The algorithm of diagnosing the development of a skid when driving a two-axle vehicle

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Abstract. Vehicle controllability and stability are the most important operational properties and components of active traffic safety, improving these qualities around the world are given great importance. One of the major challenges when designing algorithms for active safety vehicle systems is obtaining reliable information about the quantitative vehicle parameters values, allowing to judge how these parameters match the specified driver, to predict the emergency situations incident moment and diagnose these situations (e.g., front or rear axles kidding, the tipping risk, etc.). One of the most common parameters used in practice, characterizing the multiaxial wheeled vehicles motion conditions, is the vector deviation angle of the vehicle center of gravity (CoG) actual velocity from the vector of its theoretical (kinematic) speed. However, determining the actual velocity vector direction of the CoG is associated with great computational difficulties due to the need to build complex predictive Kalman filters. A method for determining the two-axle wheeled vehicles motion parameters to ensure the dynamic stabilization system operation, allowing reliable and economical diagnosis of skid front or rear axles of a two-axle vehicle.

1. Introduction

Vehicle controllability and stability are the most important operational properties and active traffic safety components, increasing these qualities around the world are given great importance [1]. As everyone knew, the main purpose of vehicle active safety systems is to prevent emergency situations.

The use of dynamic stabilization systems (DSS) allows in various critical situations to maintain control over the vehicle or, in other words, to maintain the vehicle stability and controllability.

One of the major problems in the development of work DSS is to obtain reliable information about the quantitative values of the of wheeled vehicle (WV) motion parameters, which allows to judge how these parameters match the specified driver, to predict the occurrence time of emergency situations and diagnose these situations (e.g., front or rear axles kidding, the tipping risk, etc.).

One of the most common parameters used in practice, characterizing the wheeled vehicles movement conditions, is the angle of deviation of the actual speed vector $V_F$ vehicle CoG from vector $V_T$ theoretical (kinematic) velocity $\Theta_T - \Theta_F$ (fig. 1) [2–10]. And angle value $\Theta_T$ simply determine from the kinematic ratios, knowing the geometric chassis parameters and the steered wheel rotation law, then to determine $\Theta_F$ it is necessary to determine the current vehicle speed.
Fig. 1. The deviation angle of the speed vector from the vehicle longitudinal axis: \( O \) – instant center of rotation; \( C \) – vehicle CoG.

The advantages of this method are the simplicity of diagnosing abnormal situations [11–16]. However, determining the actual velocity vector direction of the CoG is associated with great computational difficulties [17–20] due to the need to build complex observer models or predictive Kalman filters.

It is obvious that a computational procedure to determine the motion parameters WV and compute control actions should be economical, i.e. time spent in computation, and should be less throttle.

The main task of the information system DSS is the vehicle condition diagnosis, i.e. sensors need to determine which of the three possible States belongs to the current set of received data:

1. the situation is regular, no adjustments are required;
2. growth of the front axle skid process, adjustment required;
3. growth of the back axis skid process, adjustment is required.

The purpose of this work is to develop a method for determining the motion parameters of two-axle wheeled vehicles to ensure the dynamic stabilization system operation.

2. Problem statement

To achieve this goal it is necessary to solve the following tasks.

1. Propose a meter, i.e. parameter characterizing the vehicle property to maintain the course and trajectory stability.
2. To justify the choice of the stability preservation indicator, i.e. the number characterizing the measurer value, its quantitative value.
3. To develop a diagnostic feature, i.e. a rule that allows unambiguously for all of motion modes of a wheeled vehicle to uniquely determine to which of the three possible States mentioned above belongs the current set of data obtained.
4. Develop a cost-effective computational procedure that allows real-time rate to estimate the vehicle state and decide on the need to introduce corrective actions.
5. Determine the necessary set of parameters required for the diagnostic system and to be measured during the vehicle movement.
6. To conduct a study of the proposed algorithm performance by simulation methods.

