

RECONSTRUCTION OF TRAFFIC SITUATIONS FROM DIGITAL VIDEO-RECORDING USING METHOD OF VOLUMETRIC KINETIC MAPPING

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Abstract

In the past the traffic accident reconstruction was based in principle only on indirect methods that use accident marks and witness reports. These data were then used within backward reconstruction of event for determination of motion status of accident participants and expression of desirable quantities as are initial velocities, impact velocities, distances travelled or temporal conditions. These methods and their accuracy are dependent on the width of intervals of input quantities or on limited possibilities for motion synchronization between numerable participants of road traffic accidents. Existence of footage from CCTV cameras that captures traffic situations presents very valuable source of information about these accidents. The goal of the article is proposal of a volumetric kinetic mapping (VKM) method of accident reconstruction from CCTV footage. The method is based on synthesis of videoediting, videoanalysis and kinetic simulation using dedicated software for accident reconstruction. The method was furthermore validated for speed-time and distance-time variables by means of experimental test runs and by subsequent application of the method in the reconstruction of these tests using PC-Crash simulation software and two videoediting software packages. Results of the reconstructions of validation runs using VKM method were then verified by comparing them to the measured data from Corrsys Datron Microstar measuring system.

Keywords: traffic accidents, near-miss incidents, videoanalysis, accident reconstruction, PC-Crash

1. Introduction

Usability of accident reconstruction methods used most often in the past is in the current time period limited: absence of visible braking or skidding marks is almost standard, accurate estimation of deformation energy using synthetic quantity EES is bounded with existence of known value of deformation energy of similar crashtested vehicle [12], analyzing of splinter field can not be used for serious estimation of impact speed, only for estimation of collision area, etc. Retrieval of crash data from EDR (Event Data Recorder) unit is, on the

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other hand, limited in the EU due the small penetration of the market with EDR equipped vehicles.

Technological and technical advancement however causes that additional source of accident relevant data are often at disposal for forensic expert – digital video-recording of the traffic event that was captured either by security camera mounted statically in public places, or on-board camera mounted in the interior of a given vehicle. This digital video-recording intrinsically contains spatial and temporal information about the event and thus readily offers itself for quantitative reconstruction of a given event.

The goal of this article is presentation and validation of a new method of accident reconstruction from digital video-recording of static mono-camera using PC-Crash simulation software.

2. Reconstruction of traffic events using a method of volumetric kinetic mapping

Numerous works were published in the past on the topic of accident reconstruction using video footage, e.g. [3], [10] and [11]. A number of the published works deal with the reconstruction of the traffic situations from static camera, i.e. CCTV footage, e.g. [4], [5] and [7]. Another set of works presents procedures for reconstruction of traffic situations from dashcams, e.g. [1], [6] and [16]. Above stated methods use different approaches for object position identification within the video footage: virtual reality [9], close range photogrammetry [13] or 3D laser scanner [2]. Almost all presented methods are exclusively based on kinematic principles whereby positions of objects (road vehicles and other traffic participants) in time points $t_1 \dots t_n$ are identified on the video frames and using distances between these positions and time interval between two sequential video frames, the average speed between these two frames is calculated using basic kinematic equations.

Methods based on a kinematic principle have following disadvantages:

- Reduced accuracy of reconstruction influenced by parameters of videorecording: frame rate, resolution of video-recording, optical distortion, position of camera.
- Only limited set of obtainable quantities and their scope - only basic kinematic variables can be calculated (average speed, average acceleration), possibility of obtain quantification of given quantities in time domain is limited by camera frame rate, it is not possible to get directly the values of kinetic variables.
- Results of reconstruction of the dynamic event from static mono-camera is applicable only in 2D space, for the reconstruction of the movement in 3D space at least 2 non-colinear cameras are necessary.

For the purpose of complex utilization of video-recordings of road traffic events and resolving of above stated deficiencies we developed a new method of reconstruction of the movement of road vehicles from the recording of static camera (e.g. security CCTV camera) – method of volumetric kinetic mapping (VKM).

Method of volumetric kinetic mapping has the following basic tenets:

- VKM method is a fusion of video-recording and kinetic numerical simulation using simulation software for analysis of traffic accidents (e.g. PC-Crash). Method can be described as mapping of the movement of simulated vehicles using forward kinetic simulation onto images of the real vehicles recorded in the video in perspective view in time points $t_1 \dots t_n$.
- As the mapping is done using kinetic simulation of physical 3D models of vehicles with all relevant technical data involved (vehicle geometry, vehicle mass, CG position, moments of inertia, steering ratio, suspension properties, tire properties, ABS and stability control properties, etc.) then also additional information about kinetic variables or probable behavior and reaction of drivers can be obtained.
- Identification of vehicle positions in time points $t_1 \dots t_n$ is based on overlays of volumes of simulated and real vehicles and not on marker tracking – this approach makes possible to utilize also video-recording of bad quality with low spatial resolution of vehicle movement (low number of effective pixels covered by a given vehicle).
- VKM method enables accurate reconstruction of vehicle movement from video-recording also in cases with low temporal resolution (video-recording with low frame rate). This statement is based on the fact, that kinetic simulation serves at the same time as interpolant of position and dynamic condition of a given vehicle between two sequential video frames. From the character of kinetic simulation within virtual mathematical physical environment it is obvious that it is not possible to rapidly change speed or acceleration of a simulated road vehicle from one frame to consecutive frame beyond technically acceptable values as the movement status of a given simulated vehicle is tethered to input physical variables which can obtain values only from finite technically acceptable intervals (e.g. the full braking deceleration on dry asphalt surface can be normally from interval 7.5-9.5 m/s²). The simulation is furthermore conditional to intrinsic physical properties of the vehicle (mass, inertia, suspension, etc.).
- Using VKM method also reconstruction of 3D movement of given object is possible using recording only from one camera (e.g. flying phase of the post impact throwing of the pedestrian body, flying phase within the ramp induced rollover accident on highway, etc.) – in contrast to kinematic approach that requires at least 2 non-colinear cameras. This statement is based on the fact that within the VKM method the absence of the second camera is compensated by use of mathematical – physical model of the vehicle within virtual mathematical-physical 3D environment. Reconstruction of object movement in the 3D space is then determined by movement status at the beginning of the 3D movement, by mathematical-physical movement equations (with gravity taken into account) and movement status of the object at the end of 3D movement.

