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DETERMINING THE TRAJECTORY OF THE VEHICLE MOTION ON THE BASIS OF THE RECORDED PHYSICAL QUANTITIES DESCRIBING ITS DYNAMICS DURING DOUBLE LANE CHANGE MANEUVERS

TOMASZ PUSTY[1]

Abstract

The paper indicated the results of the vehicle motion trajectory calculations determined on the basis of the recorded waveforms of the acceleration vector and angular velocity components during the double lane change maneuver, taking into account the errors of acceleration sensors reset (zeroing). For the sake of simplicity, it was assumed that the zeroing errors apply only to the linear acceleration sensors, while the angular velocity sensors show exact values at the time $t = 0$ s (when starting the double lane change maneuver). During the analysis of the experimental research results, the vehicle kinematics model was used. Two right-handed local coordinate systems and one right-handed global coordinate systems were used. The differences in the results of the calculations and possible causes of these differences were indicated. The test results indicate that special attention should be paid to zeroing the acceleration sensors, in particular the a_y component.

Keywords: vehicle trajectory; lane change manoeuvres; vehicle dynamics

1. Introduction

Obtaining data on physical quantities describing the movement of vehicles is of interest to many research entities: passive safety systems [4, 7], active safety systems e.g. during the modeling of autonomous lane change algorithms [8, 9], compliance of technological solutions with applicable normative documents, e.g. LDWS (Lane Departure Warning System) or experts analyzing the records of UDS (Unfall Daten Speicher) or ADR (Accident Data Recorder) black boxes [2] or during modelling vehicle dynamics [5]. Determination of the trajectory of the vehicle motion takes place in the global reference system with the use

1 Łukasiewicz Research Network – Automotive Industry Institute, Jagiellońska 55, 03-301 Warszawa, Poland, e-mail: tomasz.pusty@pimot.lukasiewicz.gov.pl, ORCID: 0000-0003-1324-5384

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of kinematic relationships in a situation where linear accelerations, angular velocities and linear velocities in the local system were measured directly. This is important both during the experimental verification of simulation programs and the reconstruction of road accidents. In the works [2, 3] the possible errors in the processing of data recorded by EDR (Event Data Recorder) were subjected to simulation analysis. The research was based on the results of vehicle motion simulations and acceleration records of two mathematical EDR models. One records – shaft acceleration and angular velocities in relation to three axes, the other – longitudinal and transverse acceleration and yaw rate. In the latter case, significant errors are possible, in particular with regard to the reconstructed trajectory of the vehicle's movement. The paper [6] presents a comparative analysis of velocity and linear acceleration courses measured with analog devices with measurements carried out in GPS systems. The problem of reducing these values from the device mounting points to the center of masses is also discussed. An example is shown with the results of measurements carried out during the steady-state driving test.

A four-wheeled flat model and the related theory of motion kinematics were used. Acquisition of data on physical quantities describing the movement may be subject to uncertainty due to transducer noise, zeroing and calibration errors, and limited data sampling frequency [1, 10]. Therefore, research focused on determining the size of the differences in the determined trajectory end positions at a different level of accuracy of acceleration sensors zeroing (zeroing at the level of tens and hundreds). The results of the work may be a guide for people using sensor data to determine the uncertainty range of calculations of the motion trajectory based on the recorded signals from the acceleration and angular velocity sensors.

2. Calculation results

During the analysis of the results of the experimental research, the vehicle kinematics model was used, in which right-handed coordinate systems were used: global and two local coordinate systems. Local coordinate systems, rigidly associated with the car body. Coordinate systems were used:

- local coordinate system, rigidly associated with the car body. The $Oxyz$ coordinate system has an O origin at the center of the car's mass, the Ox axis is parallel to the longitudinal axis of the vehicle. In the local coordinate system $Oxyz$, the components of the acceleration vector (ax, ay, az) and the components of the angular velocity vector of the car body (P, Q, R) were recorded;

- local horizontal coordinate system, rigidly associated with the car body. The $Ox_Py_Pz_P$ coordinate system has an O origin at the center of the car's mass, the Ox_P axis is parallel to the longitudinal axis of the vehicle;

- $O_GX_GY_GZ_G$ global coordinate system related to road. The $O_GX_GY_GZ_G$ plane of this system is on a horizontal roadway, and the O_GZ_G axis is directed vertically upwards. The speed vector of the car is parallel to the O_GX_G axis before starting the measurements.

