Utilization of Software-Based Methods for Calculating Vehicle Speed in Traffic Accident Reconstruction: A Case Study

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Abstract: *The use of video surveillance systems (Closed-Circuit Television - CCTV) has become widespread across various modern applications. In the context of forensic documentation submitted for expert analysis, digital video recordings of traffic collisions are increasingly common. These recordings often capture not only the moment of impact but also crucial pre- and post-collision events. Such footage provides valuable data for understanding the dynamics of an incident and conducting detailed kinematic analyses. Accident reconstruction software, such as AnalyzerPro and PC Crash, includes specialized video analysis modules. When certain conditions are met, these modules can be used to extract quantitative information about the position and velocity of involved vehicles or individuals at specific moments in time. This paper provides an overview of the operational principles of these modules, the prerequisites for their effective use, and the precision with which they estimate kinematic parameters, as demonstrated in a case study.*
Keywords*: SPEED, VIDEO TRACK, ANALYZERPRO, PC CRASH*

1. Introduction

In today's world, security has become one of the most important aspects of both, public and private life. Technological advancements have enabled the development of sophisticated surveillance systems, with Closed-Circuit Television (CCTV) occupying a prominent position among them. The use of such systems has become standard in many areas, ranging from traffic monitoring to property protection.

In most cases, video recordings of traffic accidents are analyzed primarily to determine how the accident occurred. However, these recordings can also serve as a valuable source of information for identifying kinematic parameters essential for a high-quality and reliable time-distance analysis of the accident's progression. One of the fundamental parameters for such analysis is the speed of the vehicles involved [1].

The quality and specifications of video record can vary significantly from one recording to another. When determining the speed of the participants involved in an accident, the key parameters extracted from the footage are time (s) and distance (m) [2].

Data about the elapsed time during the analyzed video sequence can be obtained by dividing the video into time segments (frames). This can be done using professional or online video conversion tools to extract frames—usually by converting video files (e.g., AVI, MP4, or other codecs) into JPEG format. The frame rate, or frequency, is expressed in frames per second (fps). The most common standard is 25 fps, which is sufficient for the human eye to perceive a smooth and continuous image. At this frame rate, the time interval between two consecutive frames is approximately 0.04 seconds. Before analyzing the time intervals between frames, it is important to check whether the frames were captured at consistent intervals within each second or if there are variations. Regardless of the recording frequency, the primary indicator of the elapsed time between frames should be the detection of motion between two consecutive images. Another parameter necessary for speed calculation is the distance traveled. To determine this, the video must show the characteristic positions of moving objects—those being analyzed—in relation to stationary objects or markings on the road surface that can be subsequently identified. These may include road markings, the position and dimensions of objects, the pavement grid pattern, etc. [3]

The software packages AnalyzerPro and PC Crash, designed for the simulation and reconstruction of traffic accidents, include modules that, under certain conditions, can be used to determine the position and speed of the vehicle being analyzed.

The basis of these modules is the transformation of the camera image into a planar orthogonal plane, on which the traveled path of the analyzed object can be determined over time, as well as the detection of the movement of the object under analysis using machine learning (ML), i.e., artificial intelligence (AI).

In this paper, using a case study of a real traffic accident, an analysis of video analysis tools contained within the software packages AnalyzerPro and PC Crash was performed.

2.Modules for video analysis in the programs AnalyzerPro and PC Crash

During the last decades, several software packages designed for the simulation and reconstruction of traffic accidents have been developed, enabling dynamic and kinematic analysis of such events. Although most of these programs are based on similar principles, they are continuously improved, primarily by expanding the vehicle databases, as well as through the development and implementation of additional tools and specialized modules applied in traffic accident analysis.

In the latest versions of the AnalyzerPro and PC Crash programs, video analysis tools for traffic accidents are now available. These tools allow for detailed kinematic analysis to determine the exact moment of the accident, the positions of the vehicles at and immediately before the collision, as well as their speeds at the time of impact.

