SIMULATION METHOD OF CAR MOTION RECONSTRUCTION BASED ON ADR/EDR DEVICE RECORDS

Marek Guzek

Warsaw University of Technology, Faculty of Transport
Koszykowa 75, 00-662 Warsaw, Poland
tel.+48 22 2348564, fax: +48 22 8490321
e-mail: mgu@it.pw.edu.pl

Abstract

The so-called car "black boxes" – ADR recorders have been available on automotive markets for many years. The task of those devices is to record information on car motion, driver's behaviour, state of vehicle systems and neighbouring environment. The records are to allow for accident reconstruction. In general, the devices being proposed are a simplified version of devices that have been applied e.g. in aviation for a long time. The problem is how those simplifications may affect the accuracy of reconstructions being performed. The simulation method of this type of research has been presented in this paper. A proceeding diagram, mathematical models of car motion applied in the method, records of ADR devices, an algorithm for processing quantities, recorded in ADR, in order to obtain reconstructed velocities histories and trajectories of car motion have been illustrated. A special attention was paid to a mathematical description of readings of acceleration sensors of ADR devices. An example of the experimental method verification has been presented. Then, three computational examples have been presented that focused on evaluation of influence of a number of quantities, being recorded in the ADR device, describing vehicle motion. It has been indicated that missing information on some quantities in devices, typical nowadays in automotive sector, may essentially affect the accuracy of car motion reconstruction.

Keywords: *car "black boxes", EDR, accident reconstruction, vehicle dynamics, vehicle motion simulation*

1. Introduction

Car "black boxes" have been offered for many years. They are also known as EDR (Electronic Data Recorder or Event Data Recorder) or UDS (Unfalldatenspeicher) or ADR (Accident Data Recorder). Here, the ADR acronym will be used. Some of ADRs are vehicle OEM installation, other (i.e. UDS in Europe) are an additional systems. Those devices are intended to record quantities that can be useful for forensic experts in identifying the accident/crash sequence and determining its parameters (e.g. initial car velocity, its position on the road). They record selected parameters of a car movement (acceleration, body orientation angles or corresponding to them angular velocities). They can also record driver's activity (e.g. the use of external lighting) and environment conditions (e.g. temperature, moisture). The sphere of activity of these devices (number and type of recorded values, time, method and frequency of registration) varies (see for example [8]). The simpler devices, named here as ADR2, record car's longitudinal and lateral accelerations and yaw angle only. More advanced devices, named here as ADR1, record in addition vertical acceleration and two angles (or angular velocities) of a car body - roll and pitch angles.

Range and other specific parameters of the device can affect accident analysis results. In the paper author presents simulation method of evaluation of errors occurring during vehicle motion reconstruction based on ADR records. The exemplary simulation tests show significant possible errors for typical devices that are available on the market.

2. Analyzed problem

Out of the problems that occur when using ADR-type of devices, they may be of economic, social and legislative character, as well as of technical nature. This paper focuses on the latter aspect.

In general, there are a few potential sources of inaccuracies in motion reconstruction using the „black box” records. It has been symbolically illustrated on Fig. 1. The reconstruction error ΔE (understood as a difference between values of parameters, describing vehicle motion and that have been defined based on „black box” records, and accurate values of the parameters) is the function of errors effecting from ADR general characteristics (Δk), measuring and recording apparatus errors (Δa), and errors resulting from the processing of recorded quantities (Δp). The notion of ADR general characteristics (Δk) may mean e.g. a number and type of quantities being recorded (e.g. recording of one, two, or three components of the car body's acceleration, recording of quantities describing angular position of the vehicle in a form of angles or angular velocities, etc.), frequency of ADR records, reference system in which the motion-describing quantities are recorded – e.g. whether it is a levelled system or not. Also inappropriate positioning of the device inside the vehicle (e.g. erroneous directions of accelerations measurement) can be mentioned in this group of errors. The scope of error, described as the measuring and recording apparatus error (Δa) includes all inaccuracies resulting from own errors of the quantities-recording sensors, from properties of the measuring and recording system, and errors that have occurred while reading the recorded quantities. Processing error (Δp) is the error effecting from methods of integration and differentiation of recorded quantities.

The simulation method is convenient for assessing accuracy of car motion reconstruction by using records of ADR devices. It enables a wide scope of analysis at relatively small costs. This allows for conducting experiments that would either be very difficult or practically impossible to do in road testing conditions.

3. Simulation method of research

General diagram of simulation method of research is presented on Fig. 2. First, car motion simulation is performed (for a given vehicle in a defined traffic situation). The simulation results are treated as „accurate”. On the basis of those results, recordings of ADR device are simulated (recognizing a specific character of the device – see ADR general characteristics). Using the „recordings”, and by applying devised processing algorithms, a reconstruction of the earlier simulated motion is performed.

A comparison of a simulation process of a given quantity and a process obtained basing on ADR recording is the foundation for assessment of a potential error in car motion reconstruction by using such device. A difference between a value, defined using ADR (ADR1 or ADR2), and that defined in the motion simulation research was treated as the error.

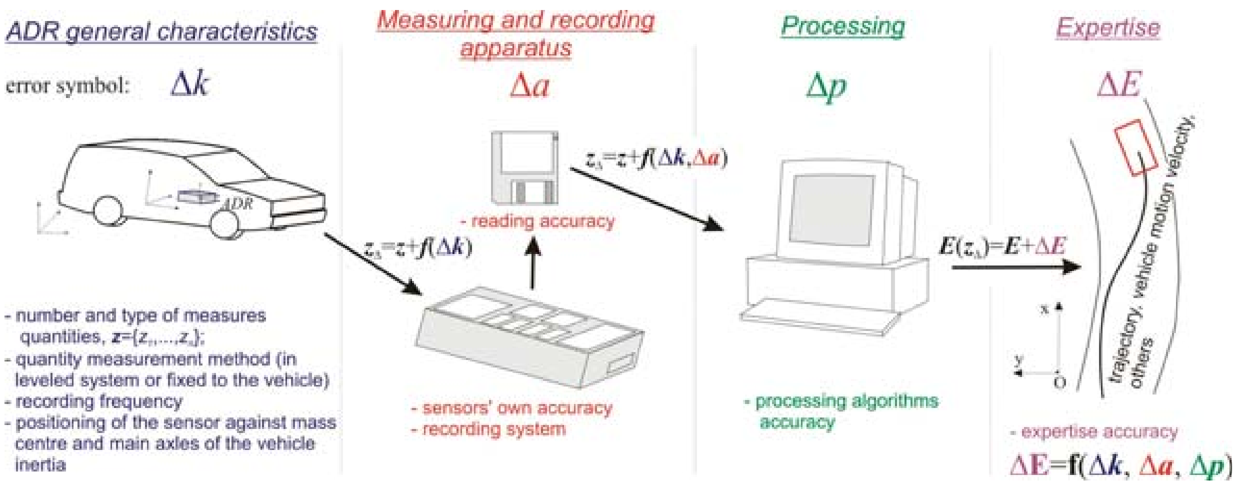

Fig. 1. Sources of errors in vehicle motion reconstruction based on records of ADR devices