The basic steps of general workflow for acquisition and processing of the relevant input data for reconstruction of road traffic events using VKM method is depicted in Figure 1.

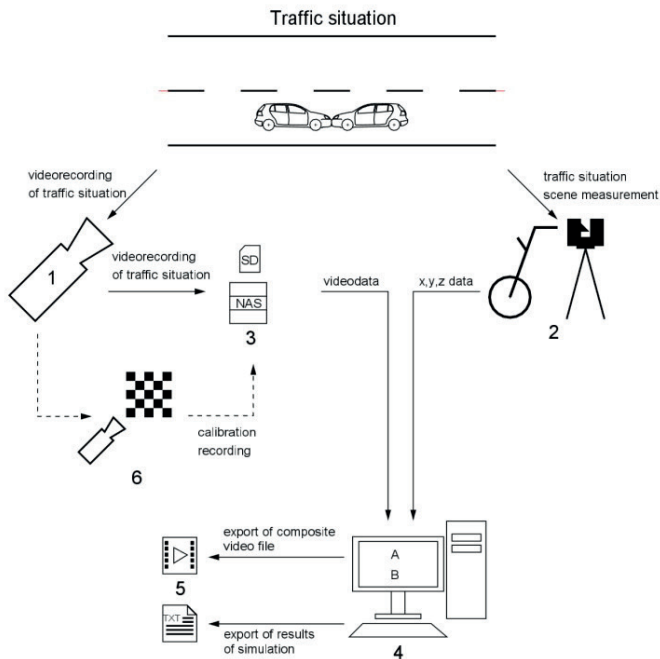


Fig. 1. Schematic depiction of basic steps for acquisition and processing of input data for reconstruction of road traffic events using VKM method

Traffic situation is recorded by static mono-camera (1), captured recording is stored on digital data storage (3) – SD card, NAS, hard disk drive. With mono-camera (1) the rectilinear calibration pattern is recorded and stored on digital data storage (3) for the purpose of camera undistortion. If optical distortion of the camera lens is not severe to influence reconstruction process or calibration profile of camera with similar optical properties is at disposal then this step can be skipped. Using equipment for measuring x, y, z coordinates (measuring wheel, 3D laser scanner, total station, etc.) the topography of the area in which road traffic event did happen is measured and documented and measured x, y, z data are imported into computer (4). Similarly, video data from digital data storage (3) are also imported into computer (4). In the next step the process of road traffic event reconstruction is realized in the computer (4) according workflow described in the following parts of this article. After successful road traffic event reconstruction is realized, then results of the reconstruction (5) are exported from the computer (4): composite video file (video recording of the real traffic event in the overlay with animation of the kinetic simulation) and quantities describing movement of the objects of interest. Based on these results further steps for in-depth analysis of a given traffic situation is possible.

A principle of reconstruction of movement of vehicles and other traffic participants in the computer (4) using VKM method is based on three main tenets:

- Reconstruction of 3D position, rotation angles and focal length of camera (that recorded given traffic event) in the virtual environment of the simulation software for accident reconstruction, or simulation of vehicle driving dynamics respectively.
- Preliminary reconstruction of quasi-static positions of the objects of interest (OI – vehicles, cyclists, pedestrians, etc.) in the time points $t_1 \dots t_n$ and preliminary reconstruction of movement trajectory of these OI.
- Interpolation of these preliminary reconstructed OI positions and trajectories using forward kinetic simulation in iterative approach.

These three basic tenets are complemented with additional processes, which serve for preparation of source video-recording for quantitative mining of relevant physical quantities or for additional processing of reconstruction results:

- Removal of optical distortion of video-recording in such a way that the undistorted video file has rectilinear character.
- Adjustment of brightness and contrast of video-recording.
- Export of animation of simulation from 3D window of simulation software.
- Creation of composite video-file as an overlay of undistorted video file and animation of simulation (synchronized in time).

Succession of individual steps in the whole process can be depicted using general scheme on the Figure 2.

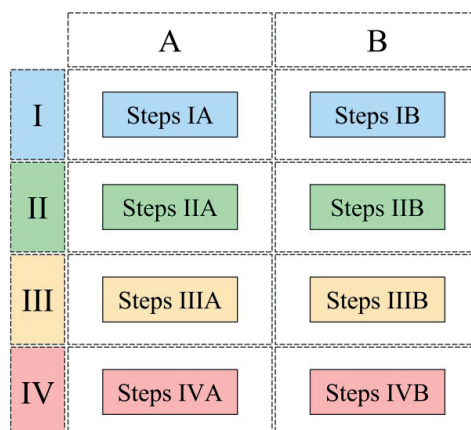


Fig. 2. General workflow scheme of traffic events reconstruction from static mono-camera using VKM method

In the above depicted scheme there is a logical succession of individual steps defined through vertical and horizontal segmentation as follows:

- I. Preparatory phase, that serves for basic preparation of kinetic simulation and for preparation of source video-recording into a state usable for further phases. In this phase the radial optical distortion (fisheye effect) is removed from the video-recording to get

a video-recording with rectilinear character.

