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Car ADR/EDR recorders – uncertainty of vehicle's speed and trajectory determination

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Abstract

One of the basic tasks of the accident reconstruction is to define values of parameters of participants of the accident before its actual occurrence. The assessment of correct behaviours is made and the court decides whether the accident participants are guilty or innocent. Therefore, the credibility of specific values is essential. The use of so-called accident recorders – EDR/ADR type of devices, as an alternative compared to classical methods for accidents reconstruction – has become more common over the past years. The paper includes basic notions related to his type of devices, describes potential sources of uncertainty of the car motion reconstruction results obtained on the basis of their records. The examples presented confirm their usefulness, however, they also indicate possible significant errors in the motion parameters assessment if simplified devices are used (where vehicle body lean movements in motion are not analysed).

Keywords: accident reconstruction, EDR/ADR recorders, uncertainty, vehicle dynamics, simulation

1. Introduction

Often a lack of a lot of key information on the course of an event is the essential problem while reconstructing accidents. For more than 50 years in aviation the so-called "black boxes" are used i.e. devices that continuously record a number of selected parameters for purposes of potential reconstruction of a crash (data characterizing a flight, status of the plane components, also voice, and recently also image from the pilots cockpit). The oldest devices recording quantities that describe motion of vehicles in road transport are tachographs. To a limited extent

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their records may be useful in reconstruction of accidents. In 90-ties of 20th century EDR (Event Data Recorder) devices occurred reminding aerial “black boxes”. Those are special devices meant for the accident reconstruction purposes. The may also be found under another English name: ADR (Accident Data Recorder) or German UDS (Unfalldatenspeicher). Further on in the paper, the acronym ADR shall be used for this type of the device. Potential advantages in using this type of devices seem to be considerably high. First of all, the information resource on the course of the event becomes more extensive. The basic advantage is the fact that here we use the values being measured in real road situation, not the ones assumed by an expert during the hereto analysis. Therefore, the problem of uncertainty of the assumed values of parameters, describing the situation being analysed as well as inadequacies of the analysis effecting from simplifications in applied mathematical models of the vehicle/s motion, their collisions, etc., does not occur. Whenever the “black boxes” records are used, there is also a simplification of the accident reconstruction process. A relevant algorithm for processing recorded parameters of the vehicle motion allows for reconstructing time-spatial relations of the situation that has occurred.

However range and other specific parameters of the ADR device can affect accident analysis results. In the paper author presents description of typical devices that are used, possible sources of vehicle motion reconstruction uncertainty. The exemplary simulation tests show significant possible errors for typical devices that are available on the market.

2. ADR/EDR recorders

ADRs have been offered for many years. Some of ADRs are vehicle OEM installation, other (e.g. 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 register selected parameters of a car movement (acceleration, body orientation angles or corresponding to them angular velocities). They can also register driver’s activity (e.g. the use of external lighting and other control elements) and environment conditions (e.g. temperature, moisture). The sphere of activity of these devices (number and type of registered values, time, method and frequency of registration) varies (see for example [1, 6, 7]).

From number of quantities that describe car body motion we can distinguish two groups of devices (see Fig. 1). The simpler ones, named here as ADR2, register car’s longitudinal and lateral accelerations and yaw angle only. More advanced devices, named here as ADR1, register in addition vertical acceleration and two angles (or angular velocities) of a car body – roll and pitch angles.

In most cases of the devices, their operational rule is as follows. All quantities are monitored on the ongoing basis. Recording on a hard memory disk commences only at the moment of collision occurrence (localised on the basis of the exceeded threshold acceleration values). Since that moment, a history is recorded from a few up to several seconds backwards with frequency ranking between a few and up to several dozens of Hz [6, 7] (in some devices it is only 1Hz). Then, a collision phase is recorded. Often that recording is saved with much higher frequency than for the motion phase before the collision (even 1000Hz, [6]). It usually lasts a few hundred milliseconds. In many devices, a post-collision phase is also saved (several seconds up to even a few minutes) with a frequency as for the pre-collision phase or much higher.

