RESEARCH OF INTELLIGENT TRANSPORT SYSTEMS MANAGEMENT OF CONVOY OF UNMANNED VEHICLES WITH THE LEAD PILOT VEHICLE FOR WORK IN THE NORTH OF THE RUSSIAN FEDERATION IN THE ARCTIC AND ANTARCTIC

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Abstract: *In the Russian Federation the problem of creating a transport system to control movement of the column of unmanned vehicles to enhance the efficiency and safety of passenger transportation in remote regions of the North, the Arctic and Antarctic is solved for the first time. The study was first developed mathematical models and algorithms for control and interaction of intelligent transport systems of traffic control columns, control system movement of the lead pilot vehicle of a column of unmanned vehicles, the motion control system driven unmanned vehicle convoys of unmanned vehicles.*

KEYWORDS*: INTELLIGENT TRANSPORTATION SYSTEM, UNMANNED VEHICLE, MOTION CONTROL SYSTEM, VISION, NAVIGATION, COMMUNICATIONS, ACTUATORS, RADAR, CAMERA, ALGORITHMS, AND SOFTWARE.*

1. Introduction

During the development of electric vehicles and unmanned vehicles [1] in the Russian Federation, a number of works on the study of intelligent transport systems are carried out. One of the objects of the research is the intelligent traffic control system for unmanned vehicles with a leading pilot vehicle, improving the efficiency and safety of cargo and passenger traffic in remote regions of the North, the Arctic and Antarctica.

Leading international firms such as Daimler-benz, Volvo, IVECO, MAN, Scania etc. are actively working on the creation of autopilots for commercial vehicles in the convoy with a pilot car driven by drivers.

However, repetition of the foreign technical solutions providing satisfactory functioning of control systems of unmanned trucks as a part of columns in road climatic conditions of the Western Europe appears impossible for road climatic conditions of the Arctic zone of the Russian Federation.

It is generally accepted that the use of unmanned cargo vehicles in the convoy is the most effective, in which the following results are expected:

- improvement of road safety, as it minimizes the negative impact of the human factor, which according to statistics is the cause of almost 80 % of road accidents;
- achieving fuel savings of up to 20 % ;
- increase in transportation productivity by 1.3-1.4 times;
- providing comfortable working conditions for drivers in driven trucks;
- minimization of harmful effects on the environment;
- reducing the need to maintain a large staff of professional drivers with high wages;
-the possibility of integration of unmanned transport systems into the technological process of enterprises, primarily large transport and logistics centers, ports, etc., ensuring their continuous round-the-clock operation.

The problem of increasing the productivity of road transport is a priority. The prospects of logistics are based on the development of transport and infrastructure technologies. At present, domestic and foreign transport enterprises implementing a modern logistics technology, transportation and freight handling: the telecommunication system forwarding, terminal system for the carriage of goods, transportation of "door to door", etc.

According to well – known estimates, the cost of transportation of goods ranges from 20 to 70% of the total cost of logistics, while the price of goods transport component has a different share depending on the type of products: 2...3% – for electronics, 5...6% – for food, 7...12% – for machinery and equipment, 40...60%-for raw materials, 80...85% for mineral products. According to experts ' calculations, the introduction of information systems can increase the average speed of vehicles by 10 ... 30 km/h.

From the standpoint of the organization of freight transport in General, a promising step is to unite the idea of unmanned transport and cargo convoy. As a result, there are two types of transport systems and infrastructure for them:

- "road train" with a virtual trailer;
- convoy (with virtual connections);
- intelligent logistics center.

2.Prerequisites and means to solve the problem.

Road and climatic conditions of the Arctic zone of the Russian Federation are characterized by the following features:

- abnormally low temperatures (up to-60 º C), impeding the start of engines and limiting the normal operation of the technical means of autopilots;
- heavy traffic conditions on off-road terrain allowing operation of vehicle only in winter conditions;
- undirected terrain that makes it difficult to visually determine the location of the pilot vehicle on the route;
- snow drifts, which does not allow to recognize a road marking and impeding the functioning of the devices technical vision;
- constancy of reduced visibility in conditions of polar night;
- unpredictable influence of geomagnetic situation and state of the earth troposphere and ionosphere in polar latitudes on the conditions of uninterrupted reception of satellite navigation signals.