A comparative study of the video analysis modules in AnalyzerPro and PC Crash was conducted under controlled conditions. The camera position during recording was precisely known, and the vehicle's speed was regulated by the driver and concurrently measured via GPS. The recording was performed from a fixed vantage point on a bridge overlooking the roadway. The comparison focuses on data obtained at a vehicle speed of 30 km/h.

2.1. Video Analysis Module in the AnalyzerPro

The video analysis module within the AnalyzerPro program includes specialized tools that, under certain conditions, enable the determination of vehicle speed from the recorded video record of the analyzed event.

After importing the video, based on the position of at least 4 characteristic points arranged in an orthogonal or other form, where the mutual distance between them is known, it is possible to establish an orthogonal view of the section that is the subject of analysis within the video analysis tool included in this software package.

Fig. 1 *Layout of the road section on which the analysis was performed with characteristic points and their mutual distances*

Then, depending on the position and characteristics of the video camera, the parameters of which are mostly unknown, the optimization of the orthogonal image is carried out using an algorithm based on the recognition of rectangular or collinear shapes, which also calibrates the image, in order to reduce as much as possible their distortion caused by the position of the camera and the lack of knowledge of its parameters. In this way, an orthogonal projection of the location where the analysis is carried out is established, which also defines the path traveled by the vehicle over time when moving through the observed section, which is the basis for determining its speed.

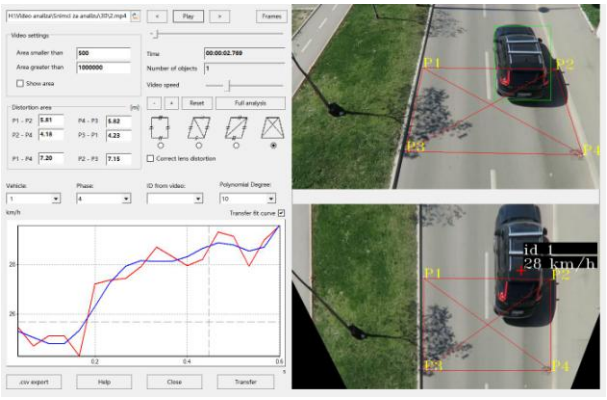

Fig. 2 *Rectified view of the section where the recording was made with the speed of the identified vehicle*

The detection of objects in motion is performed using algorithms based on ML, so the calculation of the speed of the vehicle represents the relationship between the marked section covered by the video and the time during which the analyzed vehicle passed through that section.

2.2. Video Analysis Module in the PC Crash

In the PC CRASH 15.0 software package, the video analysis module enables the determination of vehicle position and speed frame by frame, depending on the frame rate of the video. The analysis is based on establishing a correspondence between the video frames and an ortho-photo image of the actual location. This spatial alignment allows for accurate tracking of vehicle movement across time intervals, forming the basis for kinematic analysis.

In this sense, it is first necessary to define the base on which the analysis is carried out, by downloading it from some of the geoportals, as a Google Maps, by entering GPS coordinates or by importing, with the establishment of an appropriate scale, which would achieve a realistic relationship between the dimensions of the vehicles that are the subject of the analysis and the roads on which they move.

The next step is to enter the appropriate vehicle on the ortho-photo base, along with defining the kinematic parameters related to its direction and direction of movement.

Fig. 3 *Orthophoto image of the road section where the video recording was made*

Within the PC Crash 15.0 program, there are several tools intended for video analysis, i.e. determining the speed of movement and the positions of the participants in the accident [4]. One of them is the video cutter, which can be used to extract from the video only that part that is important for the event itself, which separates the important facts from the irrelevant ones and shortens the analysis time. In addition to shortening the video, with this tool the video itself, that is, its part, which is the subject of analysis, is developed into frames.