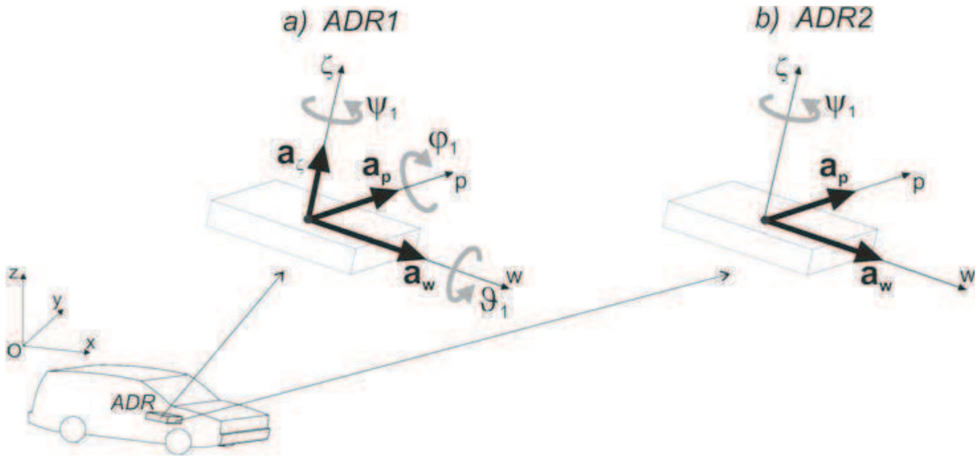

Fig. 1. Two types of ADR: ADR1 & ADR2 (w, p, ζ – accelerometer axes: longitudinal, lateral, and "vertical")

Some devices are equipped in GPS receiver allowing for localization of the place of the accident and for sending automatic information about it to relevant services [1, 6, 7].

3. Sources of uncertainty

In general, there are a few potential sources of uncertainty in motion reconstruction using the ADR records. It has been symbolically illustrated on Fig. 2. The reconstruction error ΔE (understood as a difference between values of parameters, describing vehicle motion and that have been defined based on ADR 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.

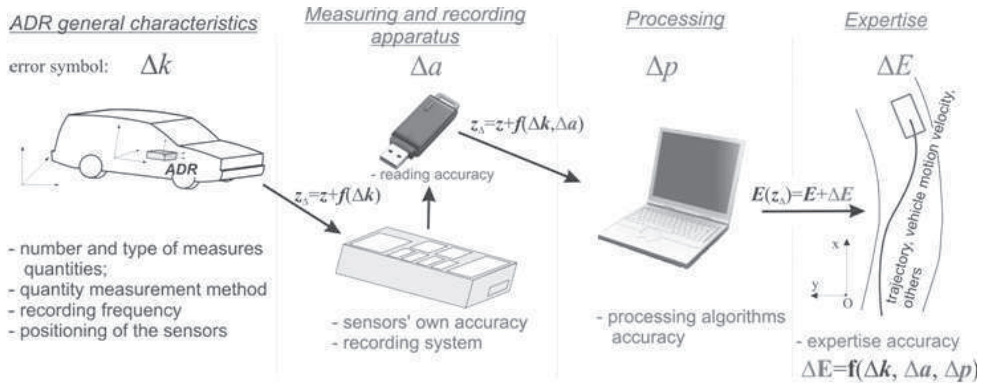

Fig. 2. Sources of uncertainty in car motion reconstruction based on records of ADR devices

This paper shall focus on the first source out of those mentioned. It will be first of all presented how in ADR2 type of device omission of assessment of certain quantities, defining vehicle kinematics, affects uncertainty of the vehicle motion reconstruction.

4. Research method

The simulation method is convenient for assessing uncertainty 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.

General diagram of simulation method of research is presented on Fig. 3. 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.

The program ZL3DSYM [5], which had been made available by its author, was applied for car motion simulation computations. The program uses a complex car motion model, which corresponds to a passenger car with front independent suspension and rear dependent one. The ZL3DSYM program has been successfully experimentally verified [5].

Vehicle motion simulation results were used as input data for simulation of ADR records. A detailed description of the ADR records model is included under [2, 3]. Under the model, an assumption was made of mutually perpendicular system of transducers axes, located at random against the vehicle body. Moreover, the fact that acceleration transducers, besides real component of acceleration of ADR fixing point, also measure relevant components of gravitational acceleration has also been taken into consideration. In case of longitudinal and lateral acceleration transducers those "additional" components were treated further as readings error that was a serious reason behind the motion reconstruction error. The pair "vehicle model + ADR model" was also experimentally verified. Good results of the verification, which are presented e.g. in [4], enable to use this method in analyzed problem.

