution of the collision prevention problem.

Usage of virtual sensors of information (Buznikov *et al.*, 2007, Yguel *et al.,* 2007, ISO 15765-4:2011 (E)), built on the basis of mathematical models and algorithms for solving ill-posed problems of indirect measurements, allows them to substitute physical sensors and improve quality of consumer properties of the control systems at the expense of minimum hardware configuration.

Intelligent active safety systems (Buznikov *et al.*, 2011, ISO 15031-5:2011 (E), Bakhmutov and Karpukhin, 2012), based on virtual sensors of information allow to increase the number of control functions without the use of additional technical means.

Problems of technical vision in controlled vehicle

Systems of technical vision, which used in automobile transport (Buznikov and Tambulatov, 2011, Prikhodko *et al.,* 2014), were designed for automatic monitoring of some state vector components and dynamic borders, replacing the operator in this problems.

The main tasks of driverless vehicles technical vision include the following items:

- Recognition of road signs and zones of their coverage;
- Recognition of road markings and the position of the objects on the lane;

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- Identification of the distances to obstacles on the lane in front and rear hemispheres;
- Recognition of road scenes in front hemisphere on the lane;

Fig. 1 and 2 show examples of the mutual location of the controlled vehicle and obstacles in front and rear hemispheres on the lane.

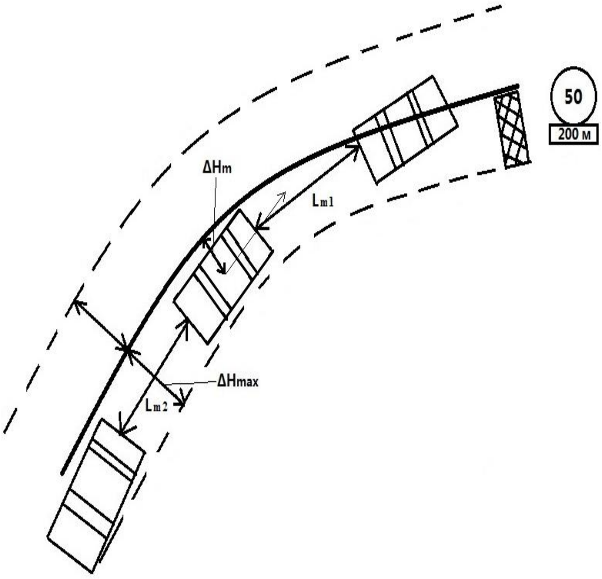

Figure 1: Relative position of passing and stationary obstacles in front and rear hemispheres on the lane (top view)

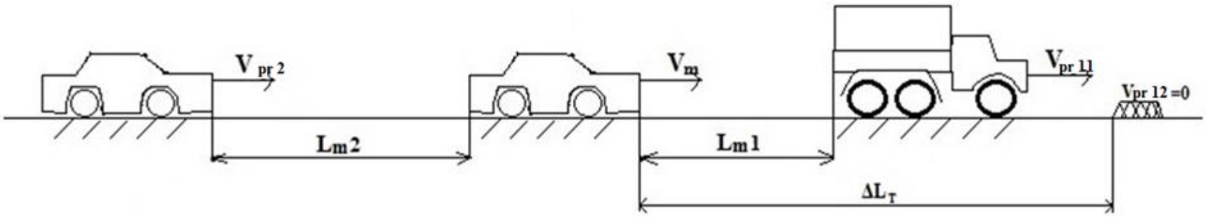

Figure 2: Relative position of passing and stationary obstacles in front and rear hemispheres on the lane (side view)

Road signs set determines components of the upper and the lower dynamic limits of the speed, limits of maneuvers, the priority of passage at intersections, etc. Road markings and position on the lane recognition allows defining both the coordinate of the object state in the form of deviation from the axis of the lane and the upper and lower bounds on the marking lines. Identification of the distances to the nearest obstacles in the front and back hemispheres on the lane allows defining one of the coordinates of the state and, considering the lower boundary of safe distance, to solve the problem of collision prevention with stationary, passing and oncoming obstacles.

Recognition of road scenes in front hemisphere on the lane should allow identifying distances to stationary obstacles, overlapped by the frontal traffic. Taking into consideration the lower limit of the safe stopping distance it becomes possible to solve the problem of collision prevention with stationary obstacle on the lane.

A number of insurmountable technical difficulties accompanies the solution of these problems with the help of modern technical vision systems: a reliable recognition of traffic signs and zones of their coverage considerably depends on the time of a day, presence of the precipitation, the spatial orientation of signs and speed of the vehicle.

The accuracy of road markings recognition and position on lane is restricted both by road surface condition and by the absence of a consistent marking.

In Russia the visual detection of road markings is only possible in summer. In winter the road surface, generally covered with snow, with a mixture of ice and dirt.

In spring and autumn dirt from adjacent unpaved roads and dust partly cover identifiable surface. Foreign systems of the vehicle position control (LDWS) react to a deviation ΔH_m from the center of the lane. However, for Russian roads the mentioned above method is inapplicable due to the presence of tracking ruts on road surface and frequent change of lane width.

The distances to obstacles on the lane are identified with technical vision systems using radar, lidar, laser rangefinders and video cameras characterized by a different detection range and depend on atmospheric conditions, presence of crosstalk, etc.

Processing of video images to identify obstacles, motion parameters and their prediction requires the processing of significant information flows and related computational resources, which indicates a lack of algorithmic solutions of this tasks compared with the visual perception of a human.

Remote recognition of the road surface state, including bumps covered with a layer of water, areas covered with ice and spilled liquids such as motor oil, protruding or recessed manholes sewage, etc., is not possible for modern vision systems. Without solving of these problems the safe usage of driverless vehicles on Russian public roads is impossible. The cost of complex technical vision devices is currently many times higher than the price of middle class car. This fact creates another obstacle for practical use of driverless vehicles.