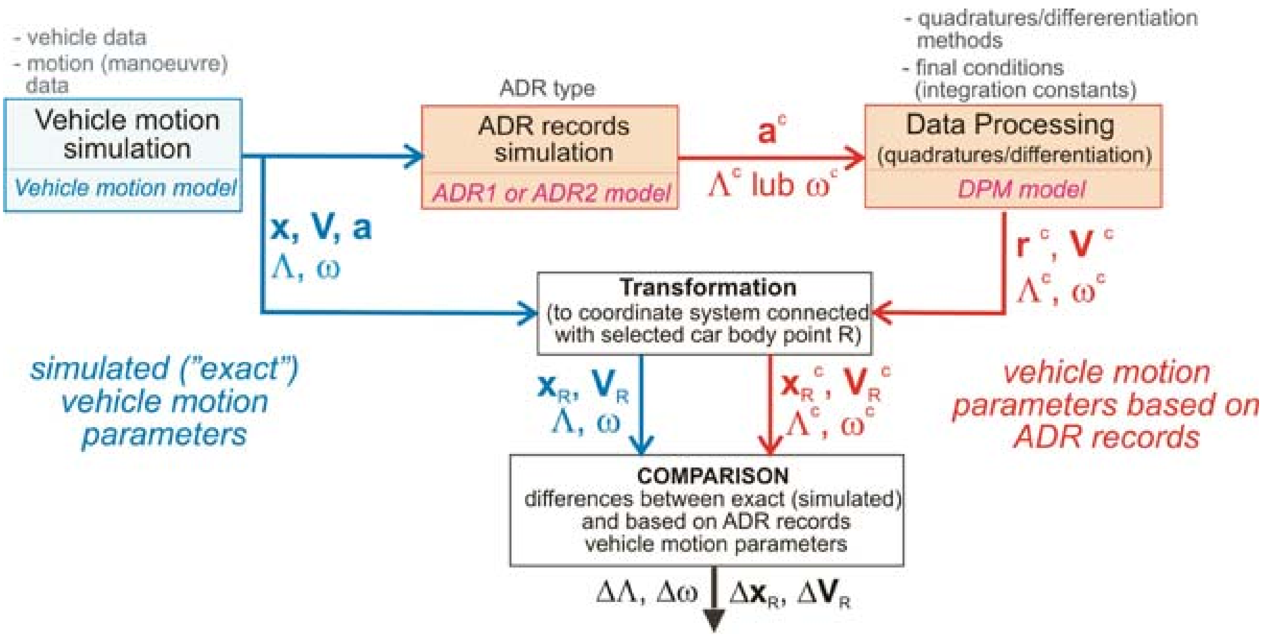

Fig. 2. Motion reconstruction accuracy assessment method based on ADR devices records: a, V, ω, r, Λ – components vectors (respectively): acceleration, velocity, angular velocity, position, angles

3.1. Vehicle motion model

The program ZL3DSYM [6], which had been made available by its author, was applied for car motion simulation computations. The program uses a complex car motion model. The model corresponds to a passenger car with front independent suspension and rear dependent one. It has 14 degrees of freedom: 6 describing a motion of the car body solid (3 movements of the centre point of the mass and 3 angles of the car body solid), 4 angles of driving wheels, 4 coordinates describing relative motions of the suspension. The model includes non-linear characteristics of suspension elasticity and dumping as well as tires. The tire shear forces model includes influence of the wheel centre velocity, normal road reaction, wheel camber angle, king-pin inclination, caster, and toe-in angles. The ZL3DSYM program has been successfully experimentally verified. A detailed description can be found e.g. in papers [6, 7]. Alternatively, a truck model of similar properties ZLSTAR (the description can be found in [6, 7]) of the same author can be used.

3.2. Model of ADR device records

A full description of a position and kinematics of the device against the car body and the distance are required to formulate a model of records from ADR device. The diagram has been illustrated on Fig. 3.

The movement of the vehicle body is treated as a combination of the translatory movement of the centre of the mass of the body O_1 and the spherical movement of the body against point O_1. Thus we consider a movement having 6 degrees of freedom (3 displacements and 3 rotations). Fig. 3 presents the assumed coordinate systems.

The following main co-ordinate systems were chosen:

– $Oxyz$ – the inertial system fixed with the road; the Ox and the Oy axis are horizontal, the vertical Oz axis is orientated upwards,

– $O_1\xi_1\eta_1\zeta_1$ – the non-inertial system fixed with the car body; The axes $O_1\xi_1$, $O_1\eta_1$, $O_1\zeta_1$ are the main central axes of inertia of the car body,

– $P\xi_c\eta_c\zeta_c$ – the non-inertial system fixed with ADR device, the $P\xi_c$, $P\eta_c$ and $P\zeta_c$ axis are ADR transducers axis (respectively: longitudinal, lateral and "vertical" axis).

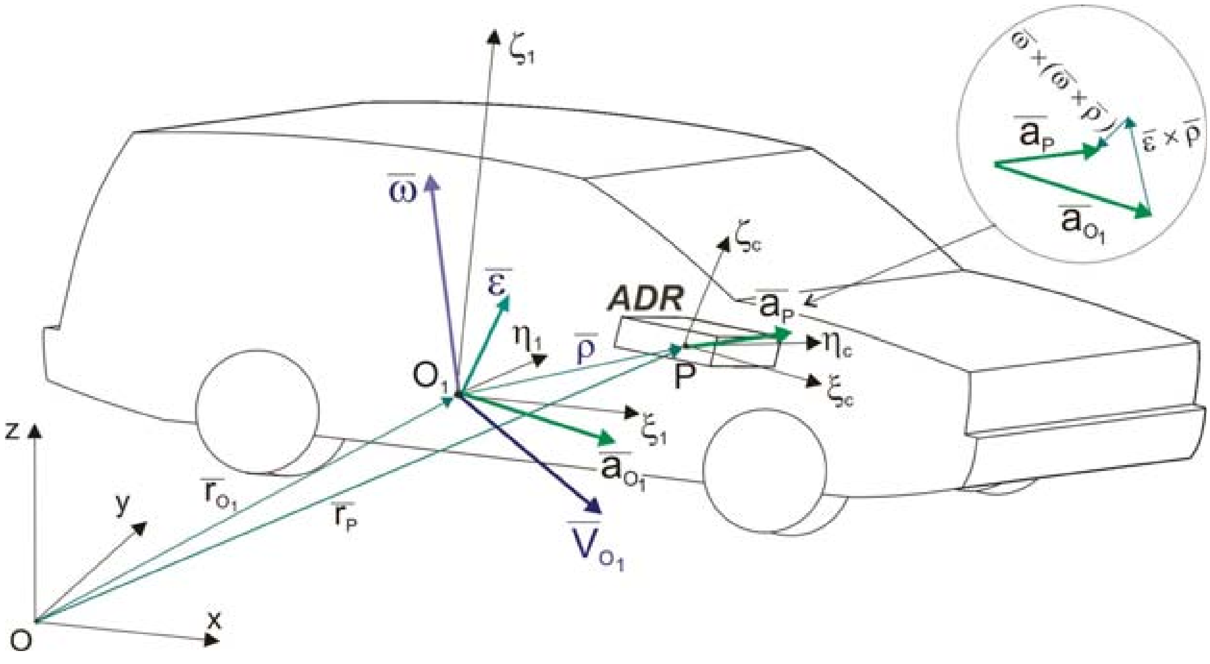

Fig. 3. The model of the kinematics of the movement of the vehicle equipped with an ADR device fixed at point P (r – translatory location; V – translatory movement velocity; a – translatory movement acceleration; ω – angular velocity; ε – angular acceleration)