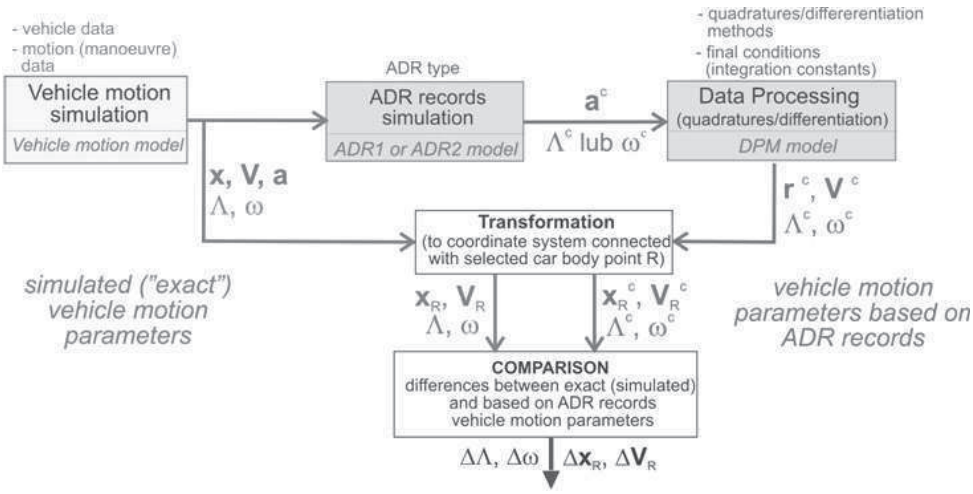

Fig. 3. Motion reconstruction accuracy assessment method based on ADR devices records. a, V, ω, r, Λ – components vectors (respectively): acceleration, velocity, angular velocity, position, angles

Reconstruction of the motion involved a respective, for a given device (ADR1 or ADR2) configuration, processing of ADR records (DPM model). The basis for the procedure was integration of registered accelerations, transformed into inertial system, related to the road. Numerical integration was being performed starting from a set final moment corresponding to a known position of the vehicle.

As a final effect, a reconstructed runs of a track and velocity of a selected car body point have been achieved. Comparison of those runs with analogical quantities registered directly in the experiment or achieved as a result of simulation was the basis for assessing uncertainty (potential error) of the reconstruction.

5. Exemplary research results

All the computations were performed for a middle class passenger car. An assumption has been made in all examples, that the ADR device is fixed under the driver's seat, and its sensors' axels have been levelled for a stand-still car with a "partial" load (weight of about 1350kg). The results that are presented hereinafter correspond to characteristic manoeuvres: straight-line braking and turn entering manoeuvre.

5.1. Braking in rectilinear motion

The example presented on Fig. 4 and 5 is related to straight-line braking from velocity of 100 km/h down to zero (the manoeuvre was forced via a process of the brake pedal force). Fig. 4 presents processes of acceleration components in point of the ADR device fixture: longitudinal acceleration a_w (a). Accurate values have been marked a_w, indications of accelerations sensors a_w^c, and differences among them – indications errors Δa_w^c. Fig 5 a and b show results of the manoeuvre's reconstruction (from the end time backwards – the fact being marked by an arrow) for the two earlier mentioned types of the ADR device: ADR1 and ADR2: car velocity V (b) 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%. Both quantities are excessive for his type of device. The main cause is in the occurrence of error Δa_w^c. The latter however results from first of all a change in longitudinal yaw angle of the vehicle body as affected by the inertia force. If we hold records of the ADR1 device that records information on such angular motion, we may define a value of the error and respectively correct the values of accelerometer readings. There is no such possibility for ADR2 type of device.

Fig. 6 presents, only for ADR2 device, a dependence of the initial velocity V_0 reconstruction results and the braking distance S_h from brake pedal force (and thus indirectly from intensity of braking). The case of braking is analyzed from initial velocity V_0=100 km/h. Fig. 6a presents average acceleration value of the vehicle (accurate value and generated for ADR device), Fig. 5b shows the length of the braking distance. Fig. 6c and 6d illustrate the reconstruction errors of initial velocity and braking distance in absolute (c) and relative form (d).