- II. Phase of reconstruction of position, rotational angles and focal length of mono-camera (that recorded a given traffic situation). The goal of this phase is to identify all 7 parameters for virtual camera (3 positional coordinates + 3 angle values + focal length) to be as close as possible to parameters of real camera. The result is the view on simulated traffic situation in virtual environment of simulation software in analogical spatial perspective view as is captured by real mono-camera.
- III. Phase of preliminary reconstruction of trajectory and motion status of real objects of interest (ROI) in the time points $t_1 \dots t_n$. Within this phase there are quasi-static positions of ROIs identified in perspective view in video-recording in frames 1...n in time points $t_1 \dots t_n$ (with time interval Δt between these time points). These positions are afterwards identified in 3D environment of simulation software by means of positioning of virtual model of simulated object of interest (SOI) until visual match between ROI and SOI is achieved on given frame. Quasistatic positions thus identified in 3D environment of the simulation software are then marked in ground view of the simulation software. From the positions marked in the ground view the trajectory of ROI is determined and also preliminary determination of motion status of ROI is realized based on kinematic approach using relative distances between consequential positions of the ROIs in time points $t_1 \dots t_n$ and value of time interval Δt .
- IV. Phase during which the kinetic simulation in mathematical-physical simulation software for accident reconstruction or simulation of driving dynamics is realized. Using this simulation the preliminary motion status and trajectory of relevant ROIs is interpolated. This simulation is realized by iterative means whereby first iteration is realized on the trajectory and with motion parameters preliminary identified in the phase III. The simulation accuracy is improved with further iterations. After each iteration the animation of simulation (from the view of the virtual simulated camera reconstructed in phase II) is made and exported as video file. This animation is then compared in overlay with source real world undistorted video-recording in the video-editing software - the time synchronized composite videofile is created from both video files (animation of simulation + undistorted real world video-recording). If there is obvious visual match on each frame of the composite video file between movement of ROI and SOI the reconstruction of traffic situation was successful and further analysis of the event is possible (i.e. collision avoidance analysis in case of traffic accident). If this visual match is not achieved for given iteration of simulation, further iterations are realized until the visual match is achieved.
 - A. Steps realized in simulation software for traffic accident reconstruction or driving dynamics respectively.
 - B. Steps realized in the videoediting software (videoeditor).

General workflow scheme on the figure 2 is modular, i.e. column B can be divided on more sub-columns if the videoediting processes need to be realized in more videoediting software packages (i.e. removal of radial distortion in one software package and rest of editing work in second videoeditor). Practical application of above depicted workflow to specific software packages is shown on the Figure 3.

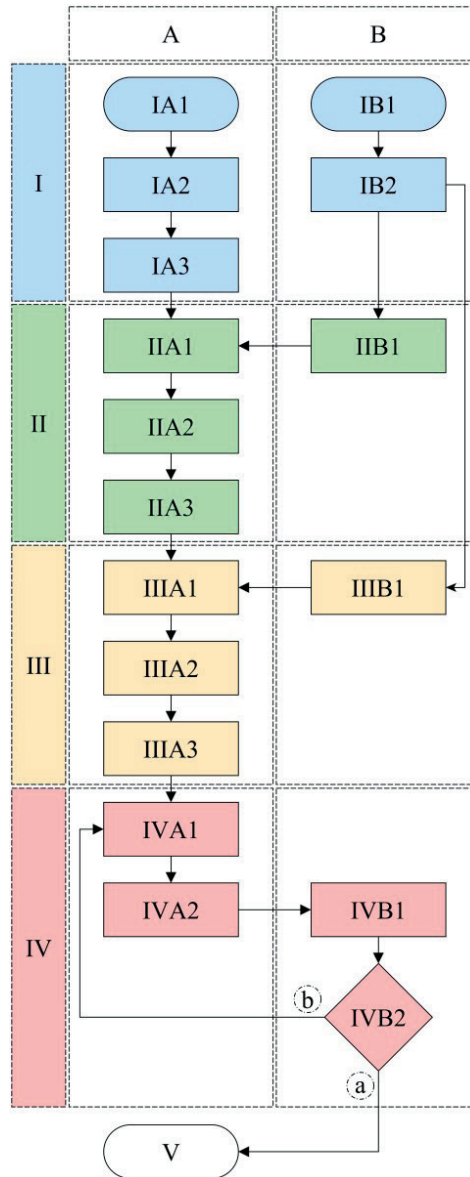


Fig. 3. Scheme for reconstruction of traffic situations from static monocular camera using VKM method

In the simulation software A is within the phase I created project file in step IA1: importing of virtual mathematical-physical model of object of interest (simulated object of interest - SOI) and importing of 2D and 3D CAD model on SOI. In the virtual environment of the simulation software A is then in the step IA2 created 2D or 3D model of topography of traffic

situation that was recorded in the real world by static moncamera. The last step IA3 in the simulation software A within the phase I is marking of aligning points on the topography model of a traffic situation. These aligning points have to be concurrently visible on the real world camera recording.

In the videoeditor B is within the phase I in the step IB1 optical radial distortion of the moncamera lens removed from the analyzed videorecording. Afterwards is the undistorted videorecording (UDV) exported from videoeditor in the step IIB2.

In the videoeditor B is within the phase II in the step IIB1 1 frame with visible aligning points exported from UDV.

The frame with visible aligning points is imported in simulation software A within phase II in step IIA1 as a background image in 3D window. Then the matching pairs of aligning points (i.e. point on topography model and corresponding point on the frame that was used as background image) are marked in the step IIA2 in 3D window of simulation software. Optimization of virtual camera parameters (3D position, rotation angles and focal length of camera) is then realized in the step IIA3 in such way that parameters of virtual camera are as close as possible with parameters of real camera – in that case the aligning points in each pair are visually in mutual overlap.

The frames 1...n from the time points $t_1...t_n$ (in the time interval Δt) are then exported from videoeditor in the step IIIB1.

The frames 1...n are then in step IIIA1 sequentially imported into 3D window of simulation software A as a background image. Subsequently in the step IIIA2 the positioning of the 3D model of SOI is realized in a such way that the volumetric overlap of the SOI over image of ROI on a given frame is achieved, this step is repeated on frame 1...n. Subsequently in the step IIIA the positions of objects of interest in frames 1...n as well as their trajectory are marked in the ground view of simulation software A.

In the step IVA1 is the first iteration of kinetic simulation calculated in such a way, that the motion status and trajectory of SOI are in correspondence with motion status and trajectory of ROI. In the step IVA2 is then animation of simulation iteration exported as video file from 3D window of the simulation software A – parameters of animation (frame rate and resolution) have to be the same as parameters of UDV.

Both video files (created animation of simulation iteration as well as UDV) are then concurrently imported into the videoeditor B in the step IVB1. Afterwards the temporal and spatially synchronized video files in mutual overlap are visually compared in the step IVB2 in videoeditor B (forward placed video file has to have its opacity reduced that backward placed video file is visible through it). If the movement of SOI in the animation of simulation is matching the movement of ROI on UDV then the reconstruction of the traffic situation is finished and the resulting simulation can be used for further analysis in the phase V. If the movement of SOI in the animation of simulation is not in the match with the movement of ROI in UDV then further iterations of simulation have to be performed in the step IVA1 followed by repeated steps IVA2, IVB1 and IVB2 until the match is achieved.