The description of vectors (notation in matrix form "T" means transposition):

- $\bar{r}_{O_1} \equiv \boldsymbol{x}_{O_1} = \left[x_{O_1}, y_{O_1}, y_{O_1}\right]^T$ - the position of the centre of the mass of the car body O_1 in the inertial $Oxyz$ system,
- $\bar{r}_P \equiv \boldsymbol{x}_P = \left[x_P, y_P, y_P\right]^T$ - the position of point P in the inertial $Oxyz$ system,
- $\bar{\rho} \equiv \boldsymbol{\rho} = \left[\xi_P, \eta_P, \zeta_P\right]^T$ - the position of point P in the $O_1\xi_1\eta_1\zeta_1$ system;
- $\bar{\omega} \equiv \boldsymbol{\omega} = \left[\dot{\psi}_1, \dot{\varphi}_1, \dot{\vartheta}_1\right]^T$ - angular velocity,
- $\bar{V}_{O_1} \equiv \dot{\boldsymbol{x}}_{O_1} = \left[\dot{x}_{O_1}, \dot{y}_{O_1}, \dot{z}_{O_1}\right]^T$ - the velocity of point O_1,
- $\bar{a}_{O_1} \equiv \ddot{\boldsymbol{x}}_{O_1} = \left[\ddot{x}_{O_1}, \ddot{y}_{O_1}, \ddot{z}_{O_1}\right]^T$ - the acceleration of point O_1,
- $\bar{a}_P \equiv \ddot{\boldsymbol{x}}_P = \left[\ddot{x}_P, \ddot{y}_P, \ddot{z}_P\right]^T$ - the acceleration of point P.

The kinematics of point P is described as follows (P is fixed with the vehicle body, $\boldsymbol{A}$ – the rotation matrix, described in Appendix A):

position: $$\boldsymbol{x}_p = \boldsymbol{x}_{O_1} + \boldsymbol{A}\cdot\boldsymbol{\rho}, \tag{1}$$

velocity: $$\dot{\boldsymbol{x}}_p = \dot{\boldsymbol{x}}_{O_1} + \dot{\boldsymbol{A}}\cdot\boldsymbol{\rho}, \tag{2}$$

acceleration: $$\ddot{\boldsymbol{x}}_p = \ddot{\boldsymbol{x}}_{O_1} + \ddot{\boldsymbol{A}}\cdot\boldsymbol{\rho}. \tag{3}$$

The rotation matrix $\boldsymbol{A}$ has the form:

$$\boldsymbol{A} = \begin{bmatrix} \cos\psi_1\cdot\cos\varphi_1 & \cos\psi_1\cdot\sin\varphi_1\cdot\sin\vartheta_1 - \sin\psi_1\cdot\cos\vartheta_1 & \cos\psi_1\cdot\sin\varphi_1\cdot\cos\vartheta_1 + \sin\psi_1\cdot\sin\vartheta_1 \\ \sin\psi_1\cdot\cos\varphi_1 & \sin\psi_1\cdot\sin\varphi_1\cdot\sin\vartheta_1 + \cos\psi_1\cdot\cos\vartheta_1 & \sin\psi_1\cdot\sin\varphi_1\cdot\cos\vartheta_1 - \cos\psi_1\cdot\sin\vartheta_1 \\ -\sin\varphi_1 & \cos\varphi_1\cdot\sin\vartheta_1 & \cos\varphi_1\cdot\cos\vartheta_1 \end{bmatrix}, \tag{4}$$

where angles ψ_1, φ_1, ϑ_1 describe spherical motion of the vehicle body against the pole O_1 (known as “quasi-Euler” angles):

- the yaw angle ψ_1 (rotation around the axis $O_1\zeta_1$),
- the pitch angle φ_1 (rotation around the axis $O_1\eta_1$),
- the roll angle ϑ_1 (rotation around the axis $O_1\xi_1$).

The succession of rotations corresponds to the succession of their description (see also Fig. 4).

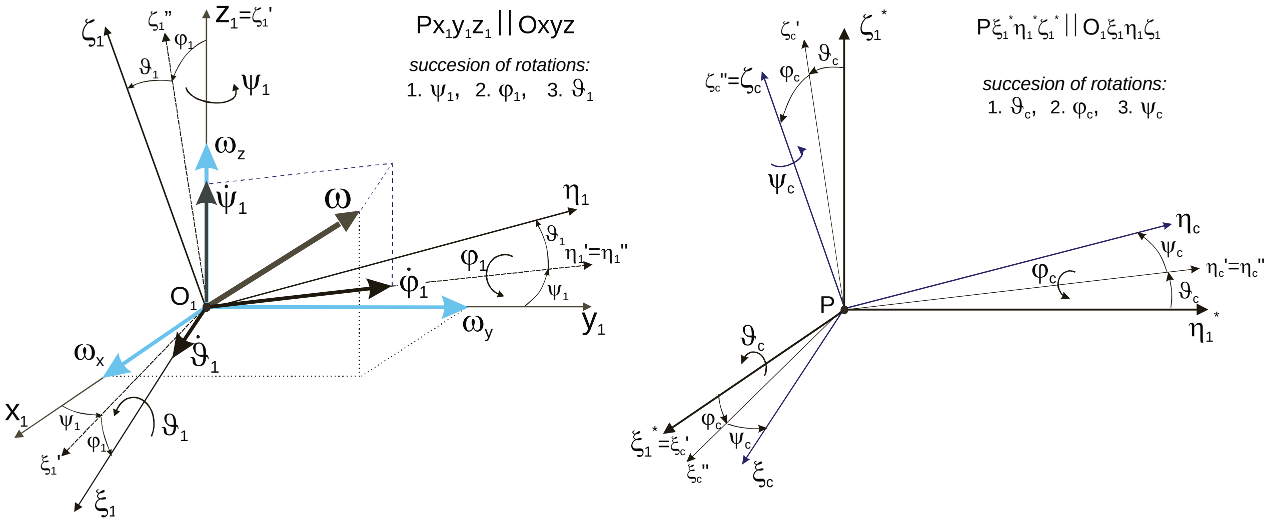

Fig. 4. The angular positioning of the coordinate systems: $O_1\xi_1\eta_1\zeta_1$ in relation to Oxyz and $P\xi_c\eta_c\zeta_c$ in relation to $O_1\xi_1\eta_1\zeta_1$

The transformation of the system $O_1\xi_1\eta_1\zeta_1$ to the system $O_1x_1y_1z_1$ is described by the relation:

$$[x_1, y_1, z_1]^T = \boldsymbol{A}\cdot[\xi_1,\ \vartheta_1,\ \zeta_1]^T. \tag{5}$$

The transformation in the opposite direction (from $O_1x_1y_1z_1$ to $O_1\xi_1\eta_1\zeta_1$) is described by the inverse matrix $\boldsymbol{A}^{-1}$**,** where:

$$\boldsymbol{A}^{-1} = \boldsymbol{A}^T, \tag{6}$$

which is derived from their mutual orthogonality.