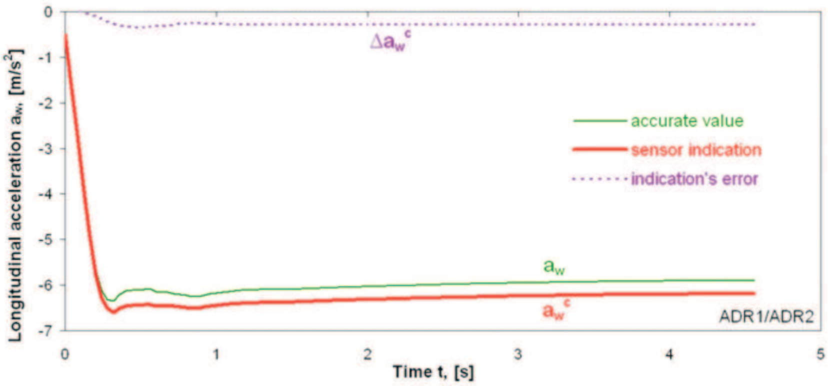

Fig. 4. Straight-line braking from velocity of V_0=100km/h. Time history of vehicle longitudinal acceleration (a) – accurate values and based on ADR sensor

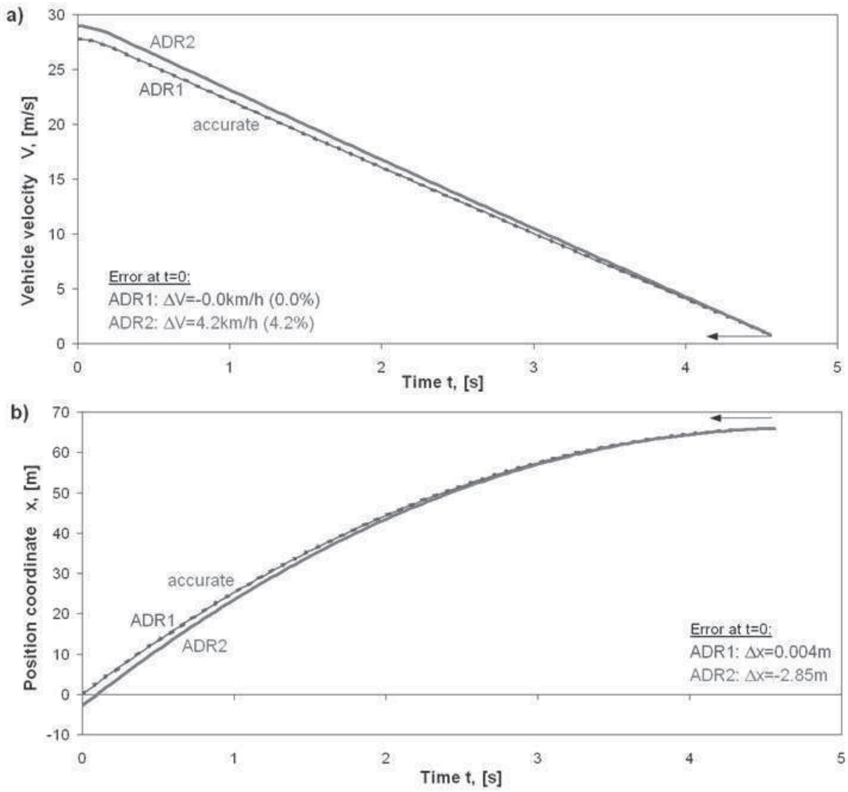

Fig. 5. Straight-line braking from velocity of V_0=100km/h. Time histories of vehicle longitudinal acceleration (a), the reconstructed velocity of the vehicle (b) and "x" position on the road (c): accurate values and based on ADR1, ADR2 records

In order to explain the reasons of reconstruction errors that occurred (Fig. 6 c, d), two overlapping phenomena have to be taken into account. The first is related to the pitch angle of the car body. The higher is intensity of braking the higher is the angle, and thus the error determining the acceleration ($\Delta a_w^c = a_w^c - a_w$) becomes higher (higher is the value of gravitational acceleration component being "detected" by the sensor) – this is visible on Fig. 6 a. This is resulting in higher reconstruction error for all levels of braking intensity. On the other hand, the absolute value of the vehicle acceleration keeps growing, more intensively in the initial phase than the above-mentioned error Δa_w^c. In its turn, this influences the time of braking and thus the period in which at reconstruction we use the value that is burdened with error Δa_w^c. This effect acts towards reducing the reconstruction error. Jointly the influence of the two phenomena gives a result that is visible at error plots. Error in velocity evaluation keeps slightly growing, and in case of the distance even initially declining. Relative errors do not essentially change in the braking intensity function; although for higher value of the braking intensity they slightly grow (this is related to a lower accumulation of the braking intensity in this area).