3. Validation of the method of volumetric kinetic mapping – materials and methods

For the purpose to determine accuracy of presented method we realized a set of experimental tests using the following parameters:

- Test vehicle (Citroen C6, 1st generation) was driven by human driver in the field of vision of digital monocamera (GoPro Hero 4 Black [19]). Driver was instructed to start concurrently maneuver of full braking as well as of rapidly steering the vehicle to given direction when the vehicle was at the level of a traffic cone. This driving maneuver made possible to validate the VKM method for change of speed as well as for change of driving direction and thus ensured universal relevancy of validation scenario for real conditions – in the road transport the movement of vehicles is in most cases quasiplanar and consists of the combination of speed change and direction change (or in ideal scenario it is uniform straightforward movement). More complex variants of quasiplanar movement then consists of combination of these two simple movements.
- We used 3 different levels of the vehicle speed (speed before deceleration and steering maneuver): "low speed" – approximately 40 km/h, "medium speed" - approximately 50 km/h and "high speed" – approximately 70 km/h. These speed levels were defined in this way to cover spectrum of travelling speeds typical for city environment. Vehicle was travelling with respect to the camera field of view in 4 modalities: movement to the camera and steering to the right, movement to the camera and steering to the left, movement from the camera and steering to the right and movement from the camera and steering to the left. Each testing scenario (defined by vehicle speed level and directional modality of the vehicle) consisted from 2 test runs. In the summary the test matrix consisted of 24 test runs. Scheme of the experiment is depicted in the Figure 4.

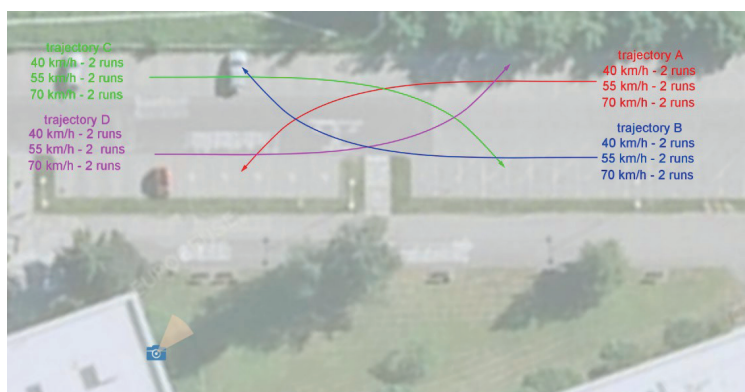


Fig. 4. Scheme of validation experiment

- The test vehicle was equipped with measuring system Corrsys Datron Microstar [20] which enables accurate speed and distance measurement in time domain using

technology based of Doppler principle (Figure 5). Sampling frequency used within the validation experiment was 200 Hz.



Fig. 5. Corrsys Datron Microstar measurement system mounted on the test vehicle

- Camera used as a static moncamera (GoPro Hero 4 Black) was positioned in such a way, that the test runs were recorded in perspective view and wide field of view was used – horizontal field of view – 118,2°; vertical field of view – 69,5° [19]. This camera setup ensured significant optical radical distortion with fish-eye effect.
- Camera recorded given situation at the resolution of 1920x1080 pixels with the framerate 50 frames per second. This setting was used only for identification of temporal synchronization point (video frame) between camera recording and Corrsys Datron Microstar system. This original videorecording was then reduced in quality to the resolution of 1024x576 pixels with the framerate 10 frames per second. Video file with these parameters (1024x576 with the framerate 10 frames per second) was then considered in the subsequent processes as source video file. This reduction in quality of videorecording together with significant fisheye effect of the camera can be considered as "bad quality" recording (compared to current status of commercially available CCTV systems). Purpose of using this "bad quality" recording for the reconstruction of vehicle movement using VKM method was to evaluate the method for worse case scenario (with respect to what could be expected in "normal" situation).
- Synchronization between camera recording and Corrsys Datron Microstar was achieved using in-house made optical synchronization device which was operated by front right passenger of the test vehicle. Engaging the central switch of this device the high brightness LED stripe was lighted up and concurrently this event was marked in the data recording of the Corrsys Datron Microstar system (Figure 6).



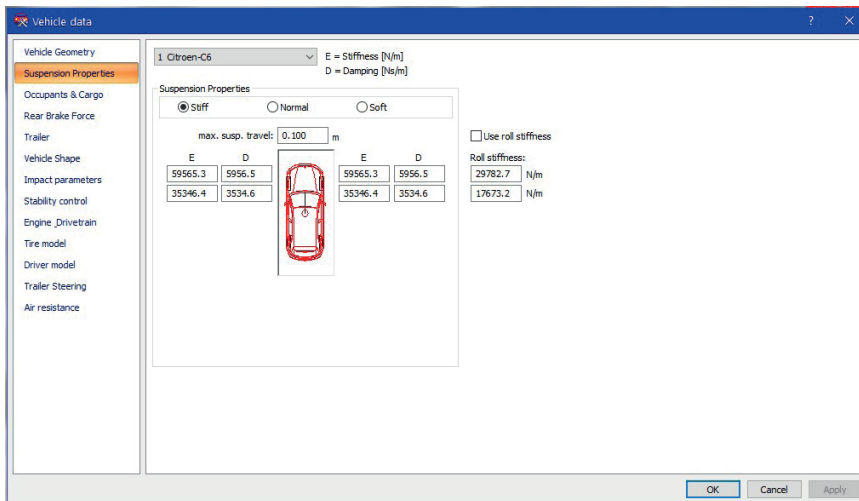
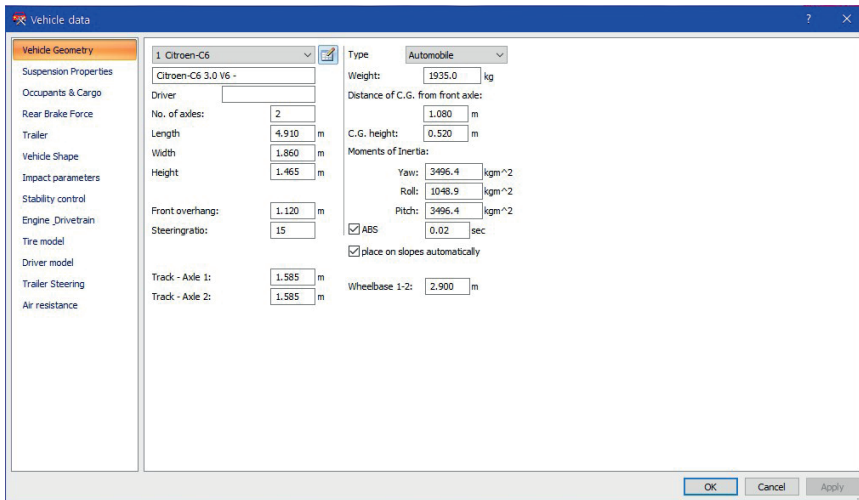
Fig. 6. View at synchronization LED strip