The technical solutions of control systems developed in this applied scientific research and experimental development should take into account the above peculiarities of the road and climatic conditions of the Arctic zone of the Russian Federation.

In the course of the work, the following goals were set:

- creation of an intelligent traffic management system column unmanned vehicles with a leading pilot vehicle, improving the efficiency and safety of cargo and passenger traffic in remote regions of the North of the country, the Arctic and Antarctica;
- obtaining significant scientific results, allowing to move to the creation of new types of cargo vehicles in unmanned design, providing a significant increase in freight traffic;
- market launch of new intellectual goods vehicles with a qualitatively new higher technical characteristics;
- ensuring better connectivity of the territory of the Russian Federation through the creation of intelligent transport and telecommunication systems, as well as holding leading positions in the creation of international transport and logistics systems, development and use in the North of the country and the Arctic and Antarctic.

For example, in the North of Russia, the Arctic and the Antarctic, the use of modern cruise control systems is impossible without improvement. Sensors serial systems do not work properly at low temperatures, which can lead to emergency situations.

In snowfall, a large amount of snow sticks to the front bumper of the car and partially closes the front radar view [2]. this, in turn, leads to inaccurate detection of the road situation and increases the risk of collision [3].

The climate of the North of Russia is characterized by strong winds that have a strong impact on the vehicle. This impact may result in unstable acceleration/deceleration of vehicles by the active cruise control system, which in turn can cause severe discomfort to the driver.

The software part of the existing cruise control systems takes into account the current value of the vehicle speed, the value of the speed of approach with the driving car and the relative distance. Based on these data, the algorithms calculate a target deceleration for the asphalt pavement of the roadway. The presence of snow and ice on the roads increases the braking distance, which in turn reduces the efficiency of the active cruise control system and can lead to a traffic accident [4]. In order to ensure an adequate level of safety, a number of calibrations are needed that will increase the distance between vehicles in pursuit mode. Also changes logic of operation: the system is the cruise control needs to begin braking at a larger distance to the leading vehicle, but with a lower maximum deceleration. This configuration will minimize the impact.

By analyzing the characteristics of the chassis design of an unmanned cargo vehicle, it is possible to draw the following conclusions.

The chassis of the unmanned cargo vehicle intended for operation as a part of a column in the conditions of the Far North, the Arctic and Antarctica shall possess high passability for what should be equipped with the drive of at least 4 wheels.

The chassis of an unmanned cargo vehicle can be equipped with a power plant of any type used in automotive technology, but it is preferable to use the electric drive of the driving wheels without speed transmissions. This conclusion is formulated on the basis of the analysis of world experience, according to which almost all modern unmanned vehicles (both freight and passenger) are equipped with electric drive.

Modern models of unmanned cargo vehicles are based on the technologies of leading manufacturers of cars and automotive components for electronic driver assistance systems (ADAS).

In the conditions of operation of a column of unmanned vehicles with a pilot driving vehicle in the conditions of the Far North, the Arctic and Antarctica there are additional restrictions associated with natural features characteristic of these areas.

One of them should include:

- lack of navigational guidance on a virtually homogeneous desert area;
- polar night periods of up to six months, making it difficult to visually detect obstacles on the lane;
- the lack of paved roads and with recognizable markings;
- increased frequency of failures in satellite navigation due to changes in geomagnetic conditions and other external factors (interference);
- abnormally low temperatures (up to minus 60 ° C and below) and winds with speeds up to 25 m / s and above;
- snow drifts that make it difficult for visual recognition of the lane itself;
- low grip of the tyres when driving on ice, snow and dirt ruts filled with water;
- the increased fuel consumption of vehicle caused by low speeds of the movement on the lowered transfers and practically the round-the-clock mode of operation of internal combustion engine in the conditions of abnormally low temperatures.

In view of the above, the navigation system, including satellite, inertial and wheeled navigation system, is required to provide high-precision positioning solutions in the conditions of loss of radio visibility of satellites, the drift of coordinates of the inertial system and wheel errors. Accuracy can be raised through the use of a weather forecast system, which will give an understanding of the roadway condition and traffic conditions [5].