The position of the sensors ADR is defined by the point of fixing P and the axes of the system $P\xi_c\eta_c\zeta_c$, fixed with the device. The $P\xi_c\eta_c\zeta_c$ system is obtained from the $O_1\xi_1\eta_1\zeta_1$ system by translation by a vector $\overline{\rho}$ and rotation described by matrix $\boldsymbol{C}$. Analogical rotations to the ones describing the angular position of the car body in relation to the road (the yaw ψ_1, the pitch φ_1, the roll ϑ_1) have been taken, but in the opposite sequence: the ADR roll ϑ_c (rotation around the longitudinal axis ξ_c), the ADR pitch φ_c (rotation around the lateral axis η_c), the ADR yaw ψ_c (rotation around the “vertical” axis ζ_c) – see Fig. 4.

Such a sequence of rotations has been taken because of the ease of levelling the sensors (orientated in relation to the vehicle). Their introduction enables any angular positioning of ADR in relation to the body. This in turn enables to account for the related errors of the readings of the ADR sensors.

The matrix **C** has the form:

$$\boldsymbol{C} = \begin{bmatrix} \cos\psi_c\cdot\cos\varphi_c & -\sin\psi_c\cdot\cos\varphi_c & \sin\varphi_c \\ \cos\psi_c\cdot\sin\varphi_c\cdot\sin\vartheta_c+\sin\psi_c\cdot\cos\vartheta_c & -\sin\psi_c\cdot\sin\varphi_c\cdot\sin\vartheta_c+\cos\psi_c\cdot\cos\vartheta_c & -\cos\varphi_c\cdot\sin\vartheta_c \\ -\cos\psi_c\cdot\sin\varphi_c\cdot\cos\vartheta_c+\sin\psi_c\cdot\sin\vartheta_c & \sin\psi_c\cdot\sin\varphi_c\cdot\cos\vartheta\ +\cos\psi_c\cdot\sin\vartheta_c & \cos\varphi_c\cdot\cos\vartheta_c \end{bmatrix}. \tag{7}$$

The transformations from the system $P\xi_c\eta_c\zeta_c$ to the system $O_1\xi_1\eta_1\zeta_1$ has the form:

$$[\xi_1,\ \eta_1,\ \zeta_1]^{\mathrm{T}} = \boldsymbol{C}\cdot[\xi_c,\ \eta_c,\ \zeta_c]^T \tag{8}$$

The opposite transformation (from $O_1\xi_1\eta_1\zeta_1$ to $P\xi_c\eta_c\zeta_c$) is described by the inverse matrix $\boldsymbol{C}^{-1}$, orthogonal against $\boldsymbol{C}$:

$$\boldsymbol{C}^{-1} = \boldsymbol{C}^{T}. \tag{9}$$

The inertial acceleration sensors show the value proportional to the sum of the components in the direction of the activity of the sensor: the force of inertia and the force of gravity. The sensor's indication is the sum of the components in the direction of the activity of the sensor of the real acceleration and the acceleration of gravity. Accepting that, in general the acceleration sensor is three-axial, that is:

$$\boldsymbol{a}^{c} = \left[a_w^c, a_p^c, a_z^c\right]^T, \tag{10}$$

we obtain the general vector relation for the readings of the sensor

$$\boldsymbol{a}^{c} = \boldsymbol{a}_{Pc} - \boldsymbol{g}_c, \tag{11}$$

where

$$\boldsymbol{a}_{Pc} = \left[a_{P\xi_c}, a_{P\eta_c}, a_{P\zeta_c}\right]^T = \boldsymbol{C}^{-1} \cdot \boldsymbol{a}_P = \boldsymbol{C}^{-1} \cdot \boldsymbol{A}^{-1} \cdot \ddot{\boldsymbol{x}}_P, \tag{12}$$

$$\boldsymbol{g}_c = \left[g_{\xi_c}, g_{\eta_c}, g_{\zeta_c}\right]^T = \boldsymbol{C}^{-1} \cdot \bar{\boldsymbol{g}}_{\xi} = \boldsymbol{C}^{-1} \cdot \boldsymbol{A}^{-1} \cdot \boldsymbol{g} \tag{13}$$

and $\boldsymbol{g}=[0, 0, -g]^T$ – the vector of acceleration of gravity.
$\boldsymbol{a}_{Pc}$ and $\boldsymbol{g}_c$ represent the acceleration of point P and the acceleration of gravity, accordingly, described in the $P\xi_c\eta_c\zeta_c$ system. The graphic illustration of the readings of the sensors in case of the ADR2 device type is shown on Fig. 5.

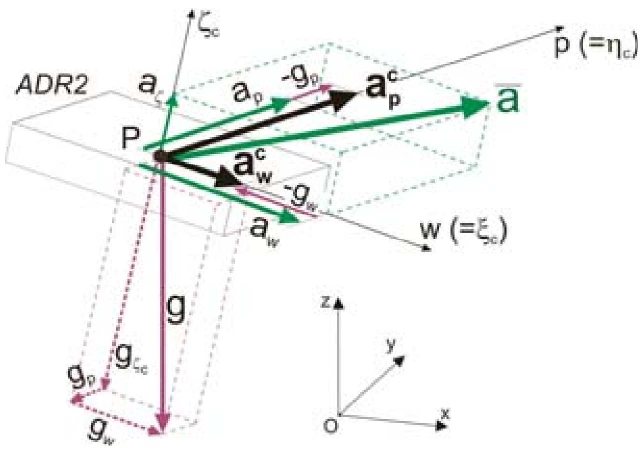

Fig. 5. Graphical interpretation of the readings of the sensors measuring the longitudinal and the lateral accelerations (example for ADR2 type device)

The presented description assumes no own errors of the sensors.

The model, relevant for the indications describing angular position (angles or angular velocities), is also prepared. Its formal description is available in [1, 3].

3.3. Data processing model (DPM)

The purpose of the car motion reconstruction is to reconstruct a time history of vehicle's velocity and its motion trajectory. Procedures of numerical integration (quadratures) of recorded accelerations (and possible angular velocities) and differentiation are used for that purpose. The diagram of proceeding in case of the body angles records in ADR device has been presented on Fig. 6. First of all, if possible (this is the case of ADR1 type of devices), the recorded accelerations are adjusted by gravity acceleration components being sensed by the sensors. Further on, the accelerations are transformed into inertial reference system (related to the road). In this form, they are integrated twice, which allows for defining velocities and positions. Computations are usually made „backwards”, which means from the last moment for which vehicle position and its velocity to the start are known. Knowing the ADR’s position in a vehicle, the results obtained are transformable to any point of the vehicle’s body.