- For the reconstruction of the vehicle movement from the videorecording using VKM method the PC-Crash 11.1 simulation software [17] was used, removal of the optical radial distortion was performed in the proDAD Defishr V1 [21] software and for videoediting purposes the HitFilm Express software package [18] was used. Topography model of the traffic situation was created in PC-Crash from ortophotogrammetry source.

4. Validation of the method of volumetric kinetic mapping – results

Together 24 test runs were realized from which 23 could be used for reconstruction of the vehicle movement using VKM method. One test run (run C3) could not be utilized for the validation purposes due the recording error within Corrsys Datron Microstar system.

The basic input parameters of the simulated vehicle are depicted in the Figure 7.



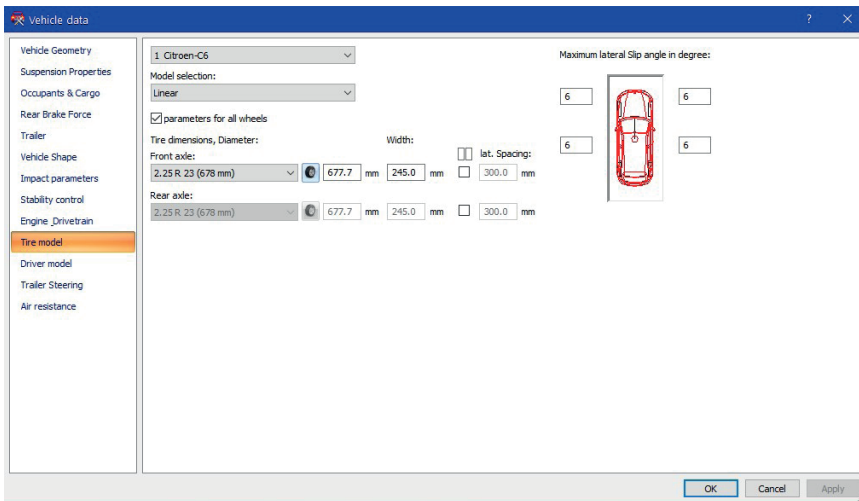


Fig. 7. Parameters of simulated vehicle: upper - vehicle geometry, middle - suspension properties, lower - tires properties

Creation of composite video file for the example frame is shown in the Figure 8. From the source video file the optical radial distortion is removed in proDAD Defishr and video file is also rotated around the optical axis of the camera (in PC-Crash only horizontal and vertical angle of the camera angle can be adjusted so rotation around optical axis of the camera has to be substituted with the rotation of the video file). After successful reconstruction of vehicle movement is realized in the PC-Crash using kinetic simulation (used mathematical-physical models for kinetic simulation are described in [14]), the animation of the simulation is exported from 3D window of the PC-Crash with the same parameters as the source video file and with the topography model visibility turned off to decrease clutter in the composite video file. Afterwards both undistorted/rotated video file and animation of simulation are imported into HitFilm Express and moved into overlay with opacity of the forward video file decreased. Simulated vehicle can be then seen as "mapped" onto real vehicle.



Fig. 8. Creation of composite video file shown on one frame: upper left – source (distorted) video, upper right – animation of simulation in PC-Crash (topography model depicted), middle left – undistorted and rotated video, middle right – animation of simulation in PC-Crash (topography model not showed), lower – composite video file

In the Figure 9 the frames from composite video file of the vehicle movement reconstruction using VKM method for the test run A6 are shown in time step 0,5 s (succession is left-right and up-down).



Fig. 9. Result of the vehicle movement reconstruction using VKM method - frames exported from composite video file in time step 0,5 s (test run A6)

Graphs depicting speed – time and distance – time dependencies for 23 reconstructed test runs using VKM method can be seen in the Figure 10-13. The presentation of the data in the graphs is following: the data obtained from Corrsys Datron Microstar system are depicted in red color, the data obtained from PC-Crash are depicted in blue color.

