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Dynamic Stabilization of Unmanned Vehicle Convoy in Road Climatic Environment of the Russian Federation

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Abstract: ***This work analyzes experimental results of traffic control of unmanned vehicle convoy (UMV) with manned master vehicle in Russian road climatic environment. The problem of obstacle avoidance in driving lanes and position stabilization on preset motion path is reduced to the problem of dynamic stabilization of state variables. Its solution is aided by virtual data sensors requiring for minimum configuration of engineering tools. Relative positions of vehicles are determined by algorithms of combined data processing of navigation systems and machine vision which make it possible to solve this problem without visible road markings and radio vision for satellite navigation. Experimental results show that the developed control algorithms of UMV convoy are capable to solve the problem of its dynamic stabilization in actual traffic environment. The developed control algorithms of traction, braking, and path provide efficient operation on all types of surfaces including slippery roads. Scientific novelty of this work is comprised of experimental verification of efficiency of the developed solutions for advanced unmanned vehicles in Russia.***

Keywords ***: vehicle, autonomous vehicle, unmanned vehicle, neuron networks, computer vision systems, traffic safety, traffic control system, convoy of unmanned vehicles, virtual sensor, dynamic stabilization, navigation, vision systems.***

I. INTRODUCTION

Increased interest of car manufacturers and possible consumers to achievements in the field of unmanned vehicles is mainly attributed to potentials of significant increase in economic efficiency of cargo-and-passenger traffic [1, 14] due to elimination of negative effect of human factor, decrease in accidents and increase in vehicle performances.

Leading foreign [2] and Russian [3] companies carry out wide scale experiments in field of intelligent control systems [4] and unmanned vehicles. Experience has shown that conversion to unmanned control is related not only with improvement of adaptive cruise control systems [5], machine vision [6] and navigation systems [7]. Key issues of control of unmanned vehicles (UMV) are stabilization on preset traffic path and obstacle avoidance.

A challenging approach to solution of this problem considered by foreign companies [8] is development of efficient systems of active safety aimed at avoidance of certain obstacles.

The issue of traffic safety becomes highly urgent upon operation of UMV on public highways.

Road and climatic environment in Russia together with extended distances between residential areas and limited hard surfaced roads is characterized by extended periods of negative temperatures (up to 8-10 months in a year); significant pollutions of road surface which prevent automatic recognition of road markings; slippery roads in winter, spring and autumn; number of traffic lanes limited to two which requires driving in the oncoming traffic lane in order to overtake vehicles moving in the same direction; significant roughness of road surfaces causing accidents.

In such environment foreign antilock braking systems and systems of path stabilization on their basis and automatic braking systems based on threshold braking are insufficiently efficient.

Operation of machine vision systems in order to control vehicle position on traffic lane is restricted by existence of recognizable road markings. Errors of detection of vehicle position on the basis of satellite navigation systems depend significantly on radio vision conditions and are unallowably high under restrained urban conditions, in tunnels, and in forest areas.

In order to solve the issue of accessibility of Russian territories by means of development of intelligent transport and logistic systems, their implementation and application in High North and Arctic regions [9], it became necessary to apply new engineering solutions free from the mentioned drawbacks.

This work discusses peculiarities of control of UMV convoy with master manned vehicles in Russian road and climatic environment.

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II. METHODS

A. General description

Analysis of structured set of collisions makes it possible to formulate conditions of their avoidance in the terms of the problem of dynamic stabilization of vector X of state coordinates of controlled objects. In particular, the problem of dynamic stabilization is reduced to compliance of inequality set in the following form:

$$X^{L}_{ilim}(U,X,t) \le x_i(t) \le X^{U}_{ilim}(U,X,t),\ 1 \le i \le n \text{ at } U \in U_{allowed} \quad (1)$$

where $x_i(t)$ is the i-th component of state vector X; $X^{L}_{ilim}(U,X,t)$ is the lower limit of allowed values x_i; $X^{U}_{ilim}(U,X,t)$ is the upper limit of allowed values x_i; $U=(U_1,U_2,U_3,U_4)^T$ is the vector of control actions on gearbox (U_1), engine traction (U_2), brakes (U_3), and steering (U_4).