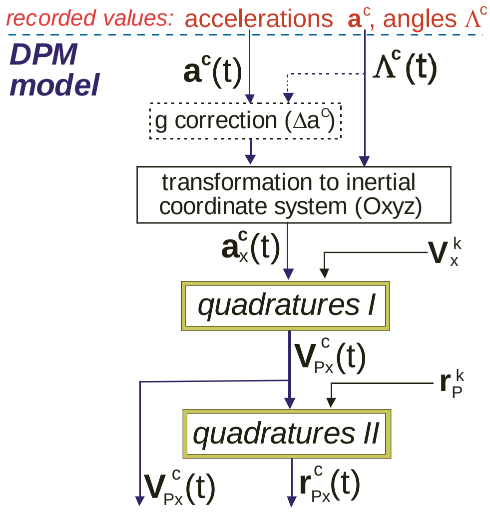

Fig. 6. Block diagram of data elaboration. a_x, V_x, r_x, - vectors of acceleration, velocity and position in the earth-fixed coordinate system Oxyz; V^k, r^k – final value of velocity and position; index P – denotes the value for point P in which ADR is fixed

$$\mathbf{a}^c : \begin{cases} a_w^c, a_p^c, a_z^c \\ a_w^c, a_p^c \end{cases} \qquad \mathbf{\Lambda}^c : \begin{cases} \psi_1^c, \varphi_1^c, \vartheta_1^c & \text{- ADR1} \\ \psi_1^c & \text{- ADR2} \end{cases}.$$

4. Experimental verification of adopted simulation method

A set of: the motion simulation program ZL3DSYM plus ADR mathematical model has been experimentally verified. A comparative assessment has been made for a few characteristic tests (straight-line braking, traffic lane-change maneuvers, and turn entering maneuver). Experimental tests have been conducted by a team managed by Dr. W. Pieniążek, Cracow University of Technology.

The verification example has been illustrated on Fig. 7. This is a comparison of selected quantities for a traffic lane double-change maneuver that is performed by a passenger car of which the basic technical data is presented in Tab. 1.

Tab. 1. Basic parameters of tested vehicle

Parameter	**Value**
Vehicle length	4.5m
Wheelbase	2.509m
Front / rear wheels track	1.375m / 1.352m
Weight at partial load (PL) / total load (TL)	1350kg / 1690g
Weight distribution on front / back axles, at partial load (PL)	670kg / 680kg
Tires, type, size	185/70 R13 86T

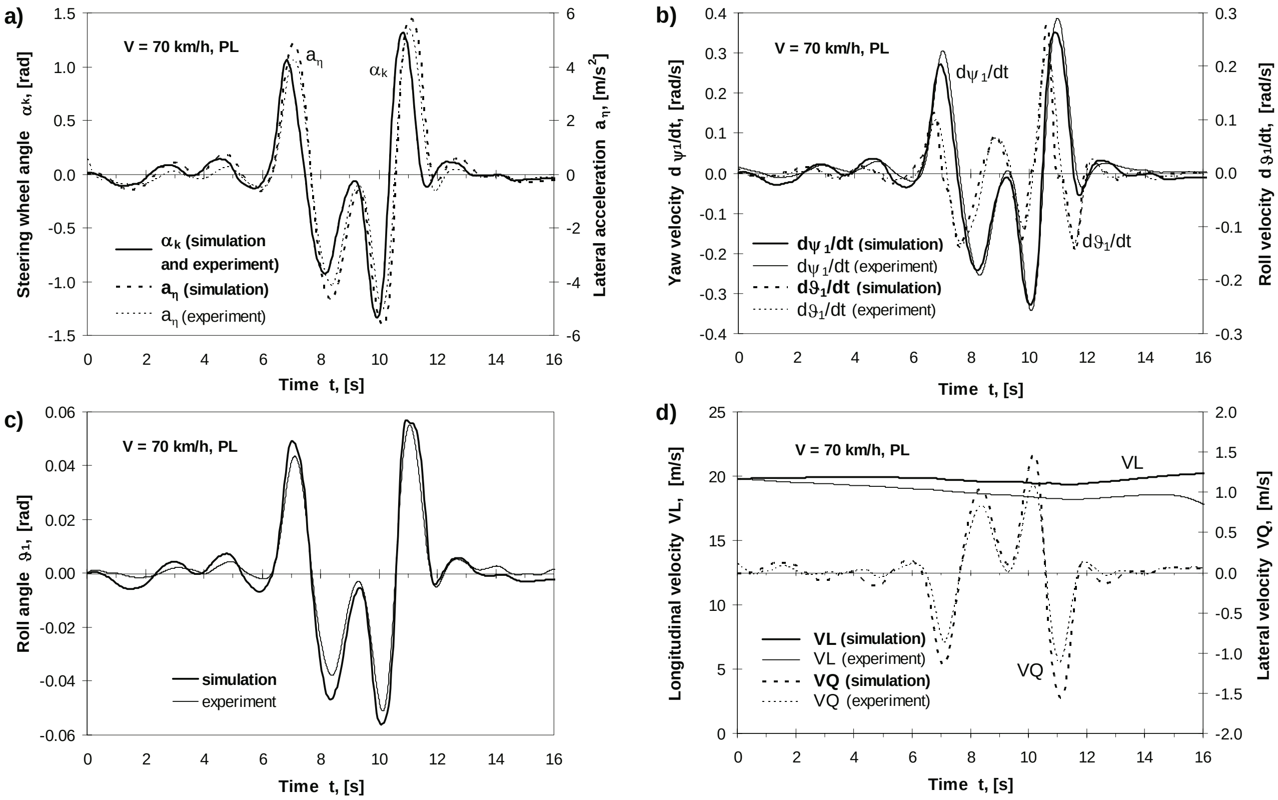

Fig. 7. Double lane - change maneuver. Comparison of selected time histories of sensors indications in the experiment and in the simulation (ZL3DSYM plus ADR): a) the vehicle lateral acceleration, b) yaw velocity $d\psi_1/dt$ and roll angular velocity $d\vartheta_1/dt$, c) roll angle ϑ_1, d) vehicle longitudinal velocity VL and lateral velocity VQ (only ZL3DSYM). Partially loaded vehicle (PL)

The presented maneuver was carried out in compliance with guidelines provided under ISO 3888 [9] standard by a partially loaded car with velocity of 70km/h. The same initial velocity of the vehicle was applied in the simulation as well as the same time history of the steering wheel angle. The same position of acceleration sensors and angular position changes has been adopted. A few basic quantities from the set's verification point of view have been illustrated on Fig. 7: ZL3DSYM program + ADR model. The example shown hereto indicates a good compliance between the experiment and the simulation.

5. Exemplary computations

Three car reconstruction examples (with data as in Tab. 1) have been presented below using the presented method. They refer to characteristic defensive maneuvers of the driver in pre-accidental situations in traffic. An assumption has been made in all examples that the ADR device is positioned under the driver's seat, and its sensors' axels have been levelled for a stand-still car with a load as in Tab. 1.