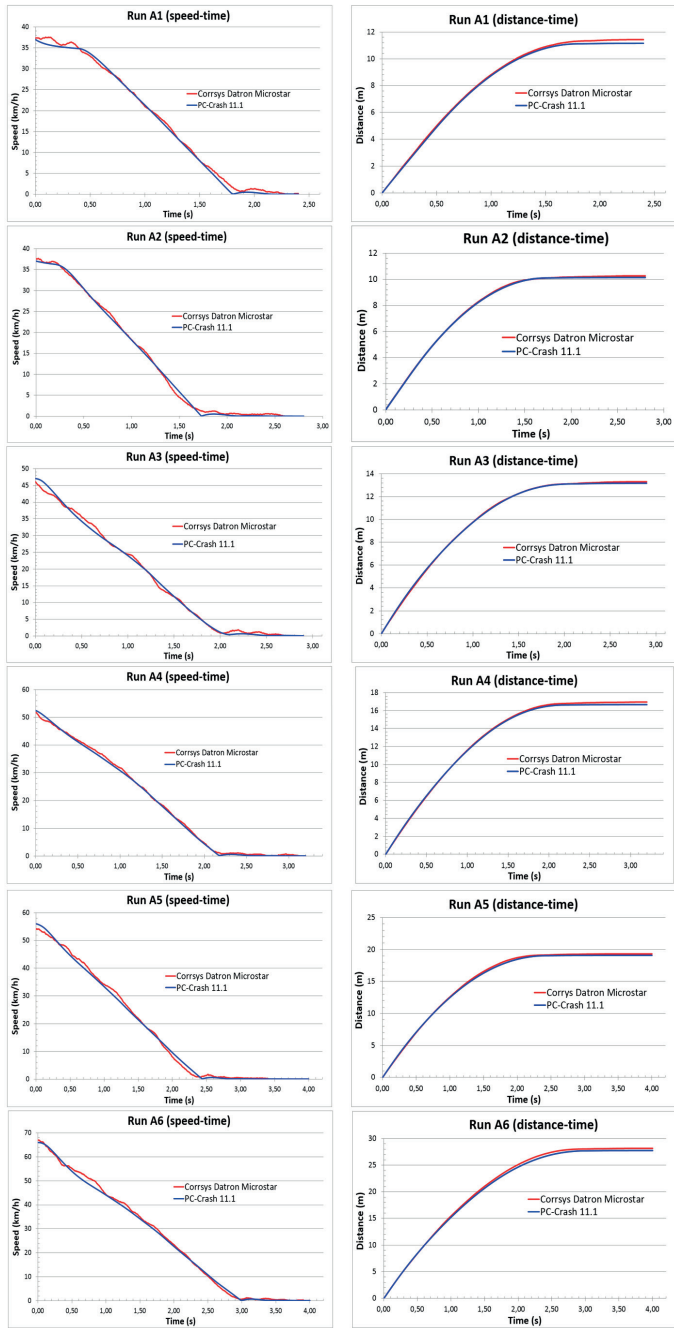


Fig. 10. Diagrams "speed-time" and "distance-time" for the trajectory A

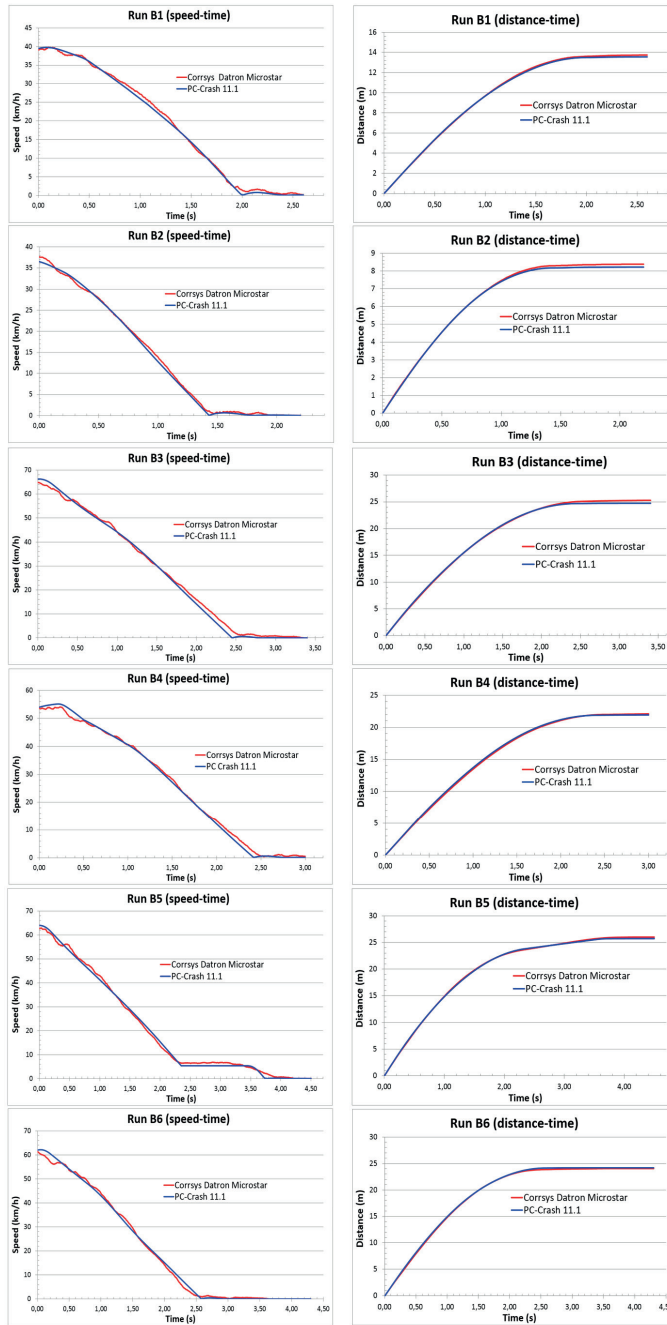


Fig. 11. Diagrams "speed-time" and "distance-time" for the trajectory B

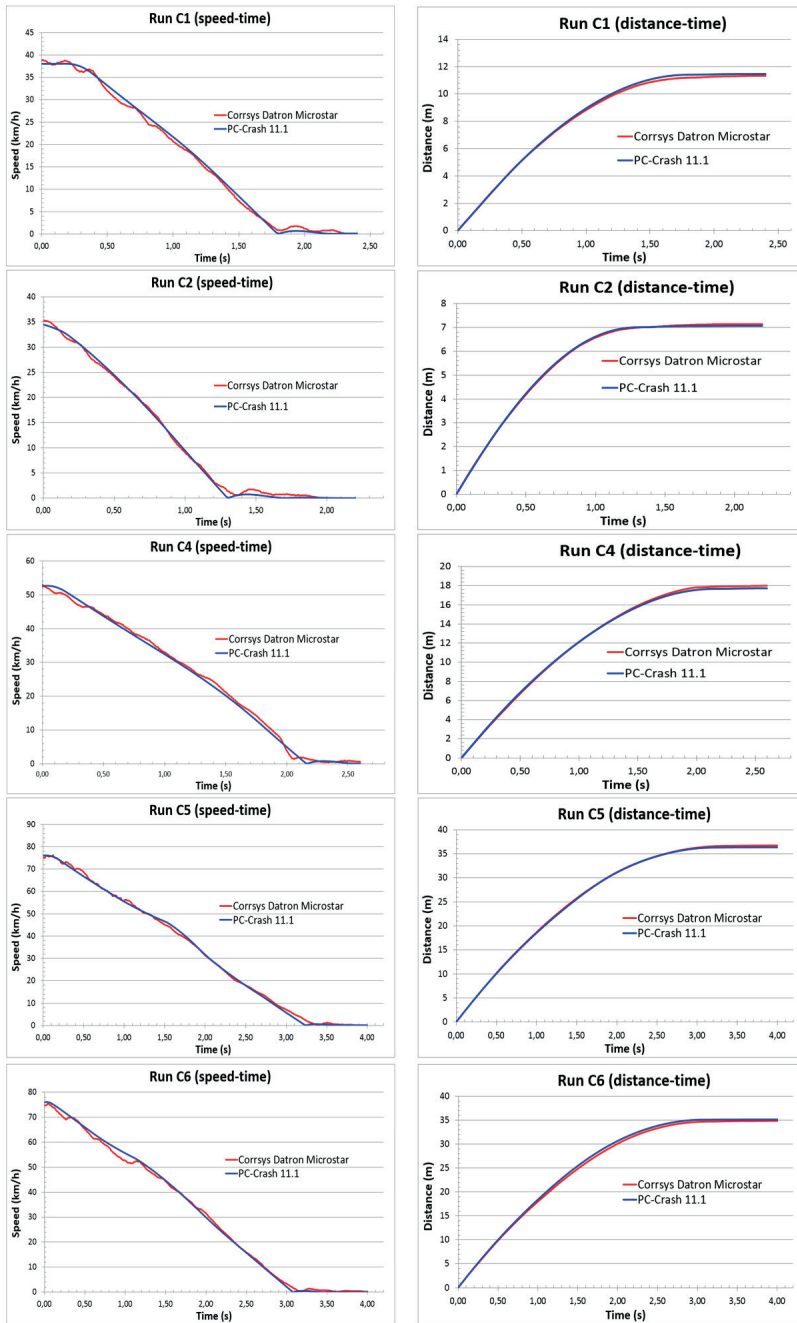


Fig. 12. Diagrams "speed-time" and "distance-time" for the trajectory C