Thus, in particular, usage of hardware and software for external video surveillance on a limited set of routes allows the building of a traffic control system by analogy with air traffic control in aviation. Engineer reconnaissance data of road surface condition, together with frequently updated data analysis of working scenes, should provide safe maneuvering with change lanes, setting speed limits and distances to unobserved due to the overlapping of objects on the lane, etc.

Recognition of all dangerous road scenes using autonomous technical vision systems, installed on the vehicle, is not possible because of the frontal traffic intervention to the fields of view.

It should be noted that stabilization of the distance to the nearest passing obstacles only creates the illusion of safety. When a vehicle from neighboring lane quickly changes the lane to the lane of driverless vehicle, there is no enough time to process this information and properly react to the situation. The same emergency may occur if self-driving car will cross intersection when the traffic lights is not fully visible, as well as in cases where the height of fixed obstacles, for example, a brick that fell from truck, may be less than clearance of the front vehicle, but more than clearance of controlled vehicle.

In addition, the emergency braking with maximum deceleration is executed regardless the distance to rear vehicle, which creates conditions for a collision with it and the subsequent “chain” collisions of several vehicles. The increase of the distance between vehicles, presumably equipped with AEBS, is inevitably accompanied by a decrease of throughput of highways. It is highly undesirable in heavy urban traffic conditions.

However, most of the discussed application tasks can be solved in other ways, free from mentioned drawbacks.

<u>An alternative way of solving the problems of technical vision</u>

The performed researches allow asserting that usage of high-precision navigation system allowing stabilizing position of the vehicle on a predetermined trajectory within the lane regardless the presence or absence of visible road markings.

The current solution implies the usage of odometrical navigation system in case of reduction in number of visible satellites when driving through tunnels, near tall buildings or groups of trees.

The data about velocity of mass center and the rotation angle of the steered wheels are formed according to the frequencies of wheels rotation and converted into changing the course and increment of the coordinate position (Mihailov, 2011, Saykin *et al.,* 2014, Ivanov *et al.,* 2014, Felix *et al.,* 2015). Fig. 3 shows tracks of the circular route on the NAMI territory obtained from the parallel functioning DGPS type NAVIS NV08C-CSM-BRD with programmable transformation of angular coordinates into the topological projection Gauss-Kruger and automobile system INCA.

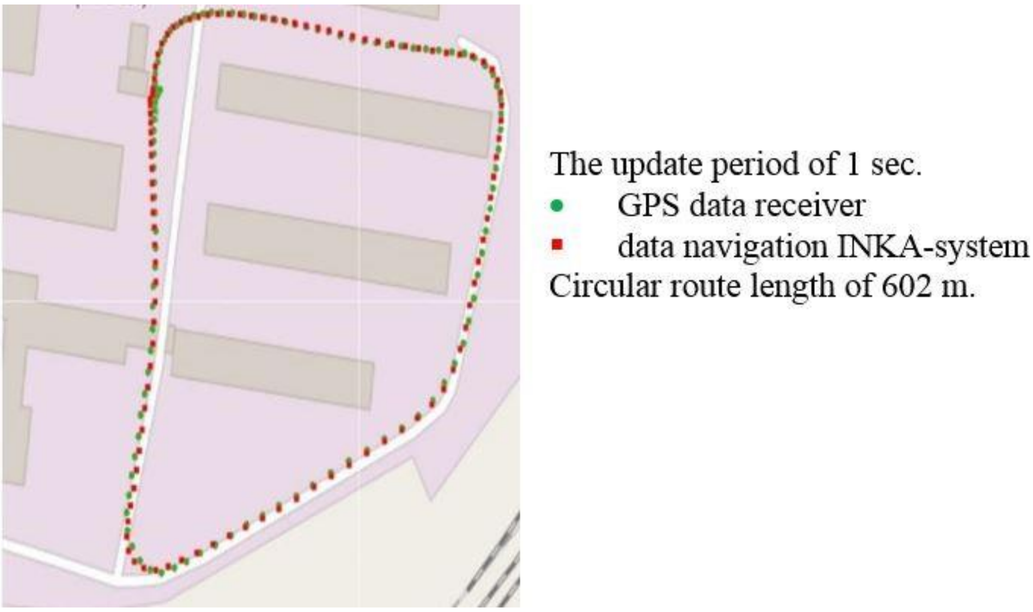

Figure 3: Tracks of the circular route on the NAMI territory

Laying of the route based on the conditions of the road surface by writing motion parameters during the test passing of the route by experienced driver.

The analysis of experimental results allows making a conclusion about high precision of DGPS navigation.

Recognition of stationary (permanent) road signs and zones of their coverage, marked on the electronic map along the route, is not difficult and reliable.

High-precision identification of the distances to large obstacles on the lane can be performed by laser rangefinders. The system for centralized monitoring of traffic on the territory allocated for driverless driving should be used for recognition of hazardous road scenes, quickly change of the routes and modes of motion.

CONCLUSIONS

The analysis of the applied problems inherent to the technical vision of driverless vehicles allows to formulate the following conclusions:

- Modern autonomous technical vision systems for driverless vehicles do not provide a satisfactory solution to major problems in real driving conditions;
- These problems are fully solved by using high-precision redundant navigation systems in combination with laser rangefinder and system for centralized monitoring and motion control in the restricted areas;
- Proposed technical solutions assume the creation of a specific infrastructure with a motorway traffic without traffic lights, people and animals on the roadway;
- Modern level of hardware and software exceeds the required for solving of the discussed problems level that allows realizing of driverless control at minimum cost and in the nearest future.

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