PC Crash 15.0 includes several tools dedicated to video analysis, specifically for determining vehicle speeds and positions of accident participants [4]. One such tool is the Video Cutter, which enables users to extract only the relevant segment of the video that pertains directly to the incident. This functionality helps isolate critical data, eliminate irrelevant content, and significantly reduce analysis time. In addition to trimming the video, this tool also decomposes the selected segment into individual frames, allowing for frame by frame analysis essential for precise motion tracking and timing measurements.

To maximize coverage, most security cameras employ wide-angle lenses, which typically do not provide sufficient metadata for accurate calibration [2]. Additionally, the exact spatial position and orientation of the recording camera are often unknown. For video analysis to produce valid results, especially when determining vehicle positions and velocities at specific time points, it is essential to compensate for lens distortion by characterizing the lens curvature and accurately defining the camera's spatial location and orientation. These parameters are crucial for correcting perspective distortion and ensuring the spatial fidelity of the analysis.

To begin calibration, it is necessary to identify a line in the video that is realistically straight in the real world. Examples include curbs, horizontal lane markings, pedestrian crossings, or vertical objects such as streetlight poles and building edges. Unless the video footage is recorded orthogonally, the drawn line in the image will typically deviate from its true straight form due to distortion.

To correct these distortions, five calibration parameters are adjusted:

- Radial distortion parameters (K1, K2, K3):

K1 - corrects distortion affecting the entire image;
K2 - addresses distortion near the image edges;
K3 - compensates for distortion at the outermost edges.

- Tangential distortion parameters (P1, P2) correct image tilt caused by lens misalignment or camera orientation.

The next step involves determining the camera's position during recording. This is done by aligning the approximate camera location with an ortho-photo of the area. Initially, the camera is roughly placed on a two-dimensional ortho-photo base near its actual position during the video capture.

Then, by overlaying a three-dimensional representation of the analyzed section with the two-dimensional ortho-photo—allowing

adjustment of transparency—the virtual camera is positioned so that at least five characteristic points or mutually parallel lines, visible in both the video and ortho-photo, overlap precisely.

Using the program's optimization tools, the camera position and distortion parameters are iteratively refined to achieve the best fit between the video and ortho-photo. A combination of parallel lines and characteristic points typically yields the most accurate calibration results.

Fig. 4, 5 *Comparative display of the recorded section during research with the position of the virtual camera after its position has been optimized*

Object identification in motion is also achieved using machine learning (ML), which aims to develop statistical algorithms capable of "learning from experience." These algorithms predict future behavior based on observed past patterns [5], [6].

Fig. 6, 7 *Identification of the vehicle that was the subject of the investigation, with a speed diagram*

3. Application of the tools for video reconstruction of traffic accidents: a case study

In the analyzed traffic accident, a car ran into a pedestrian, who was crossing the road along the edge of the pedestrian crossing, closer to the oncoming vehicle, from the right to the left side, viewed in the direction of the vehicle's movement. As part of the submitted documentation, a video recording was also available, from which it was possible to see the course of the accident itself. Based on the video analysis, it was determined that the pedestrian, after starting to cross the road, turned from the right to the left towards the oncoming vehicle with the front side of his body, and that the contact occurred in the area of the left edge of the pedestrian crossing, viewed in the direction of his movement.

The basis for analyzing a video of a traffic accident lies in identifying orthogonal forms visible in the video recording whose dimensions are known, or in locating characteristic points or parallel lines that are visible both in the video and on the ortho-photo base of the specific microlocation where the analysis is conducted.

In this particular case, consideration was given to the fact that the marking of horizontal traffic marks follows standards specifying that the width of each white field is 0.5 meters, and the gaps between the fields are also 0.5 meters. An analysis of the ortho-photo of the accident scene confirmed that the pedestrian crossing where the traffic accident occurred adheres to the standard width of 4.0 meters.

By dividing the video of the traffic accident into individual frames, it was determined that the recording was made at a frame rate of 15 frames per second (fps).

