Autonomous tracked vehicles effectiveness estimation

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Abstract. Effectiveness of application of autonomous tracked vehicles depends on many factors. For the manned car, the driver decides how to choose the optimal speed. The speed of autonomous vehicles, especially over highly rough terrain, is significantly lower and is caused by the operation of an autonomous control system. In tracked chassis, one of the agility components is the turnability, which characterizes the control ability of the vehicle under the given conditions. Controllability and ride comfort define how the power-weight ratio influence the average vehicle speed. At the same time, the behavior of an autonomous vehicle during rotation depends not only on the power-weight ratio, but also on the dimensions of the tracks support surfaces; pressure on the ground; steering radius provided by steering drive; traction properties, as well as on road conditions (path curve, traction and steering resistance coefficients). The report presents the analysis of the dependence of tracks slipping on the speed of the tracked autonomous vehicle chassis. The parameters that determine the state of the chassis of an autonomous tracked vehicle are listed. The results of mathematical simulation of the tracked mobile robot movement for different types of soils and with different speeds are presented.

The mobility requirements of both manned and unmanned transport systems are significantly stiffened with the development of technologies. In general, the autonomous wheeled vehicles are mainly considered. However, lack of attention is paid to the effectiveness of autonomous tracked transport systems.

Traditionally, the speed of tracked vehicles increased due to the increase in power-weight ratio and the ride comfort and due to the steering drive improving [1,2]. At the same time, the degree of influence of power-weight ratio on the average speed depends on such properties of the chassis as controllability and ride comfort, and with the increase of power-weight ratio the influence of controllability on the tracked vehicles speed is increased too.

In the figure 1 the graphic representation of the main chassis parameters influence on the maximum tracked vehicle speed ($V_{max}$) and average tracked vehicle speed on dry ground roads ($\bar{V}$) is given.
Figure 1. Influence of limiting factors on the maximum $V_{\text{max}}$ and average velocity $V$ at various levels of power-weight ratio $N_{\text{max}}$: 1– factor of external conditions; 2 – controllability; 3 – ride comfort.

From the plots in the figure 1 follows: the dependence of the average speed on the power-weight ratio is essentially nonlinear in the 10-15 kW/t power-weight ratio range, and 20% power-weight ratio increase leads to an 15 % average speed increase. In tracked chassis, one of the agility components is the turnability, which characterizes the control ability of the vehicle under the given conditions. At the same time, the behavior of an vehicle during steering depends not only on the power-weight ratio, but also on the other technical parameters (dimensions of the tracks support surfaces; pressure on the ground; steering radius provided by steering drive; traction properties, tracks stability in the caterpillar contour and others) as well as on road conditions (path curve, traction and steering resistance coefficients).

In the 25-30 kW/t range, the same increase of $N_{\text{max}}$ by 20% corresponds to increase of speed $V$ by 6% only.

In addition, the speed of the tracked vehicle during the steering is influenced by factors such as the turning road radius and the steering drive radius mismatch, the requirement to define angle steering, the trajectory uncertainty with partial movement of the steering control, the ratio between the external dimensions of the tracked vehicle and the roadway width etc.

All this intensifies differences between the tracked vehicle speed technical capabilities and the degree of their operation implementation. In practice, the dynamics of tracked vehicle is realized through the driver’s skill [3, 4].

Modern design technologies of the engine, drivetrain and the chassis allow the movement of tracked robotic systems with speeds not lower than the existing tracked vehicles speeds on roads with a hard surface (60-70 km/h) and on rough terrain (25-35 km/h).

It should be emphasized that such speeds of movement are limited by the possibility of the control system and the potential growth of average and maximum speeds will be carried out as the development of robotics technologies and autonomy increasing.

During the unmanned driving, the most difficult for the control system of tracked vehicle is to provide a curvilinear motion with the drift and traction limit steering speeds [5, 6, 7]. The signs of the
sidewise drift appearance are not known by the control system, and it should reduce the movement speed in order to avoid loss of control or emergency situation.

The critical drift speed is determined experimentally [8] during the passage of the «snake»-type track shown in the figure 2.

![Figure 2. Experimental route.](image)

The dependence of the relative displacement of the instantaneous steering center of vehicle on the relative speed is shown in the figure 3:

![Figure 3. Plot of the dependence of the relative displacement of the vehicle’s instantaneous steering center on the relative speed [8].](image)

The main controllability evaluation criterion of robotic tracked vehicle is the average speed on the «snake»-type track. It characterizes the ability of vehicle to realize its potential under the controllability restrictions.