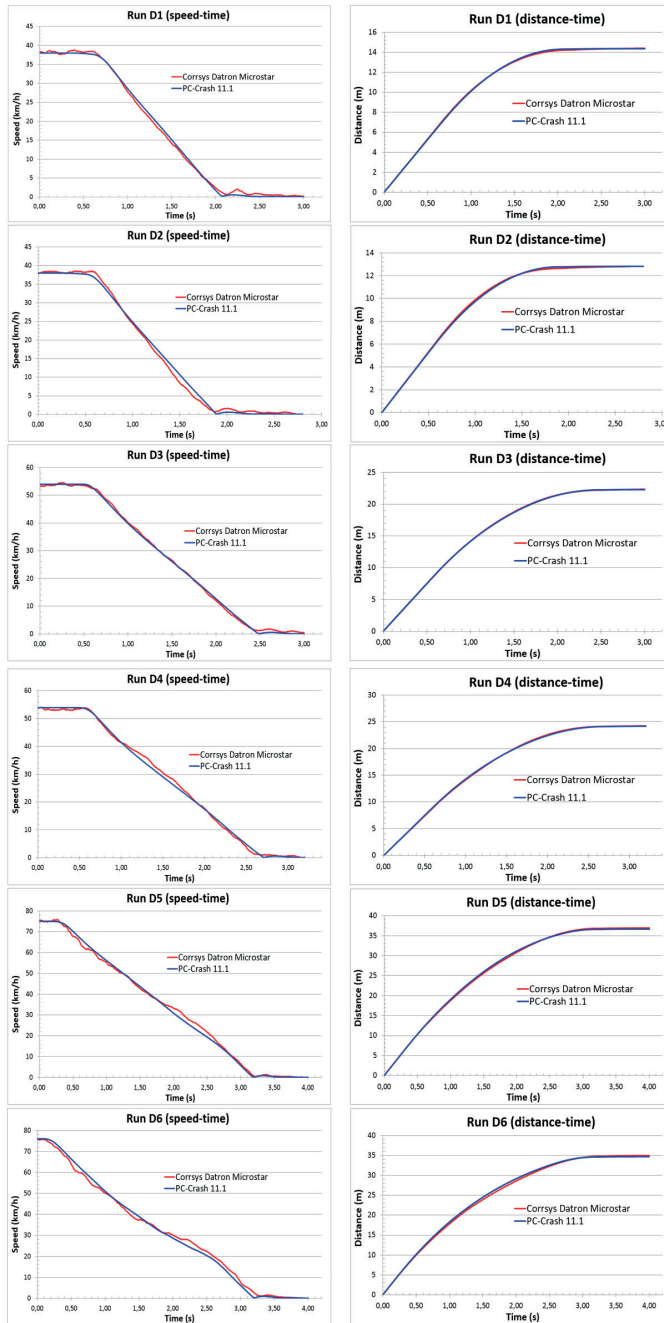


Fig. 13. Diagrams "speed-time" and "distance-time" for the trajectory D

In the table 1 the comparison between measured and calculated values of the speed at the beginning of the reconstructed scenario (starting at the synchronization point) as well as total travelled distance are presented.