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Vehicle movement is identified, among others. in relation to the road infrastructure, the location of which is described in the global coordinate system. Therefore, it is necessary to transform the measurement results of the local components of the acceleration vector (a_x, a_y, a_z) into the global system (a_X, a_Y, a_Z). The angular velocities of the car body in the global coordinate system are described by the expression:

$$\begin{bmatrix}\dot{\Phi}\\ \dot{\Theta}\\ \dot{\Psi}\end{bmatrix} = \begin{bmatrix}1 & \sin\Phi \mathrm{tg}\Theta & \cos\Phi \mathrm{tg}\Theta\\ 0 & \cos\Phi & -\sin\Phi\\ 0 & \frac{\sin\Phi}{\cos\Theta} & \frac{\cos\Phi}{\cos\Theta}\end{bmatrix}\begin{bmatrix}P\\ Q\\ R\end{bmatrix} \tag{1}$$

$$\begin{bmatrix}a_{xP}\\ a_{yP}\\ a_{zP}\end{bmatrix} = \begin{bmatrix}\cos\Theta & \sin\Theta\sin\Phi & \sin\Theta\cos\Phi\\ 0 & \cos\Phi & -\sin\Phi\\ -\sin\Theta & \cos\Theta\sin\Phi & \cos\Theta\cos\Phi\end{bmatrix}\begin{bmatrix}a_x\\ a_y\\ a_z\end{bmatrix} \tag{2}$$

$$\begin{bmatrix}a_{Gx}\\ a_{Gy}\\ a_{Gz}\end{bmatrix} = \begin{bmatrix}\cos\Psi & -\sin\Psi & 0\\ \sin\Psi & \cos\Psi & 0\\ 0 & 0 & 1\end{bmatrix}\begin{bmatrix}a_{xP}\\ a_{yP}\\ a_{zP}\end{bmatrix} \tag{3}$$

where:
Ψ, Θ, Φ – quasi-Euler angles, defining the orientation of the local system $\{C_s\}$ relative to the global system $\{O\}$;
P, Q, R – components of the angular velocity vector of the body in local coordinate systems.

To achieve the planned aim of this work, a double lane change maneuver was performed, during which the acceleration and angular velocity waveforms were recorded in the local reference system. For registration of the above-mentioned waveforms, the OXTS RT 3002 measurement set was used, which recorded signals at a frequency of 100 Hz. The waveforms of accelerations and angular velocities have been centered by removing the so-called offset and filtered with a 2nd order Butterworth lowpass filter with no phase shift with a cutoff frequency of 25 Hz. The OXTS RT 3002 measuring set was placed inside the car (test object) near the location of its center of mass (Figure 1a and Figure 1b). The tests were conducted during double lane change with a constant forward speed v_X=58 km/h. View from the vehicle during test and view from inside of the vehicle has been shown in the Figure 1c and 1d.

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Fig. 1. Picture from the test object, a) and b) view of the OXTS RT 3002 apparatus installed in the car, c) view from the vehicle during test, d) view from inside of the vehicle

The determined acceleration of the center of mass of the vehicle in the global system aGx, aGy, aGz was used to determine the coordinates of the center of mass of the car by double numerical integration. The error of zeroing the acceleration sensors at the start of the maneuver was assumed to be:

- variant 1: a_{x0}=(−0.4÷0.4) m/s^2 with a step of 0.1 m/s^2, a_{y0}=0 m/s^2;
- variant 2: a_{x0}=0 m/s^2, a_{y0}=(−0.04÷0.04) m/s^2 with a step of 0.01 m/s^2;
- variant 3: a_{x0}=(−0.04÷0.04) m/s^2 with a step of 0.01 m/s^2, a_{y0}=0 m/s^2.