Auxiliary indicators are the critical drift speed and the acceleration characteristics.

The «snake»-type track with a variable curvature makes it possible to evaluate the controllability under the most critical driving regimes - during the change of vehicles movement direction to the opposite.
During the controlled movement, the center of mass of tracked vehicle will move tangentially to the trajectory of movement. The longitudinal axis of vehicle will rotate around the center of mass at an additional angle relative to the tangent to the trajectory of movement [5].

The longitudinal axis rotation of the robotic vehicle chassis relative to the tangent to the trajectory occurs due to the skidding and slipping of the tracks. The lagging caterpillar track switches from the skidding mode to the slipping at the approach to the critical controllability speed. The slipping speed of the outrun caterpillar is increased and during the drift both caterpillar tracks have comparable slipping index (figure 4).

![Figure 4](image-url)

**Figure 4.** The dependence of the slippage speed of tracks $V_s$ on the speed of the robotic tracked vehicle chassis $V_m$ for different $\rho$ values.

In this process there is a condition that there is the driving mode of the vehicle, when the slipping speeds of the caterpillar tracks will be the same $V_{S2} = V_{S1}$. In this case, the boundary conditions of the controlled movement of the robotic tracked vehicle chassis are characterized by the following expression $\omega_t = \omega$. That is the equality of the real angular speed of the robotic chassis (given the external conditions) to the angular velocity determined by the kinematics of its steering drive (as the speed of the chassis moves to the controllability critical speed) [8].

The steering is carried out from a certain angular velocity $\omega$, due to the characteristic of the steering drive and the movement mode of the tracked chassis, taking into account that the boundary condition of the controlled motion $\omega_t = \omega$ characterizes accurately the moment of the uncontrolled movement beginning.

On the dependencies $\omega_t / \omega = f(V / V_{kr})$ (figure 5) it can be seen that the established controlled movement boundary condition characterizes accurately the moment of the uncontrolled movement beginning. Here $V$ – is the current speed of the center of mass of the vehicle chassis, $V_{kr}$ – is the critical value of the chassis speed for this steering radius.
Figure 5. Dependence of the steering relative angular speeds on the relative speed of the chassis for different steering radii.

From the qualitative and quantitative analysis of the controlled curvilinear movement of the robotic chassis, shown in figure 5, it is obvious that during the steering automated control system creating, the relative angular velocity can be used to predict the uncontrolled movement.

The advantage of this parameter is that it does not require the complex design solutions. It will allow to create a reliable parameter measurement system, which characterizes the reliability of the entire automated movement control system of the robotic tracked vehicle chassis.

The parameters that determine the control status of the robotic chassis are the following:
- angular velocity of the chassis;
- rotation frequency of the chassis driving wheels.

The critical control algorithm of the tracked robotic chassis uncontrolled movement preventing (drift overcoming) can be represented as follows: when the robotic vehicle is moving, the angular velocities of the right and left boards are determined. The angular velocities enter the valuator unit for calculating the theoretical angular velocity of the chassis steering. Next, go to the divider unit. The actual angular velocity from the sensors is fed into the divider unit. Next - the comparison with the reference signal and the command to the actuator.

The structural diagram of the system is shown in the figure 6.
Figure 6. Scheme of the robotic tracked vehicle uncontrolled movement prevention system.

Simulation of the tracked vehicle movement along the arc of a circle was performed in the software packages «Universal Mechanism» and «Simulink MATLAB» (figure 12). The simulation was performed at different speeds with a steering radius of 25 meters. As a model of the soil, a linear elastic model was chosen. The simulation results are presented in the figures 7-9.

Figure 7. The tracked vehicle simulation model in the «Universal mechanism» software.
Figure 8. The steering of the tracked vehicle simulation results.
Figure 9. Relative angular velocity $\omega_t/\omega$ for different speeds.
Conclusion
The uncontrolled movement preventing algorithm for tracked robotic vehicles is presented. A mathematical simulation of the vehicle movement for various types of soils has been carried out. Analysis of the results showed that the value $\omega_t / \omega_0 = 1$ is a boundary condition for the signs of uncontrolled movement. It coincides with the theoretical calculations presented above.

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