The state coordinates of objects in addition to their traffic variables and critical for safety data on state of wheels, tires, brakes, transmission, etc., include also Cartesian coordinates of position of the center of mass

B. Algorithm

Solution of the problem of dynamic stabilization of vehicle state variables, which is the reduced variant of obstacle avoidance in the most complete algorithmically solved formulation, requires for use of numerous various sensors of primary information. Trivial solution of this problem is reduced to installation of numerous additional sensors, application of more complicated functional circuits, applied algorithms and control software, which is related with impairment of nearly all consumer performances including operation expenses and costs of overall system.

Nontrivial solution of the problem is possible by means of virtual data sensors based on mathematical models of object and algorithms of indirect measurements. In this case the number of required data sensors is reduced to minimum retaining observability of vector of object state and its dynamic boundaries. However, implementation of indirect measurements using mathematical models of object can be reduced to solution of ill-conditioned problems [10, 11].

The issue of development of efficient traffic control system requires to change the focus of development from the hardware field to the field of mathematical simulation and software. Modern systems acquire intelligent properties by means of virtual data sensors which allow to expand data functions on the basis of minimum hardware configuration. Virtual data sensors are comprised of algorithmic designs which replace physical sensors of object state variables. Development of such designs requires for creation of new mathematical models, procedures of solution of ill-conditioned problems and algorithms of data processing [12, 13].

The path of UMV convoy is preset by automatic path plotting of master manned vehicle. The path of master manned vehicle is generated by data of specialized wheel and stellite navigation system.

In order to compensate the influence of accumulated errors of imposition on paths of slave UMV, their paths are corrected by data from cameras installed in these objects.

Processing of images from cameras makes it possible to determine center of rear part of preceding vehicle, displacement of longitudinal axis of following UMV, and to estimate the distance between them.

Distances between the vehicles are determined by solutions of navigation problem for each vehicle in the convoy and corrected at straight segments by machine vision data.

When a slave vehicle loses a track of master vehicle, the path and traffic speed are controlled by data of autonomous navigation systems.

III. RESULTS

Experimental studies of traffic control system of UMV convoy with master manned vehicle were performed in winter season (December 2018) at Dmitrov test track, NAMI. Lada Vesta 1.8 with automated gearbox was used as unmanned vehicle (studded snow tires: Yokohama Ice Guard IG55 205/55 R16 94T) equipped with machine vision systems (radars and cameras), satellite and wheel navigation systems, as well as with control unit via traction, braking and steering channels. General view of UMV convoy with master manned vehicle is illustrated in Fig. 1.

Fig. 1: UMV convoy with master manned vehicle

Tests of traffic control system of UMV convoy with master manned vehicle were comprised of automatic braking in front of fixed obstacle, starting with automatic traction restriction and moving along the path predetermined by manned vehicle with stabilization of speed and distances between vehicles.

Tests of automatic braking in front of fixed obstacle (Fig. 2) were aided by controllable target: Euro NCAP Vehicle Target (EVT).

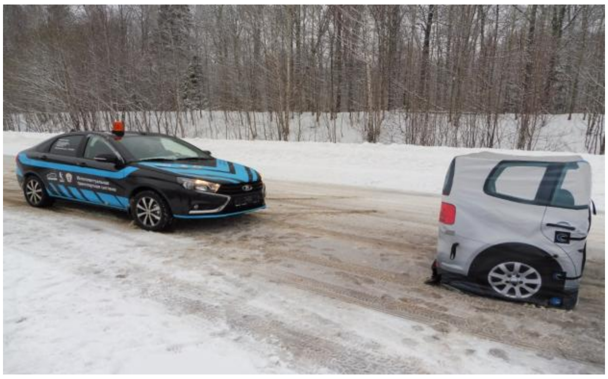

Fig. 2: Testing automatic braking by means of Euro NCAP Vehicle Target (EVT).

Automatic braking was performed at the speed of Vm=80 km/h (22.22 m/s) on road covered with snow and ice with variable coefficient of adhesion between wheels and surface. Time diagrams of traffic variables upon automatic braking are illustrated in Fig. 3.