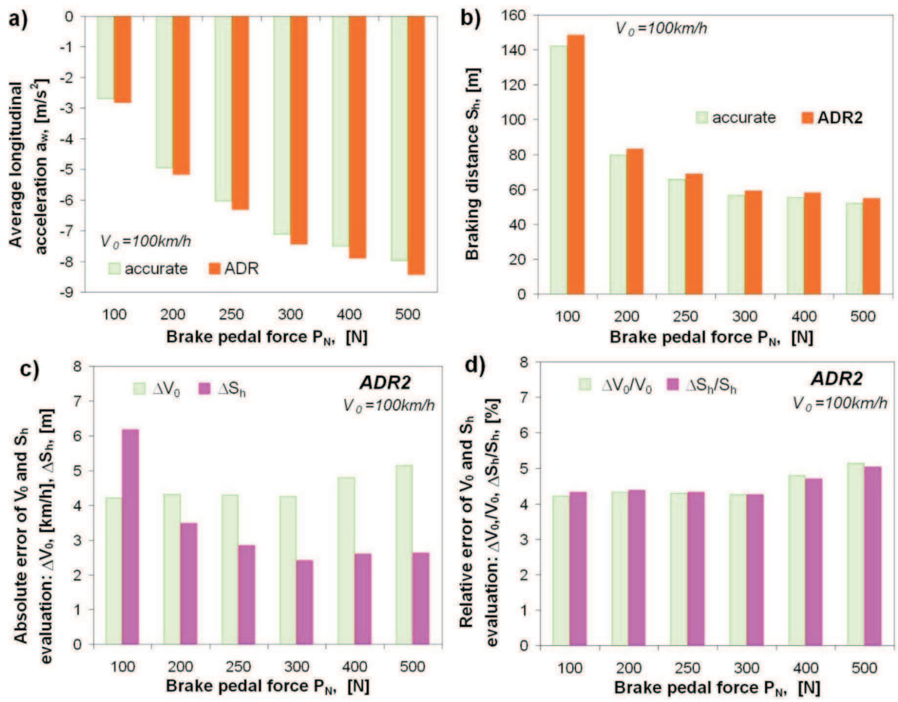

Fig. 6. Braking in rectilinear motion from velocity of V_0=100km/h. Average values of the vehicle longitudinal acceleration: accurate and according to ADR (a), the reconstructed, by using ADR2, length of the braking distance S_h (b), absolute errors of initial velocity reconstruction and braking distance (c), relative errors of initial velocity reconstruction and braking distance (d), in a function of the brake pedal force P_N

In addition, the papers [2, 3, 4] also indicate that vehicle load can also affect reconstruction results being obtained. Significant here is the level of the load at which the device sensors have been calibrated ("levelled"). In the event of the manoeuvre under the analysis, a higher vehicle load than that during calibration of the sensors will lead to insignificant reduction of the reconstruction error – see [4].

5.2. Turn entering manoeuvre

Another example is the reconstruction of the turn entering manoeuvre. Such a manoeuvre was being excited by the angle of the steering wheel rotation in a form of a fixed value proceeded by the linear ramp input (as a time history). The value of the steering wheel rotation angle has been matched in the way to obtain large values of lateral acceleration for a given configuration of the vehicle parameters (load, velocity). For presentation purposes, an example has been selected where set value of the steering wheel angle is 1.6 rad, while the ramp input period is 0.3 s. The manoeuvre starts after 0.5s from the initial moment (t=0). Fig. 7 presents the time history of vehicle lateral acceleration a_p (accurate value and ADR sensor reading).