3.Results and discussion

Mathematical models and control algorithms are the conceptual core of intelligent control systems, largely determines the technical characteristics and basic consumer properties of the final product. One of the obvious and main requirements for mathematical models and algorithms used is their adequacy in the entire operating range of parameter changes, along with the possibility of their use for indirect measurements and for the formation of control actions.

3.1 Description of mathematical models of longitudinal movement of the center of mass of the driven unmanned vehicles

For the development of control algorithms and interaction of intelligent transport control system column below is a description of the mathematical models of longitudinal motion of the center of mass of the guided unmanned . To determine the control actions on the engine, transmission and brake system adequate mathematical model of longitudinal motion of the center of mass of the vehicle.

As a vector of control actions is considered.

(1) $(U = (U_1, U_2, U_3)^T$, when

U_1 – gearbox transmission number $1 \leq U_1 \leq U_{1max}$; $U_1 = 0$ – corresponds to the neutral state of gearbox;

(2*)* $U_2 = 2sin^2(\frac{\varphi_{\text{др}}}{2})$ – the control action of the accelerator corresponding to the rotation angle of the throttle $\varphi_{\text{др}}$ engine;

(3) $U_3 = P_T P_{Tmax}^{-1}$ – control action on a braking system equal to the ratio of pressure P_T к its maximum allowable value P_{Tmax} .

The longitudinal motion of the center of mass of the car is described by a system of differential equations, in which the first equation of the system is a special case of the second Newton's law, and the second equation is the definition of speed as a derivative of the path [6]:

$$(4)\begin{cases}\dot{V}_m = a_m = a_{dT}(U) - k_x m_0^{-1} V_m^2 - k_{\text{тр}} g - \alpha_T g \\ \dot{L}_m = V_m\end{cases}$$

when

$a_m = \dot{V}_m$ – longitudinal acceleration of the centre of mass;

(5) $a_{dT} = a_d(U_1, U_2) - a_T(U_3)$ – traction and acceleration created by the engine to the transmission to the drive wheels (a_d) and brake deceleration (a_T), generated by the braking system;

(6) $k_x = 0{,}5 C_x S_x \rho$ – drag coefficient, aerodynamic drag;

C_x – specific coefficient of aerodynamic drag;

S_x – cross-sectional area (midsection) of the object;

m_0 – vehicle weight;

$k_{\text{тр}}$ – the coefficient of rolling friction of the tires;

α_T – pitch angle equal to the angle of slope of the road surface to the horizon;

g – acceleration of gravity.

Drag coefficient, aerodynamic drag k_x and rolling friction of tires $k_{\text{тр}}$ unknown in advance and determined experimentally.

3.2. Development of the algorithm of brake control

The problem of development of the brake control algorithm is solved for the adaptive cruise control system, advanced emergency braking system and auxiliary braking system.

The principal differences of the considered algorithm of automatic braking of the developed systems of power-driven vehicles from those used in existing foreign systems of active safety are:

- installed on modern vehicles, automatic emergency braking (AEBS) systems are used in braking ABS function, therefore, they have all the disadvantages of anti-lock systems, namely the cyclic principle of action, which does not allow for effective braking on slippery and uneven surfaces. The algorithm does not depend on ABS and works on the principle of limiting the braking deceleration, taking into account the slippery surface;
- preventing collisions with passing objects in the rear hemisphere is not part of the functions of the currently used systems. However, the danger of such collisions and the severity of their consequences is no less significant than in the front hemisphere.

To describe the algorithm of automatic braking should describe the conditions of collisions of objects when moving in the same lane.

Consider the differential equations of distances L_1 and L_2 between the driven car and the obstacles in the front and rear traffic lights on the same lane:

(7) $\begin{cases} \frac{dL_1}{dt} = V_{пр1}(t) - V_m(t); \\ \frac{dL_2}{dt} = V_m(t) - V_{пр2}(t), \text{when} \end{cases}$

$V_m(t)$ – speed of driven car,

$V_{пр1}(t)$ and $V_{пр2}(t)$ – speed front and rear obstacles.

Figure 1 shows the relative position of the front and rear obstacles on the lane..