Fig. 8, 9 *Positions of vehicles and pedestrian in relation to the edges of the marked pedestrian crossing*

By analyzing the video frame by frame, it was determined that the vehicle under analysis crossed the pedestrian crossing within 9 frames, equivalent to 0.6 seconds. Based on this, the vehicle's speed at the moment of impact with the pedestrian was calculated to be 24 km/h.

3.1. Application of the Video Analysis Module in the AnalyzerPro Software: A Case Study

The first step in analyzing the traffic accident using the AnalyzerPro software is to identify orthogonal forms visible in the video, whose relative dimensions can be determined either directly or indirectly. In this case, the width of the pedestrian crossing, measured at 4 meters, was obtained from the ortho-photo view of the accident scene. Using the standard dimensions of pedestrian crossing markings on the roadway, an orthogonal projection of the accident scene was created, based on a 4.0 by 4.0 meter reference area.

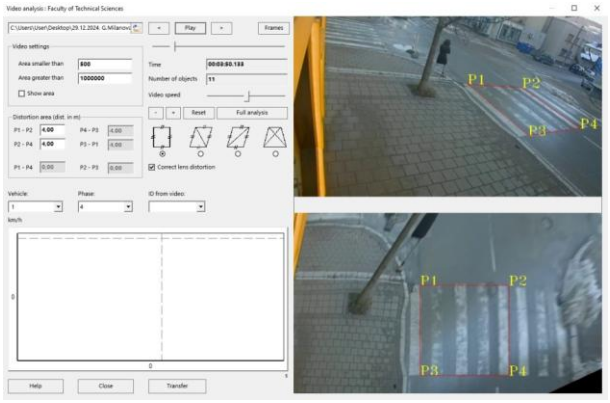

Fig. 10 *Basic and rectified views of the accident scene at the moment the pedestrian enters the roadway, displayed within the AnalyzerPro software environment*

By activating the "play" command, the procedure for determining vehicle speeds based on the rectified video is initiated. The display then shows the speeds of the vehicles present in the video, each identified by a unique serial number (ID).

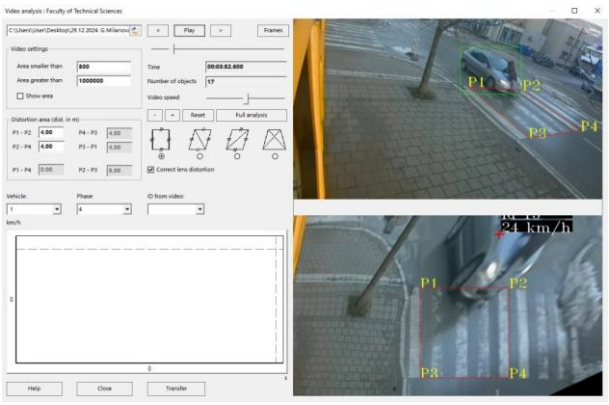

Fig. 11 *Relationship between the video frame and its rectified output with the recorded vehicle speed*

As part of the analysis of this accident, in the AnalyzerPro program, the pedestrian was not detected as a moving object, so his speed could not be determined.

3.2. Application of the Video Analysis Module in the PC-Crash Software: A Case Study

After setting up the ortho-photo of the accident scene, the camera parameters used to capture the video were optimized as part of the video analysis. Since the video was not recorded from an orthogonal perspective but rather from a three-dimensional viewpoint, determining the exact position and parameters of the camera is a highly complex task. Consequently, only an approximate match can be achieved, allowing for the estimation, rather than the precise determination of the vehicle's speed at the moment under analysis.

Fig. 12, 13 *Comparison of the pedestrian's position based on video frames and the reconstructed position in the PC-Crash software*

In this specific event, two moving objects were identified: a vehicle, assigned the identification number ID9, and a pedestrian, assigned ID7.