5.1. Straight-line braking example

The example related to straight-line braking from velocity of 100 km/h down to zero (the maneuver was forced via a process of the brake pedal force) has been presented on Fig. 8. Those are processes of acceleration components in point *P* of the ADR device fixture: longitudinal acceleration a_w (a), lateral acceleration a_p (b) and „vertical" acceleration a_z (c). Accurate values have been marked (components of acceleration on sensors axles $a_w = a_{P\xi_c}$, $a_p = a_{P\eta_c}$, $a_z = a_{P\zeta_c}$), indications of accelerations sensors (a_w^c, a_p^c, a_z^c), and differences among them – indications errors (Δa_w^c, Δa_p^c, Δa_z^c). Moreover, the exact value of the car body's longitudinal pitch angle φ_1 has been presented (d). The charts e and f present results of the maneuver's reconstruction for the two earlier mentioned types of the ADR device: ADR1 and ADR2: car velocity V (e) and longitudinal position of the mass centre (C.G.) on the road. In the event of ADR1 device, the reconstruction results practically overlap with accurate results. In the event of simplified ADR2 device, the vehicle's initial velocity reconstruction error and that of travelled distance ranges at the level of 4-5%.

5.2. Example of traffic lane single-change maneuver

The traffic lane single-change maneuver has been simulated by time process of the steering wheel angle in the form of a single sinusoidal period. Its amplitude has been matched so that sideway transposition of the vehicle reached about 3.5m (a typical width of traffic lane). The adopted period value was equal to 2 seconds.

On Fig. 9, selected processes related to the maneuver that is performed at velocity of 100 km/h have been presented. As previously, those are processes of acceleration components in point of the ADR device fixture: longitudinal acceleration a_w (a), lateral acceleration a_p (b) and „vertical" acceleration a_z (c) - accurate values $a_w = a_{P\xi_c}$, $a_p = a_{P\eta_c}$, $a_z = a_{P\zeta_c}$, indications of accelerations sensors a_w^c, a_p^c, a_z^c and differences among them – indications errors Δa_w^c, Δa_p^c, Δa_z^c. The chart d illustrates accurate values of the car body's position angles: the yaw angle ψ_1, the pitch angle φ_1 and roll angle ϑ_1.

The charts e and f present results of the maneuver's reconstruction for ADR1 and ADR2 devices: car velocity V (e) and a trajectory of the mass centre (C.G.) on the road surface. In the event of ADR1 device, the reconstruction results overlap with accurate results. In the event of simplified ADR2 device, the initial velocity assessment error is also practically omitable. It is at the level of the hundredth parts of the percentage. There are slightly worse results for reconstruction of the vehicle trajectory. The error in assessment of lateral position on the road reaches about 0.4 m. Taking into consideration that total lateral transposition reached about 3.5 m while the maneuver, this gives a relative error of about 11.4%.

5.3. The „turn entering" maneuver example

On Fig. 9, the „turn entering" maneuver example has been presented. The maneuver involves setting a fixed value of the steering wheel angle (preceded with linear accumulating period). The angle value was matched in order to obtain a high level of lateral acceleration. The maneuver was considered complete at the moment when the mass centre moved in lateral direction of the road (y direction) by more than 7 m (approximately it may correspond to a situation when a vehicle leaves a single-lane road with a wide shoulder).

Results of the test performed at a car's initial velocity of 60km/h have been presented in the form analogical to the one before. They are the processes of acceleration components in point at which ADR device has been fixed: longitudinal acceleration a_w (a), lateral acceleration a_p (b) and „vertical" acceleration a_z (c) - accurate values $a_w = a_{P\xi_c}$, $a_p = a_{P\eta_c}$, $a_z = a_{P\zeta_c}$, indications of accelerations sensors a_w^c, a_p^c, a_z^c and differences among them – indications errors Δa_w^c, Δa_p^c, Δa_z^c. The chart d illustrates accurate values of the vehicle body's position angles: the yaw angle ψ_1, the longitudinal pitch angle φ_1 and roll angle ϑ_1.

The charts e and f present results of the maneuver's reconstruction for ADR1 and ADR2 devices: car velocity V (e) and a trajectory of the mass centre (C.G.) on the road surface. For ADR1 device, the reconstruction results overlap with accurate results. According to the reconstruction on the basis of ADR2 records, the initial velocity is 2.3% lower than the accurate value. The trajectory, reconstructed on the basis of ADR2, does not reflect the „real one" in the best way. The error in assessment of the initial position in lateral direction reaches 1.42 m. If we take into consideration the fact that total transposition of the vehicle in that direction reached about 7.3 m, we shall obtain a relative error of 19.5%.