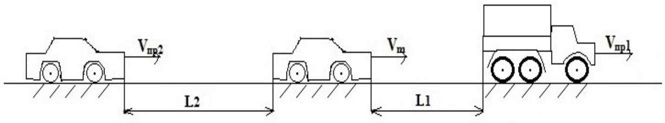

***Figure 1**-Relative positioning of the front and rear passing obstacles on the lane*

The solution of differential equations (8), presented on the time interval $(t \div t_S)$ to the complete stop of objects:

(8) $\begin{cases} L_1(t_S) = L_1(t) + \int_t^{t_S}[V_{пр1}(\tau) - V_m(\tau)]d\tau; \\ L_2(t_S) = L_2(t) + \int_t^{t_S}[V_m(\tau) - V_{пр2}(\tau)]d\tau. \end{cases}$

A natural condition for preventing collisions is the implementation of inequalities $L_1(t_S) > 0$ and $L_2(t_S) > 0$, which are converted to the following:

(9) $\begin{cases} L_1(t) > \int_t^{t_S}[V_m(\tau) - V_{пр1}(\tau)]d\tau; \\ L_2(t) > \int_t^{t_S}[V_{пр2}(\tau) - V_m(\tau)]d\tau \end{cases}$

The right-hand sides of the inequalities (9) represent the lower bounds of safe distances $\Delta L_{гр1}$ и $\Delta L_{гр2}$ to front and rear hurdles.

Given the time lag of actuation of the brake systems of the vehicle τ_m and rear obstacles $\tau_{пр2}$ the lower bounds of the safe range $\Delta L_{гр11}$ and $\Delta L_{гр21}$ at intervals, delays are:

(10) $\begin{cases} \Delta L_{гр11} = 0{,}5\hat{a}_{пр1}\tau_m^2 + (V_m - V_{пр1})\tau_m; \\ \Delta L_{гр21} = 0{,}5\hat{a}_{Tm}\tau_{пр2}^2 + (V_{пр2} - V_m)\tau_{пр}, \ when \end{cases}$

$\hat{a}_{пр1}$ – projected estimation of the deceleration of the front obstacle;

$\hat{a}_{Tm}$ – forecast estimate of deceleration of the driven vehicle.

The second pair of lower boundaries of safe distances $\Delta L_{гр1}$ and $\Delta L_{гр2}$ determined at the time interval until the complete stop:

(11) $\begin{cases} \Delta L_{гр12} = V_m\tau_m + 0{,}5V_m^2\hat{a}_{Tm}^{-1} - 0{,}5V_{пр1}^2\hat{a}_{пр1}^{-1}; \\ \Delta L_{гр22} = V_{пр2}\tau_{пр2} + 0{,}5V_{пр2}^2\hat{a}_{пр2}^{-1} - 0{,}5V_m^2\hat{a}_{Tm}^{-1}. \end{cases}$

The resulting bounds of the safe range $\Delta L_{гр1}$and $\Delta L_{гр2}$ defined as the maximum of a pair ($\Delta L_{гр11}$, $\Delta L_{гр12}$) and a pair of ($\Delta L_{гр21}$, $\Delta L_{гр22}$):

(12) $\begin{cases} \Delta L_{гр1} = \max[\Delta L_{гр11}, \Delta L_{гр12}] \\ \Delta L_{гр2} = \max[\Delta L_{гр21}, \Delta L_{гр22}] \end{cases}$.

In this case, the inequalities are fulfilled

(13) $\begin{cases} L_1(t) > \Delta L_{гр1}(t); \\ L_2(t) > \Delta L_{гр2}(t), \end{cases}$

means that the collision avoidance conditions are met both on the lag interval and on the interval to a full stop.

To prevent collisions with an oncoming obstacle $V_{пр1} < 0$ the value of the boundary distance is

(14) $\Delta L_{гр1} = V_m\tau_m + V_{пр1}\tau_{пр1} + 0{,}5V_m^2\hat{a}_{Tm}^{-1} + 0{,}5V_{пр1}^2\hat{a}_{пр1}^{-1}$

Analysis of the conditions for collision prevention, presented in the form of the problem of dynamic stabilization of distances, shows that the highest values of boundary distances is characteristic for the oncoming obstacles [7]. Uncertainty of estimates of delays in braking of the driven vehicle and obstacles, along with uncertainty of their decelerations in case of manual control creates difficulties of adequate forecasting of boundary distances.