The results of the calculations are presented in Figures 2a–2d in the form of the trajectories of the center of mass during lane change.

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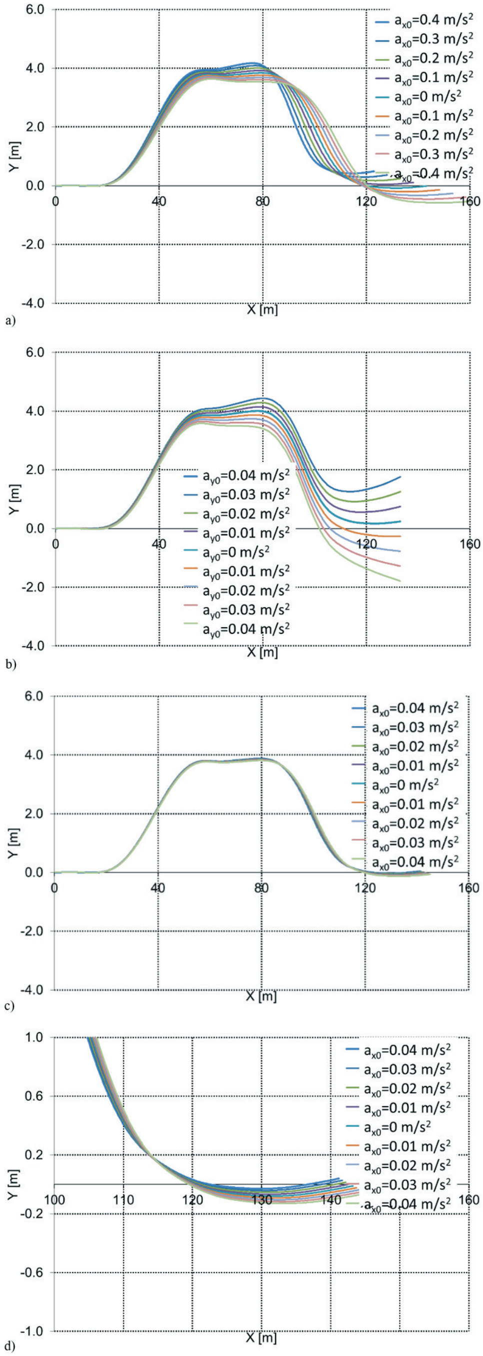

Fig. 2. Trajectories of movement of the car; a) variant 1, b) variant 2, c) variant 3, d) a fragment of variant 3 enlarged in the interest area

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The scope of the obtained calculation results for the variant

- 1 is: x_G from 122.93 m to 163.47 m and y_G = from 0.49 m to -0.51 m;
- 2 is: x_G from 133.07 m to 133.02 m, y_G = 1.76 m to -1.79 m;
- 3 is: x_G from 141.17 m to 145.23 m, y_G = 0.04 m to -0.06 m.

3. Conclusions

During the analysis of the experimental research results, the vehicle kinematics model was used. Two right-handed local coordinate systems and one right-handed global coordinate systems were used.

In case of errors in resetting the longitudinal component of the acceleration sensor a_{x0}=(-0.4÷0.4) m/s^2, the range of end positions was within the range D_{xG}=40.54 m and D_{yG}=1 m after covering the designated road section. In the case of errors in resetting the longitudinal component of the acceleration sensor a_{y0}=(-0.04÷0.04) m/s^2, the range of end positions was in the range D_{xG}=0.5 m and D_{yG}=3.55 m after driving the designated distance. In the case of errors in resetting the transverse component of the acceleration sensor a_{x0}=(-0.04÷0.04) m/s^2, the results of the calculations were D_{xG}=4.06 m D_{yG}=0.1 m after driving the designated road section.

The differences in the results of the calculations and possible causes of these differences were indicated.

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5. Nomenclature

LDWS	Lane Departure Warning System
UDS	Unfall Daten Speicher
ADR	Accident Data Recorder
EDR	Event Data Recorder

https://doi.org/10.14669/AM/151703

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