3. Choice justification of the measurer and the indicator of course and two-axle vehicle trajectory stability

Consider the growth process of a wheeled vehicle. If the vehicle is moving at a speed of \( V_a \), growth skid front (fig. 2a) or rear (fig. 2b) axis at a speed of \( V_z \), that is as a result of geometric speeds addition \( V_a \) and \( V_z \), this axis moves in the resulting velocity direction \( V_R \). Because the second axis is still moving at a speed of \( V_a \), this causes the car to turn around the center \( O \) and the appearance of centrifugal force \( P_c \) and inertial moment \( M \). Thus, it can be argued that when driving without skidding linear velocity vehicle axes centers will be approximately the same in absolute value. In case of skidding, the modulus of the axis center linear velocity vector that enters the skidding will always be greater than the same index for the axis that is not skidding. This reasoning can be extended to any two points, for example, the of the front and right axis wheels centers.

To determine the ratio between linear speeds, consider the «ideal» rotation scheme of the two-axle vehicle (Fig. 3) relative to the instantaneous center \( O \). Take the pole as the vehicle CoG (point \( C \)). Then
the vector of linear velocity of the front axis center (point A) \( V_A \) will be equal to the sum of vectors:
portable (linear velocity of point) \( V_C \) and the relative velocity of point A relative to pole \( CV_{AC} \) (fig. 4a).

Fig. 2. Skid of front (a) and rear (b) axles of the vehicle: 
C – vehicle CoG; O – instant center of rotation; A, B – the middle of the respectively front and rear axis WV; \( V_a \) – the movement WV velocity vector; \( V_s \) – skid velocity vector; \( V_R \) – resultant velocity vector; \( P_C \) – centrifugal force vector; \( M \) – inertial moment; \( P_y \) – projection of centrifugal force on y axis

Fig. 3. Scheme of two-axle vehicle rotation: w1…w4 – numbers of wheels; C – vehicle CoG; O – instant center of rotation; A, B – the middle of the respectively front and rear axis WV; \( V_A \), \( V_B \), \( V_C \) – velocity vectors of A, B, C points; \( \omega_C \) – vehicle yaw rate; \( \Theta_1, \Theta_2 \) – steering wheel angles of the vehicle front axle
If we consider the "perfect" turn, when the vehicle wheels move without withdrawal and without sliding, you can write

\[ V_A = V_C + V_{AC} \]  \hspace{1cm} (1)

where \( \omega_A = \frac{(\omega_1 + \omega_2)}{2} \) – average angular speed of front axle wheels; \( r_1 \) – dynamic wheel radius.

Dependencies similar to (1) and (2) can be written for the center of the rear axis – point B (Fig. 4b)

\[ V_B = V_C + V_{BC} \]  \hspace{1cm} (3)

where \( \omega_B = \frac{(\omega_3 + \omega_4)}{2} \) – average angular speed of rear axle wheels; \( r_2 \) – dynamic wheel radius.

The distances AC and BC (Fig. 3) for a particular vehicle are known and do not change in the driving process.

4. Development of a diagnostic feature to detect the onset of skidding of the vehicle front or rear axles

The main idea of the proposed method is to estimate the linear velocity vector \( V_C \) two methods: first, by using expressions (1) and (2) – obtained value \( V_{C1} \), and then using expressions (3) and (4) – obtained value \( V_{C2} \). It is logical to assume that for a vehicle moving without skidding, the condition is fulfilled

\[ |V_{C1}| \approx |V_{C2}|. \]  \hspace{1cm} (5)

Consider now the case

\[ |V_{C1}| > |V_{C2}|. \]  \hspace{1cm} (6)

Taking into account that the evaluation vectors \( V_{AC} \) and \( V_{BC} \) no doubt (because yaw rate \( \omega_C \) can be easily measured, a distance \( AC \) and \( BC \) unchanged). Means,

\[ |V_A| > \omega_A r_1 \] \hspace{1cm} and \hspace{1cm} \[ |V_B| < \omega_B r_2. \]  \hspace{1cm} (7)

At the same time, given (6), it is logical to assume that

\[ |V_A| > |V_B|. \]  \hspace{1cm} (8)

On the basis of conclusions made in section 3, have a skid for the front axle. This case

\[ |V_{C1}| < |V_{C2}|. \]  \hspace{1cm} (9)
and reasoning similarly, we come to the conclusion that

$$|\mathcal{V}_A| < |\mathcal{V}_B|$$ \hspace{1cm} (10)

This means that there was a rear axleskid.