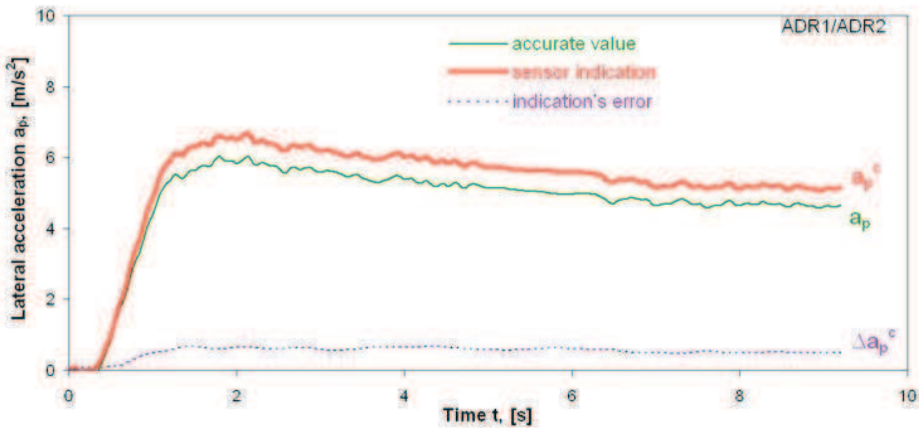

Fig. 7. Turn entering manoeuvre at a velocity of V_0= 60km/h. Time history of the vehicle lateral acceleration – accurate values and based on ADR sensor

When reconstructing the motion, three variants were considered, depending on the moment of the manoeuvre completion, see also Fig. 8:

A: y^k=7m – the moment, when the lateral position of the vehicle mass centre (in direction y) is higher than 7m; the assumption has been made that practically it reflects the situation when the vehicle, moving on straight double-lane road (with a shoulder), left its area while making a turn manoeuvre.

B: ψ_1^k=90° – the moment, when driving on the road arch the vehicle makes a 90° turn (yaw angle ψ_1 = 90°).

C: ψ_1^k=180° – the moment, when driving on the road arch the vehicle makes a 180° turn (yaw angle ψ_1 = 180°).

The reconstruction results for ADR2 type of device are shown on Fig. 9. It is the time history of the vehicle velocity (Fig. 9a) and the body C.G. trajectory (Fig. 9b). In both cases, the accurate plot (the result of the vehicle motion simulation) has been marked and the reconstructed ones for the aforementioned variants of the manoeuvre completion (symbols: ●, ▲, ■ stand for a moment and final position for the variants A, B, C, respectively).

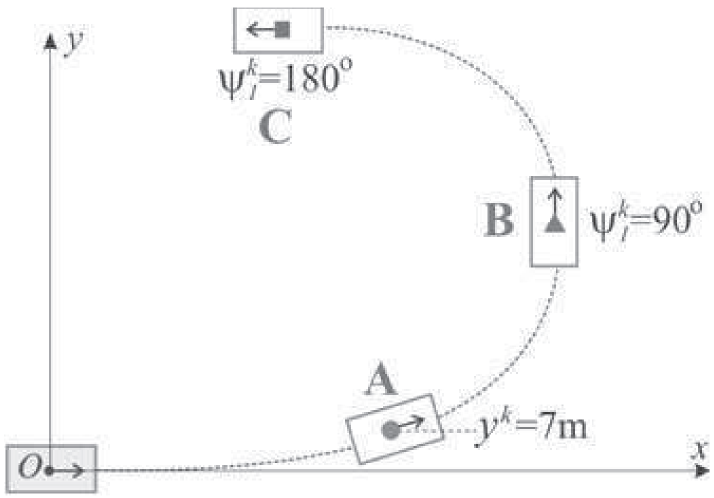

Fig. 8. Turn entering manoeuvre. Considered variants of the manoeuvre completion

On figures referring to velocity, values of reconstruction errors have been provided in their initial moment (t=0) in absolute and relative form. Trajectory charts include absolute errors of longitudinal and lateral position of the mass centre (marked as Δx, Δy), and the error referring to a distance travelled by the vehicle (marked as ΔS, here also in relative form).

In case of variant A (y^k=7m), we have got quite good accordance of velocity and slightly worse of the motion trajectory. Absolute error of the lateral position (Δy) in the initial moment is significant (reaching 1.42m), however, the remaining parameters vary in a range of 1-2%.