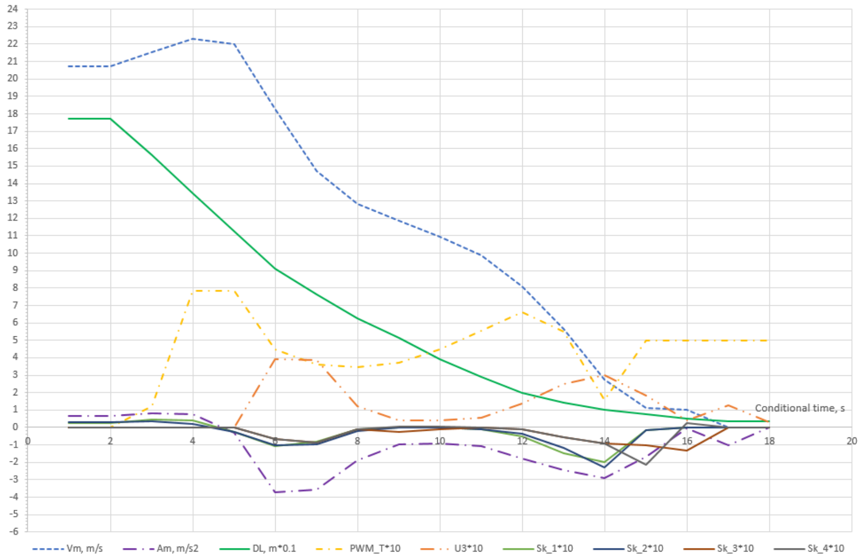

Fig. 3: Time diagrams of traffic variables of slave UMV during automatic braking: Vm, m/s – longitudinal speed of motion of center of mass of slave UMV; Am, m/s2 – longitudinal acceleration of center of mass of slave UMV; DL, m*0.1 – distance to obstacle, scaling coefficient 0.1; PWM_T*10 – control action on braking system, scaling coefficient 10; U3*10 – control action on braking system calculated by traffic control system of slave UMV, scaling coefficient 10; Sk_1*10 – slipping on the front left wheel in %, scaling coefficient 10; Sk_2*10 – slipping on the front right wheel in %, scaling coefficient 10; Sk_3*10 – slipping on the rear left wheel in %, scaling coefficient 10; Sk_4*10 – slipping on the rear right left wheel in %, scaling coefficient 10.

Thus, at the initial braking stage, the deceleration reaches 4 m/s^2 and slipping of front and rare wheels does not exceed 20%. Final distance to obstacle is about 3 m.

Tests of the developed traction control system were performed on road covered with snow and ice at the coefficient of adhesion equaling to 0.3. Figure 4 illustrates time diagrams of traffic variables of Lada Vesta 1.8 UMV in convoy with activated traction control system.

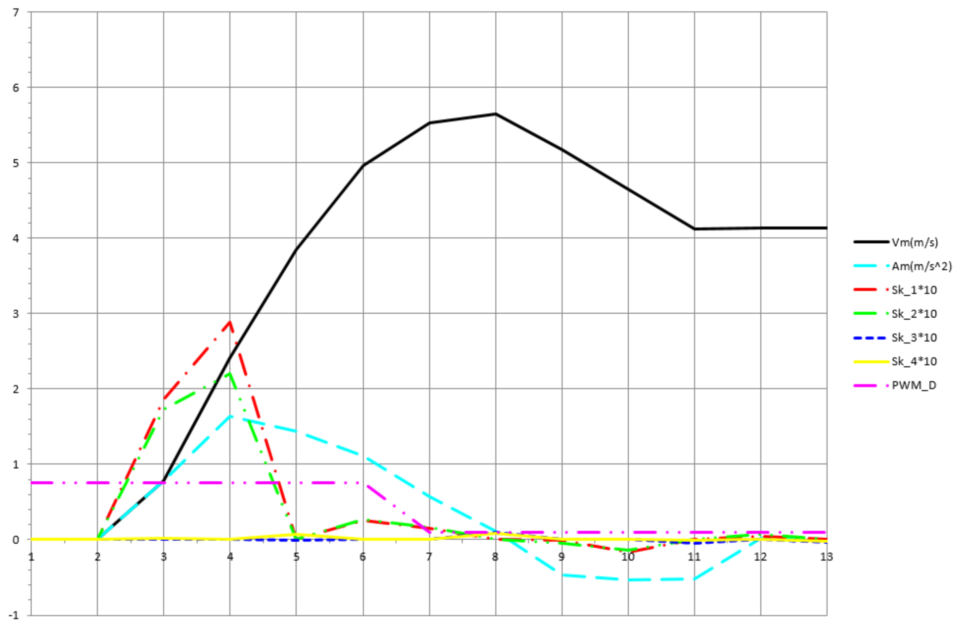

Fig. 4: Time diagrams of traffic variables with activated traction control system

The control action on accelerator PWM_D is restricted by limit traction acceleration, and slipping of drive wheels Sk_1 and Sk_2 is 28% and 22%, respectively. The longitudinal acceleration Am is 1.64 m/s^2, which corresponds to the limit of traction acceleration for this coefficient of adhesion.