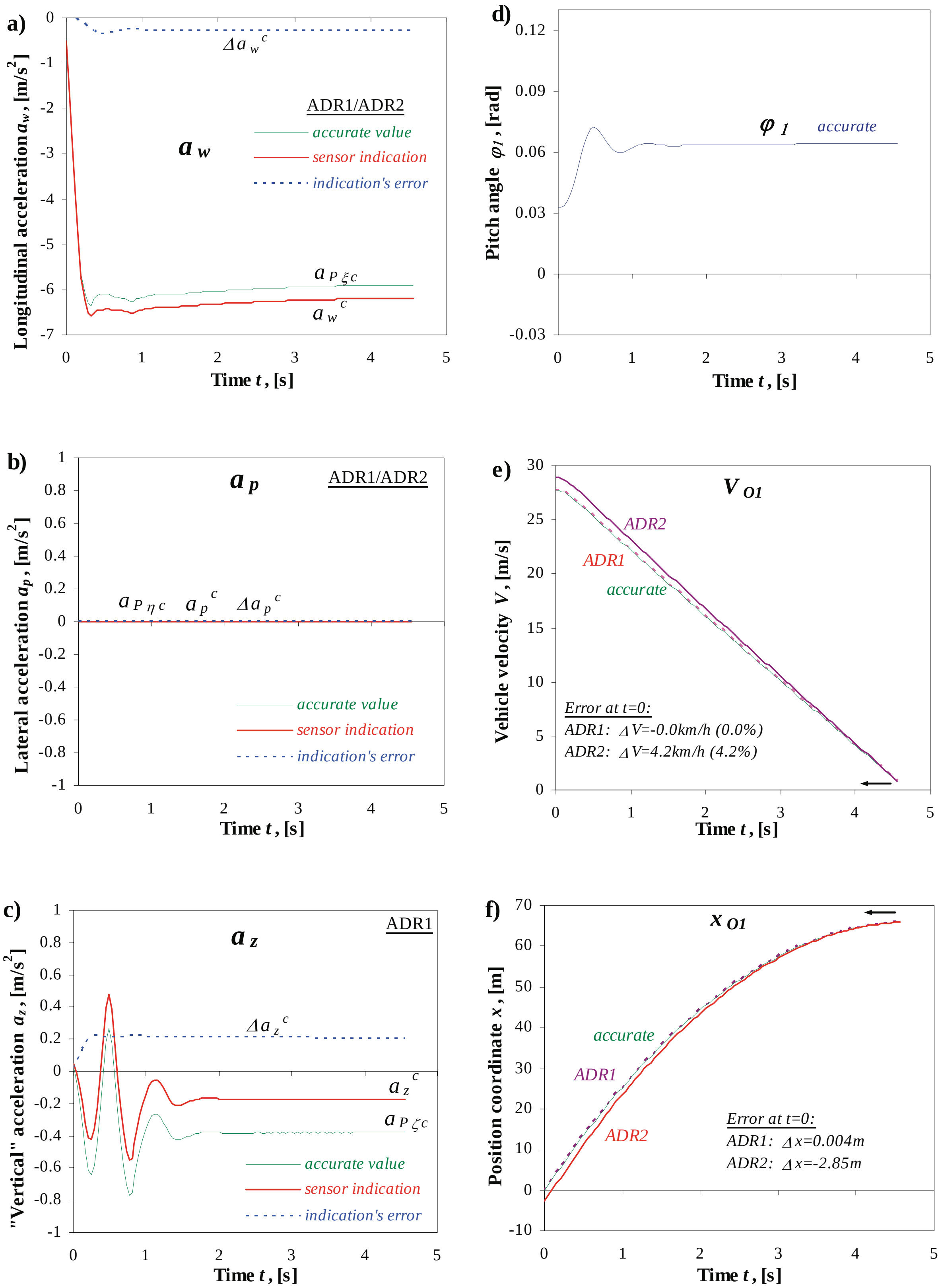

Fig. 8. Straight-line braking from velocity of V_0=100km/h. Time histories of vehicle longitudinal (a), lateral (b) and „vertical" (c) accelerations: accurate values, sensors indications and their differences – indications errors. Time history of pitch angle accurate value (d). The reconstructed velocity of the vehicle (e) and „x" position on the road (f): accurate values and based on ADR1, ADR2 records

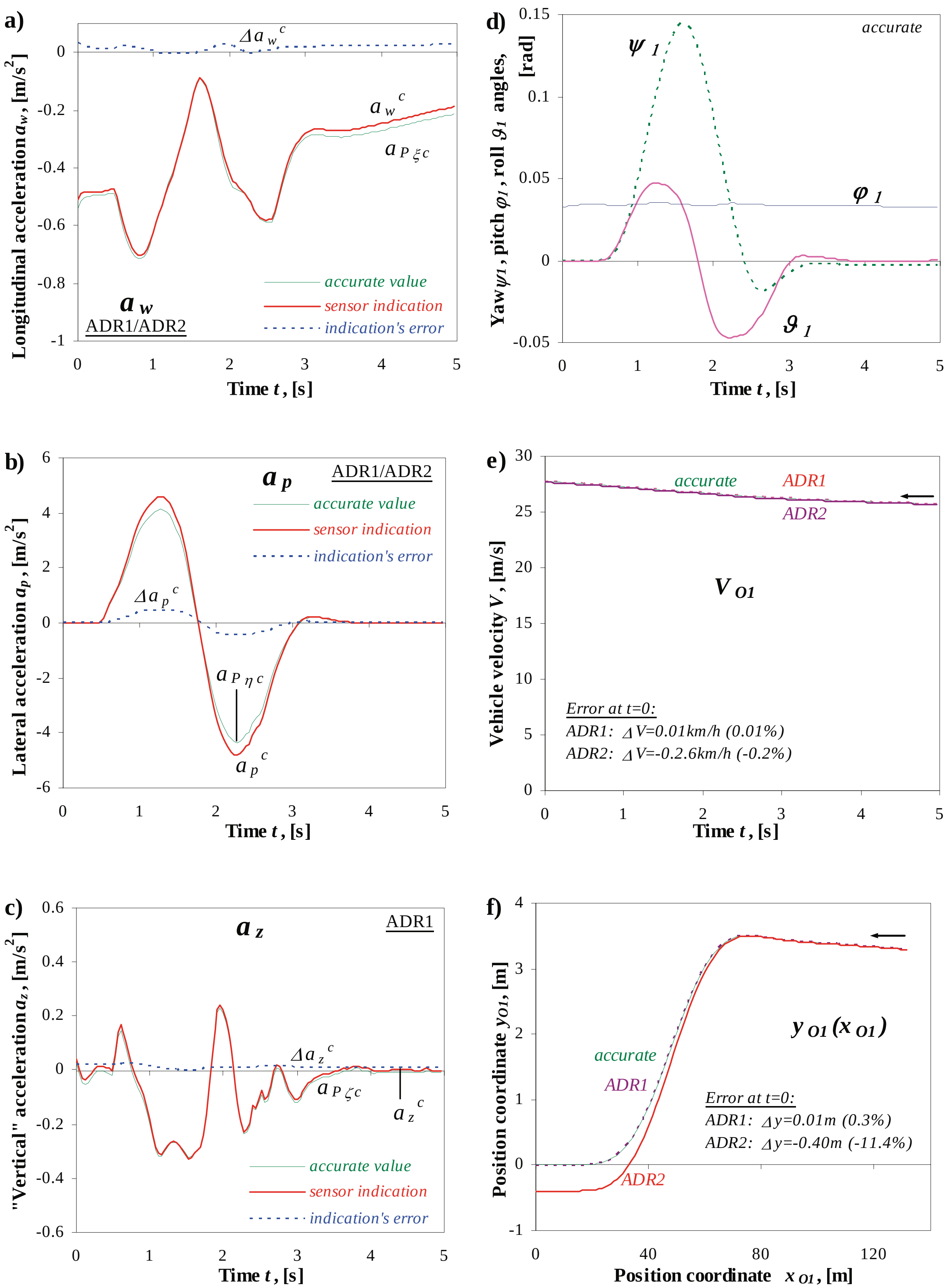

Fig. 9. Singular lane-change maneuver at velocity of V_0=100km/h. Time histories of vehicle longitudinal (a), lateral (b) and „vertical“ (c) accelerations: accurate values, sensors indications and their differences – indications errors. Time histories of yaw, pitch and roll angles accurate value (d). The reconstructed velocity of the vehicle (e) and vehicle's C.G. trajectory on the road (f): accurate values and based on ADR1, ADR2 records