If we start reconstructing the vehicle motion from later moments (corresponding to "farther" position on the road), then the situation will change considerably. The reconstruction errors will become very significant. For velocity, in variant B, the error has exceeded 10%, while in variant C – it reached almost 20%. From the situational assessment point of view (made by expert), those values are much too high. The case of trajectories is similar. The initial positions, generated through the reconstruction, are far from being "realistic". The differences range several meters (about 6 m in variant B and almost 16 m in variant C). This basically undermines the sense of such reconstruction. Similar results are in case of travelled distance. In variant B, the relative error reached "only" 5.7% (the absolute error 4.34 m), but already in variant C – ca. 11.6% (in absolute form 15.8 m).

Results similar by their quality have been achieved for other parameters of the motion (velocity, turning intensity) or the vehicle (see e.g. [2, 3, 4]).

The reconstruction results for ADR1 type of device are practically the same as the accurate ones (that is why they have not been presented on the diagrams).

6. Conclusion

Solutions of ADR/EDR devices being offered nowadays on the automotive market differ at number of quantities being recorded. Author of this research work has focused his attention on assessment of the impact of simplifications applied therein, described in the main body of this paper, on uncertainty of values of the key parameters, defining the vehicle motion (velocity, motion trajectory), essential at e.g. reconstruction of road events for the justice authorities. The main focus was on a concept of the device.

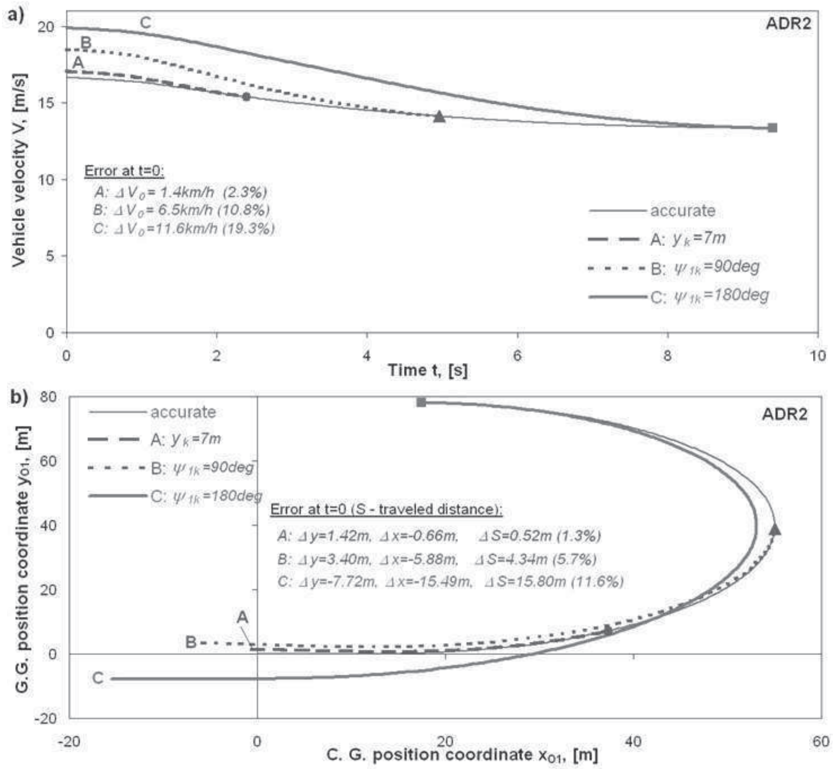

Fig. 9. Turn entering manoeuvre at a velocity of V_0= 60km/h. The reconstructed, using ADR2, velocity of the vehicle (a) and a trajectory of mass centre motion (b)

Based on simulation research it has been proven that the applied simplifications in many solutions of ADR may lead to considerable errors in the motion reconstruction. This mostly refers to reconstruction of the vehicle motion trajectory. Also in case of velocity reproduction, a result that is significantly different from the real one is possible. The basic reason for it is that devices of ADR2 type do not provide information on angles of the car body orientation. No essential errors of the reconstruction have been found in case of devices of ADR1 type.

The size of the error in reconstruction of the motion parameters, both in a qualitative and quantitative sense, is affected by: a type of manoeuvre under analysis (rectilinear/curvilinear motion, its parameters (e.g. vehicle acceleration level), time of the manoeuvre duration. The experimental studies (see e.g. [2, 3, 4]) also prove that properties of the vehicle itself may also affect the reconstruction accuracy.

A wider scope of research results, confirming the above statements and delivering more detailed information can be found e.g. in papers [2, 3, 4].

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