Tab. 1. Difference between measured and calculated values

RUN	SPEED				DISTANCE			
	Actual (km/h)	Simulated (km/h)	Difference (km/h)	Difference (%)	Actual (m)	Simulated (m)	Difference (m)	Difference (%)
A1	37.26	36.98	-0.28	-0.75	11.42	11.16	-0.26	-2.28
A2	37.53	36.99	-0.54	-1.44	10.25	10.12	-0.13	-1.27
A3	46.17	46.99	0.82	1.78	13.31	13.17	-0.14	-1.05
A4	51.75	52.48	0.73	1.41	16.95	16.64	-0.31	-1.83
A5	54.09	55.91	1.82	3.36	19.34	19.08	-0.26	-1.34
A6	66.96	65.99	-0.97	-1.45	28.17	27.74	-0.43	-1.53
B1	39.06	39.51	0.45	1.15	13.75	13.54	-0.21	-1.53
B2	37.53	36.49	-1.04	-2.77	8.37	8.21	-0.16	-1.91
B3	64.89	66.30	1.41	2.17	25.25	24.75		-1.98
B4	53.55	54.01	0.46	0.86	22.08	21.93	-0.15	-0.68
B5	62.73	63.99	1.26	2.01	26	25.73	-0.27	-1.04
B6	61.47	62.01	0.54	0.88	24.05	24.18	0.13	0.54
C1	38.79	38.00	-0.79	-2.04	11.32	11.46	0.14	1.24
C2	35.28	34.49	-0.79	-2.24	7.13	7.06	-0.07	-0.98
C3	NA	NA	NA	NA	NA	NA	NA	NA
C4	53.01	52.51	-0.5	-0.94	18.01	17.73	-0.28	-1.55
C5	74.97	76.00	1.03	1.37	36.68	36.35	-0.33	-0.90
C6	74.70	76.01	1.31	1.75	34.85	35.1	0.25	0.72
D1	38.34	38.00	-0.34	-0.89	14.38	14.36	-0.02	-0.14
D2	37.71	38.00	0.29	0.77	12.82	12.83	0.01	0.08
D3	53.37	54.00	0.63	1.18	22.36	22.29	-0.07	-0.31
D4	53.91	54.00	0.09	0.17	24.22	24.13	-0.09	-0.37
D5	75.42	75.00	-0.42	-0.56	36.94	36.64	-0.3	-0.81
D6	75.60	76.00	0.4	0.53	34.93	34.7	-0.23	-0.66
MEAN	-	-	0.24	0.27	-	-	-0.16	-0.85
STD.DEV.	-	-	0.83	1.61	-	-	0.18	0.91
MIN	-	-	-1.04	-2.77	-	-	-0.5	-2.28
MAX	-	-	1.82	3.36	-	-	0.25	1.24

5. Discussion

The graphs in Figures 10-13 clearly show good quantitative as well as qualitative agreement between results obtained from PC-Crash simulation using VKM method and real world measured values. This could be stated both for speed results in time domain as well as distance results in the time domain. In all presented validation cases macroscopic character of the vehicle movement was captured reasonably well. Change of vehicle speed (deceleration due braking) is in accord with the measured values, so deceleration rates could be expected to be estimated realistically and be further used to analyse behavior of the driver with respect to his/her reaction. The match between curves of simulated and measured values in distance – time graphs shows that also trajectory match between simulated and real world vehicle can be expected as the vehicle was moving in the curve and decelerating. Numerical evaluation of accuracy for acceleration/deceleration calculation as well as for accuracy of trajectory reconstruction for given object of interest will be focus of follow-up studies with appropriately designed and equipped experiments.

From the cases presented in Figures 10-13 it is obvious that the kinetic simulation used to map the movement of the real vehicle in PC-Crash using VKM method tends to smooth the real world values for vehicle speed, i.e. the simulation tends to interpolate local increase/decrease of vehicle deceleration value (which can be seen in the graphs in Figures 10-13 as increase/decrease of the slope of the tangent to the speed curve). This difference between simulated vehicle and real world vehicle movement in case of our experiment and with respect to the exact value of acceleration/deceleration would not have impact on the analysis of the traffic situation with respect of estimation of driver reactions as the vehicle is still decelerating rapidly and thus this maneuver would be classified as conscious behavior of the driver. This effect could potentially have impact on classification of certain traffic situations in near-miss incident detection in which defined deceleration value is used for identification of these traffic accidents [10]. Influence of this effect will be investigated in the future work.

Analyzing the result data in Table 1 particularly for the vehicle speed at the beginning of a given scenario it can be seen that mean value of difference between speed calculated using PC-Crash simulation within VKM method and actual measured value from Corrsys Datron Microstar is 0.24 km/h with standard deviation 0.83 km/h. So on average the speed is overestimated by only 0.24 km/h. Direct comparison to the data from published works (based on kinematic principle) is not directly possible as these works state average speeds over reconstructed distance. On the other hand, in case of accident reconstruction this value of average speed would be used also in further analysis for evaluation of driving speed at the beginning of driver reaction (comparable to the speed at the beginning of our scenarios) so tentative comparison is possible. When comparing accuracy of presented method with respect to published works the error for speed estimation is smaller. The results from [7] indicate for example difference of 0.65 km/h between the value of speed measured and estimated from video recording. The results from [8] then indicate even greater average difference of -1.36 km/h.

6. Conclusion

The presented method of volumetric kinetic mapping offers new approach to obtain the data about movement of various objects of interest in road transport at in-depth level. The reconstruction is done as synthesis of video analysis and kinetic simulation that takes into account detailed physical parameters of a given object of interest whereby simulation of movement considers force interactions of the object of interest with its environment. Thus the potential of the method to obtain accurate data not only about object speed but also about its 3D acceleration, angles, angular velocities or driving wheel angle is sizable.

This work presented validation of the method for speed and distance in time domain with very good results for video recording of "bad quality" with relatively low resolution of recording (1024x576 px), low frame rate (10 fps) and for diverse vehicle movement (change of speed, change of direction, various trajectories with respect to camera position).

The future work will be focused on the following:

- validation of the method for acceleration, angle of object of interest and for angular velocities,
- validation of the method for steering wheel angle,
- evaluation of the influence of various variables on the accuracy of the method (resolution of video recording, frame rate, number of effective pixels covered by object of interest, camera height, etc.)

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8. Nomenclature

ABS	Antilock Braking System
CAD	Computer Aided Design
CCTV	Closed Circuit Television
CG	Center of Gravity
EDR	Event Data Recorder

EES	Energy Equivalent Speed
EU	European Union
LED	Light Emitting Diode
NAS	Network Attached Storage
OI	Object of Interest
ROI	Real Object of Interest
SD	Secure Digital
SOI	Simulated Object of Interest
UDV	Undistorted Video Recording
VKM	Volumetric Kinetic Mapping (method)

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