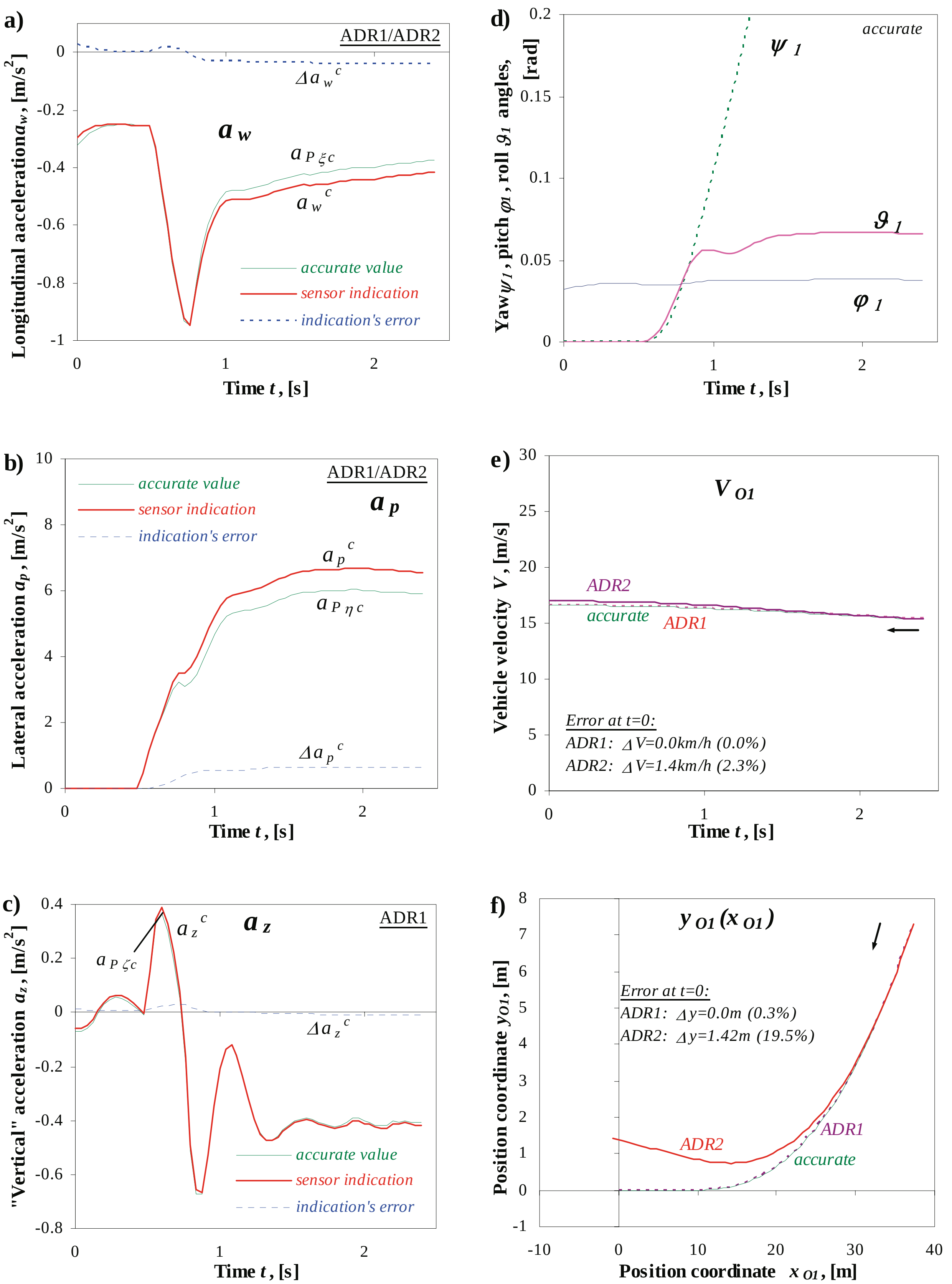

Fig. 10. Turn entering maneuver at velocity of V_0=60km/h. Time histories of vehicle longitudinal (a), lateral (b) and „vertical“ (c) accelerations: accurate values, sensors indications and their differences – indications errors. Time histories of yaw, pitch and roll angles accurate value (d). The reconstructed velocity of the vehicle (e) and vehicle's C.G. trajectory on the road (f): accurate values and based on ADR1, ADR2 records

6. Conclusion

The solutions of ADR-type of „black boxes" that are currently proposed on the automotive market are mostly the simplified version of solutions applied for many years in aviation. In this paper, the author has focused on assessment of the impact that the applied simplifications, described in the core part of the paper, have on errors in values of the key parameters describing the vehicle motion (velocity, motion trajectory). The main focus has been on the device concept. Problems such as those related to e.g. measuring and recording apparatus applied in the devices have not been considered.

The experimentally verified simulation method has been used here for research purposes. On the basis of exemplary tests (characteristic defensive manoeuvres in pre-accident situations, such as: braking, an attempt of passing round), it has been illustrated that the simplifications applied in "black boxes" solutions (ADR2 type of devices), typical for automotive sector, may lead to significant errors in motion reconstruction. This mostly refers to the car motion trajectory reconstruction. Also, a result that considerably differs from the real one is a possibility in case of velocity reconstruction. The basic reason for it is that ADR2-type of devices does not provide information about angles of the car body solid's orientation: about the pitch angle and the roll angle. In case of ADR1-type of devices, which collect such information, no essential reconstruction errors have been found.

The simulation method is a convenient tool for assessment of accuracy of the motion reconstruction that is conducted based on records of the ADR type of devices. It allows for a wide scope of analysis and its relatively low costs. However, the condition required for using the results obtained by this method is a positive and experimental verification of the simulation models applied. The example, presented in the paper, is evidence for a positive assessment of the method.

A wider scope of research results, confirming the above statements and delivering more detailed information can be found e.g. in papers [1-5].

References

[1] Guzek, M., *Methods of computational error determination in an analysis of selected pre-accident situations in road traffic,* PhD thesis, Warsaw University of Technology, Faculty of Transportation (in Polish language) Warsaw, 2002.

[2] Guzek, M., *Selected problems related to vehicle motion reconstruction accuracy by using car „black box" records,* Mechanics Technical Magazine, Booklet 7-M/2004, Publisher of Cracow University of Technology, Volume 1, „Motor Vehicles", pp. 229-236 (in Polish language), 2004.

[3] Guzek, M., Lozia, Z., *Possible errors occurring during accident reconstruction based on car "black box" records,* 2002 World SAE Congress and Exposition. Detroit, Michigan USA, 2002, SAE TP 2002-01-0549 (Published also in the Special Publication SP-1666 "Accident Reconstruction 2002" and in SAE Transaction 2002, Section 6, Vol. 111), 2002.

[4] Guzek, M., Lozia, Z., Pieniążek, W., "*Accident Reconstruction Based on EDR Records – Simulation and Experimental Study*", 2007 World SAE Congress and Exposition, Detroit, Michigan USA, 2007, SAE TP 2007- 01-0729, Separate booklet, 12 pages of text. (Published also in SAE Special Publication SP-2063 "Accident Reconstruction 2007," pp. 137-148), 2007.

[5] Guzek, M., Maniowski, M., Pieniążek, W., *Reconstruction of car motion parameters during straight-line braking by using experimental tests results,* Scientific Booklets of the Vehicles Institute, Warsaw University of Technology, Booklet No. 2 (57)/2005 pp. 45-58 (in Polish language), 2005.

[6] Lozia, Z., *Analysis of biaxial car motion based upon dynamics models*, Monograph. Scientific bulletins of the Warsaw University of Technology, Transport (in Polish language), Warsaw 1998.

[7] Lozia, Z., *Vehicle Dynamics and motion simulation versus experiment*. 1998 SAE International Congress and Exposition. Detroit, Michigan USA. February 23 - 26, 1998. SAE TP 980220. (Published also in the Special Publication SP-1361 “Vehicle Dynamics and Simulation, 1998” and in the SAE Transactions 1998).

[8] Submittal of Meeting Minutes of the NHTSA R&D Event Data Recorder (EDR) Working Group.

[9] ISO 3888. Road vehicles – test procedure for a severe –change maneuver.