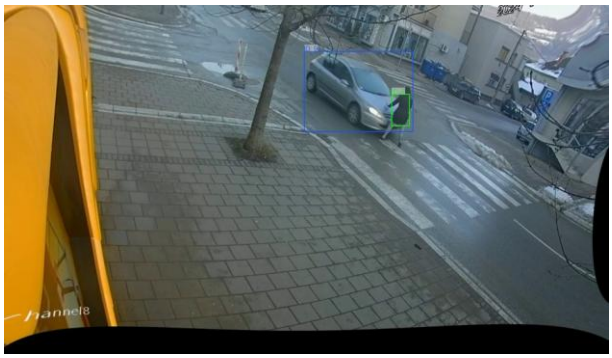

Fig. 14 *Moment and location of contact with identification numbers of accident participants (PC-Crash 15.0)*

The analysis determined that the vehicle's impact speed at the moment of collision was between 18 and 20 km/h.

Fig. 15 *Vehicle speed diagram determined by video analysis in PC-Crash software*

In the video analysis conducted using the PC-Crash software, the pedestrian was detected as a moving object, with a crossing speed of approximately 5 km/h. This speed aligns with normal walking mode, which was consistent with the conditions of the analyzed traffic accident.

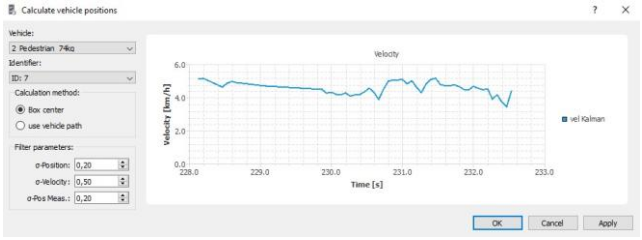

Fig. 16 *Pedestrian speed diagram determined by video analysis in the PC Crash software*

3. Conclusion

The use of CCTV (Closed-Circuit Television) recordings in traffic accident analysis is becoming increasingly common due to the numerous advantages they offer in accurately and efficiently reconstructing events. Unlike witness statements, which can be subjective, video recordings provide a credible and unbiased account of the accident.

Camera recordings provide clear insight into the sequence of events before, during, and immediately after an accident. Advances in AI and ML have made it possible to recognize moving objects in videos, allowing for the analysis of factors such as vehicle speed, signaling, and driver and pedestrian behavior.

Newer versions of software packages for traffic accident reconstruction and simulation, such as AnalyzerPro and PC-Crash, include video analysis modules. These modules can be used to determine the kinematic parameters of accident participants, primarily focusing on their speeds.

The video analysis module in the AnalyzerPro software package detects moving objects using AI, based on photogrammetry principles. This involves creating a rectified orthogonal representation of the surface captured in the video, using clearly identifiable reference points with known distances between them.

Within the PC-Crash, the video analysis module also relies on ML and moving object recognition. However, it is based on establishing the correspondence between the camera's position during the video recording and its position on the ortho-photo base of the accident scene, sourced from geoportals.

In research conducted under controlled conditions, where the camera parameters were known, the deviations between the actual and measured vehicle speeds on the virtual surface were minimal when using both software packages.

In the case study of a real traffic accident, the vehicle's speed was initially analyzed using clear CCTV record by dividing the video into frames and relating their duration to the length of a characteristic section the vehicle crossed, in this case, a pedestrian crossing.

The vehicle speed determined by the AnalyzerPro software closely matched the speed obtained through analytical video analysis.

Defining the position of the camera from which the video was recorded is fundamental for establishing correspondence between the ortho-photo—sourced from geoportals—and the traffic accident video within the PC-Crash software. In controlled research conditions, where the camera's position and parameters were known, the vehicle speed determined by this software closely matched the actual measured values. However, in the analysis of a real traffic accident, accurately establishing the camera's position relative to the ortho-photo base proved very challenging. This difficulty primarily stems from the ortho-photo's resolution, which

hinders the identification of characteristic points necessary to align the images. Consequently, a reliable determination of the vehicle's speed using video analysis in PC-Crash was not possible in this case. Nonetheless, future versions of video analysis tools for traffic accidents are expected to offer improved reliability and precision.

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