Tests of stabilization of speeds and safe distances were performed for convoy of two UMV with master manned vehicle at Dmitrov dynamometric test track, NAMI. Figure 5 illustrates time diagrams of traffic variables of manned vehicle at the speed of Vm1, as well as two UMV at the speeds of Vm2 and Vm3.

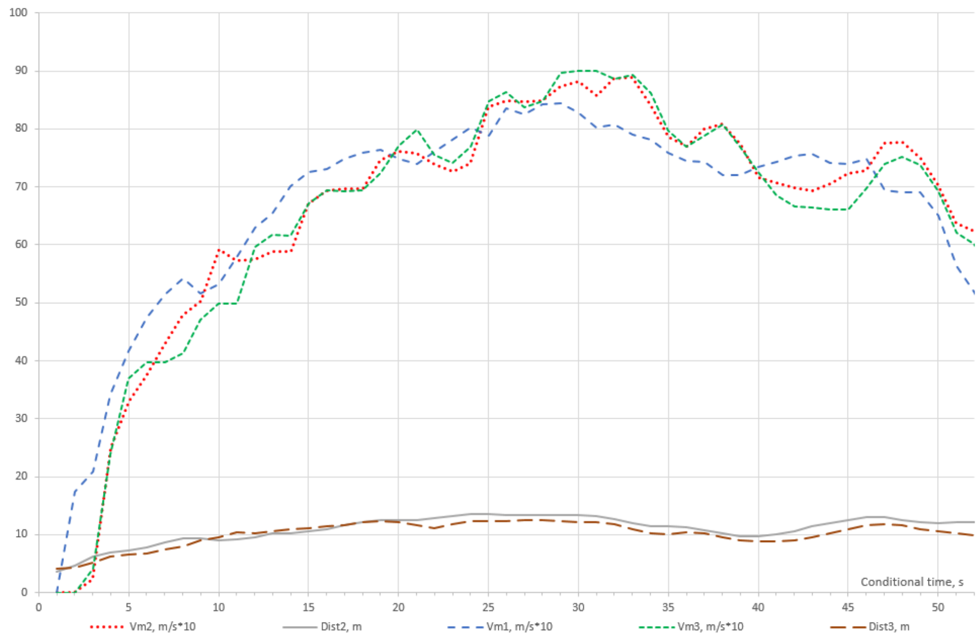

Fig. 5: Time diagrams of traffic variables of vehicle convoy

The distances between the manned vehicle and the first slave UMV (Dist2) and the first and the second slave UMV (Dist3) vary in the range of 10-12 m. The speeds of slave UMV repeat the speed of master manned vehicle varying from 0 to 9 m/s.

IV. DISCUSSION

Experimental results obtained during testing of traffic control system of UMV convoy with master manned vehicle in winter season at test track do not contradict with theoretical results and confirm possibility of implementation of the developed algorithms of control and data processing.

Efficiency of automatic braking without wheel locking is determined by implemented identification of maximum coefficients of rubbing friction of drive wheels under varying conditions.

Efficiency of implemented traction control system is also determined by identification of maximum coefficients of rubbing friction of drive wheels, which makes it possible to constrain automatically acceleration traction at ultimate levels corresponding to the highest longitudinal acceleration of the center of mass at allowable wheel slippage.

Stabilization of speeds and safe distances between convoy vehicles under adaptive cruise control complies with the requirements to traffic control system of UMV convoy with master manned vehicle.

V. CONCLUSION

The following conclusions have been obtained on the basis of the obtained results:

– the developed control algorithms of UMV convoy make it possible to solve the problem of dynamic stabilization of traffic variables upon actual operation;

– the use of virtual sensors of vehicle traffic variables significantly decreases the total number of physical data sensors, improves operation reliability, and reduces total cost of control system;

– using manned vehicle as master one simplifies plotting of preset motion path for slave UMV without visible road markings.

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