Thus, the diagnostic signs of skidding of the front or rear axles of the car can be formulated as follows. If

$$|\delta_V| = |\mathcal{V}_{c1}| - |\mathcal{V}_{c2}| \leq \Delta V, \hspace{1cm} (11)$$

Then there is no skid, the control system reaction is not required. Dead zone $\Delta V$ is introduced, firstly, to compensate for the errors of calculations associated with the failure to account for the removal of tires, etc., and, secondly, from the need to avoid self-oscillations that may occur during the operation of the dynamic stabilization system.

If

$$\delta_V = |\mathcal{V}_{c1}| - |\mathcal{V}_{c2}| > \Delta V, \hspace{1cm} (12)$$

that is diagnosed skidding of the front axle. If

$$\delta_V = |\mathcal{V}_{c1}| - |\mathcal{V}_{c2}| < -\Delta V, \hspace{1cm} (13)$$

it is diagnosed by a skid of the rear axle.

5. Development of a computational procedure that implements the vehicle motion statediagnosis

Consider writing expressions (1)–(4) in projections on the X and Y axes associated with the center of mass of the car. For the center of the front axle

$$\mathcal{V}_{c1x} = \omega_A R_1 \cos \Theta_{c1p},$$
$$\mathcal{V}_{c1y} = \omega_A R_1 \sin \Theta_{c1p},$$ \hspace{1cm} (14)

where $\Theta = (\Theta_1 + \Theta_2)/2$ – the average angle of rotation of the front steering wheels.

For the center of the rear axle

$$\mathcal{V}_{c2x} = \omega_B R_2,$$
$$\mathcal{V}_{c2y} = -\omega_C |BC| = 0.$$ \hspace{1cm} (15)

Then the velocity modules $|\mathcal{V}_{c1}|$ and $|\mathcal{V}_{c2}|$

$$|\mathcal{V}_{c1}| = \sqrt{\mathcal{V}_{c1x}^2 + \mathcal{V}_{c1y}^2},$$
$$|\mathcal{V}_{c2}| = \sqrt{\mathcal{V}_{c2x}^2 + \mathcal{V}_{c2y}^2}. \hspace{1cm} (16)$$

The resulting expressions (14)–(16) are quite simple and do not require cumbersome computational procedures, which suggests that the proposed methods of ware implementation will be quite economical.

6. Justification of the necessary set of parameters required for the diagnostic system and to be measured in the driving process

On the expressions basis (1)–(14), constituting the computational procedure of the diagnosing process the occurrence of skidding of the front or rear axle of the car, it is possible to make a physical signals list to be measured during the movement.
1. Angular speeds of rotation of wheels of the car.
2. Angular vehicle yaw rate of the relative to the vertical axis passing through its CoG.
3. The steering wheel angle.

It is also necessary to know the dynamic wheels radius in order to perform calculations in motion, but it is very difficult to measure these values. However, since the dynamic radius can slightly differ from static, with a reasonable accuracy degree when performing calculations, you can use the static radius, ignoring their dependence on possible changes in the vehicle CoG in motion, the redistribution of loads between the axles, etc.

Constants required for system operation:
1. distances $AC$ and $BC$ (fig. 4);
2. the static radius of the wheels.

7. Results

1. A method for determining the motion parameters of two-axle wheeled vehicles to ensure the operation of the dynamic stabilization system, allowing reliable and economical diagnosis of skid front or rear axles of a two-axle vehicle.

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