The solution of the problem of dynamic stabilization of safe distances [8] or deceleration a_{Tm} the driven vehicle is determined from the boundary distance equations provided

(15) $L_1 = \Delta L_{гр1}$ и $L_2 = \Delta L_{гр2}$.

So, in particular, brake deceleration a_{Tm}, sufficient to prevent collision with a forward fixed, passing or oncoming obstacle is equal to:

(16) $a_{Tm} = \begin{cases} \bar{a}_{Tm}, \text{если } \Delta L_{m1}^* > 0 \text{ и } \bar{a}_{Tm} \le a_{Tmax}; \\ a_{Tmax}, \text{если } \Delta L_{m1}^* \ge 0 \text{ или } \bar{a}_{Tm} > a_{Tmax}, \text{when} \end{cases}$

(17) $\bar{a}_{Tm} = 0{,}5V_m^2(\Delta L_{m1}^*)^{-1}$;

(18) $\Delta L_{m1}^* = \begin{cases} [L_1 - V_m\tau_m + 0{,}5V_{пр1}^2\hat{a}_{пр1}^{-1}], \text{если } V_{пр1} \ge 0; \\ [L_1 - V_m\tau_m + V_{пр1}\tau_{пр1} - 0{,}5V_{пр1}^2\hat{a}_{пр1}^{-1}], \\ if\ V_{пр1} < 0; \end{cases}$

$\hat{a}_{пр1}$ – assessment of the developed brake deceleration of the front obstacle;

Braking deceleration a_{T1}, sufficient to prevent a collision with the rear of the associated constraint on the delay interval braking $\tau_{пр2}$ equally:

(19) $a_{T1} = \begin{cases} \bar{a}_{T1}, \text{если } \bar{a}_{T1} \le a_{Tmax}; \\ a_{Tmax}, \text{если } \bar{a}_{T1} > a_{Tmax}, \end{cases}$

when $\bar{a}_{T1} = 2[L_2\tau_{пр2}^{-2} + (V_m - V_{пр2})\tau_{пр2}^{-1}]$.

3.3. Development of algorithm of interaction of CU in the column

After switching to the operating mode, following in the column the leading vehicle, the leading vehicle, on which the Bluetooth access server devices are located, begins the exchange with the driven unmanned vehicles equipped with Bluetooth client modules [9].

Performing the functions of a server (hereinafter server) device with Bluetooth access, transmits to customers (driven by unmanned vehicle) information, on the basis of which the task of managing the course of driven unmanned vehicles is formed.

Messages are exchanged between the server and clients in accordance with the Protocol of exchange that guarantees the delivery of the message.

The exchange session always initializes the server, to verify communication, the server, with the operator specified frequency, sends a command to all clients to send telemetry, the clients, if they have a new regular or emergency telemetry, sends it to the server.

According to the results of telemetry processing, the control program of the column or the operator sends to the selected unmanned vehicle control command to perform certain actions specified in paragraph 3.1.

Driven unmanned vehicles transmit to the server telemetric information necessary for trouble-free movement as part of the column.

In the case of identifying obstacles on the lane column in front of one of the unmanned vehicles, the unmanned vehicle, in the presence of (according to the engineer reconnaissance), the second lane begins the maneuver detour obstacles, with a notification over the communication channel leading unmanned vehicle otherwise the unmanned vehicle is stopped and sends a notification about an emergency stop [10,11].

In the event that one of the unmanned vehicles makes an emergency stop associated with the diagnosed malfunctions, the emergency unmanned vehicle transmits to the driving car a message about the emergency stop.

3. Conclusion

The analysis of results of the carried-out researches in the field of perspective directions of development of systems of functioning of the unmanned vehicle allows to formulate the following conclusions: the principles of construction of multilevel information management systems of the unmanned vehicle and their hierarchy are defined; the review of technical characteristics of available devices and systems of technical vision is carried out; the comparative analysis of opportunities and technical characteristics of systems of navigation and orientation of the unmanned vehicle; modern intelligent communication systems of unmanned vehicles and their technical characteristics are considered..

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