Application of photogrammetry in the analysis of vehicle collision processes

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Abstract: *The analysis of each traffic accident is carried out based on recorded traces at the scene of the traffic accident and the damage caused to vehicles. One of the basic parameters in the analysis of traffic accidents is the mutual position of the vehicle at the time of the collision. To define the collision position of the vehicle, it is necessary to determine the intensity and compliance of the vehicle damage. The development of photogrammetry has enabled the creation of 3D models based on which the intensity and mutual compliance of vehicle damage can be more clearly shown, which increases the relevance of the determined collision position of the vehicle. Accordingly, this paper will present the process of creating 3D models of damaged vehicles and will analyze all the possibilities of applying photogrammetry in defining the collision positions of vehicles.*
Keywords: *TRAFFIC ACCIDENTS, PHOTOGRAMMETRY, VEHICLE 3D MODELS, VEHICLE COLLISION.*

1. Introduction

After the collision process of one or more vehicles, it is necessary to enable the forensic expert to reconstruct the collision process based on the investigation and calculate the necessary parameters. One of the most important parameters is the speed of the vehicle before the collision. Today’s vehicles are much more resilient and can absorb much more energy in a collision process than vehicles twenty or more years ago. In the design of passenger cars, there are different types of bodies: sedan, convertible sedan, coupe, extended sedan, van, convertible, multi-purpose vehicles and special vehicles. Apart from the type, it is more important to differentiate the body according to the construction of the superstructure. There are three basic types of body construction: separate body, body with load-bearing frames and self-supporting body.

The most used materials for vehicle body construction are steel, galvanized steel, aluminium sheets, plastics and composite materials. Carbon fiber is increasingly used in sports cars due to its very good properties and strength-to-weight ratio. The bodywork as such is an important part of passive vehicle safety. The role of passive body safety is to mitigate as much as possible the impact of vehicle kinetic energy in a traffic accident. To mitigate the impact of impact kinetic energy, the bodywork must be solid, torsional, tensile, and compressive, bending, and thermal stress resistant.

The body can be divided into internal and external safety area. Internal safety reduces the risk of injury to the vehicle's passenger compartment by reducing acceleration and forces acting on passengers and the driver. The aim of the measures is to ensure the survival of passengers and drivers and to ensure the operation of those systems that affect the safe removal of passengers. According to the analysis of traffic accidents, the most common causes of injuries to passengers are direct (direct, frontal) collisions with 60 - 65% and side collisions with 20 - 25%.

The materials used in the design of the structure are adapted to absorb as much kinetic energy as possible during the collision. Today's vehicles would have to pass a crash test to be on the market, and important data on the speed and amount of damage are collected from these tests.

The application of photogrammetry in the creation of 3D models of the vehicle involved in the collision makes it easier to determine the damage and determine the speed of the collision.

2. Theoretical basis of photogrammetry

Photogrammetry has been defined by the American Society for Photogrammetry and Remote Sensing as the art, science, and technology of obtaining reliable information about physical objects and the environment through the processes of recording, measuring, and interpreting photographic images and samples of recorded radiant electromagnetic energy and other phenomena. As the name implies, science originally consisted of photo analysis, however, the use of film cameras has greatly diminished in favor of digital sensors. Photogrammetry has expanded to the analysis of other records, such as digital images, aerial acoustic energy patterns, laser measurements, and magnetic phenomena. [1]

The basic idea of the photogrammetric method is the reconstruction of optical directions, i.e., defining the equations of directions connecting points on an object and their projections in photography. When measuring in space, it is necessary to capture the object from at least two camera positions. The two images then form a stereo pair, and the photogrammetric reconstruction of space using stereo pairs is called stereophotogrammetry. In the past, optical directions have been reconstructed by the optomechanical process using large and expensive devices or stereo instruments. The analysis of the images was lengthy and complicated and limited to specialized measuring institutes, so photogrammetry was rarely used in industry. With the development of digital cameras and computer image processing, automated photogrammetric systems have been developed. The development of the method connected two areas, which are:

- photography and
- metrology.

Due to the need for high accuracy of measurement results, reliability and automation of the photogrammetric system, photographs must be of high quality. Digital cameras are getting better and better day by day, the limits of photo quality and resolution size are constantly shifting, which is important for measurement accuracy. At the same time, the prices of equipment on the market are falling, so the equipment is becoming more widely available. Metrology deals with techniques for determining the 3D coordinates of a measuring object from photographs. [2]

The advantage of this scanning method is that it is not necessary to have physical contact with the object being scanned. With the development of technology, today's sensors for collecting information are, in addition to digital photography, thermal or multispectral cameras. LIDAR systems are also used to create a digital 3D model of the observed object or area.

Areas where photogrammetry is applied:

- forensics,
- archeology,
- architecture,
- building,
- automotive industry,
- medicine,
- mapping of geological information,
- reverse engineering, etc.

For the operation of a computer program in photogrammetry, the basic algorithm is SFM based on stereoscopic photogrammetry. Using the collected photographs taken from various angles around the SFM object, the algorithm allows the determination of the internal and external orientation parameters of the camera. In this way, it is not necessary to enter additional coordinates by geodetic methods, which reduces the complexity of the scanning process itself, but by entering them, the accuracy and speed of the procedure itself is increased. In order for the process to be successful, it is necessary to have as many photos of the object being scanned as possible.

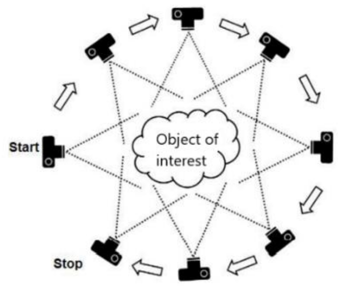

Fig. 1 *The way to properly photograph an object for the needs of the SFM algorithm [3]*

For each photo, points of interest are detected, and those points are tracked through other captured photos to determine the camera position and coordinates of the captured object. In this procedure, errors occur that can be corrected by using the least squares method for nonlinear functions.

The first and basic problem affecting the SFM algorithm is the determination of three-dimensional coordinates of corresponding features on multiple photographs taken from different angles. The initial step is to identify features in individual photos that can be used to link shots. Today, the established method of solving the latter problem is the SIFT mathematical algorithm. It is a system used to identify features in each shot that are invariant to scale change and rotation, and partially invariant to changes in lighting and camera point of view (Figure 2). Points of interest, that is, the observed features are automatically detected through all scales and all locations in each image. A corresponding descriptive vector is added to each identified and isolated feature. The descriptive vector is obtained by transforming local image gradients into sizes that are quite insensitive to variations in illumination and orientation. The mentioned vectors that describe a particular feature are unique enough to allow the recognition of corresponding features in extremely large data sets. [2]

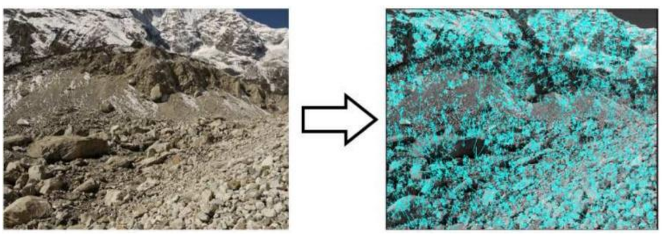

Fig. 2 *The SIFT algorithm parses a photo into a database of extracted features*

3. Determining the speed of movement of vehicles based on deformations

The expression for the kinetic energy comparison is defined by ½ · M · ETS^2, where ETS is the speed at which the comparison is performed in the collision experiment. Regardless of the partial deflection when the vehicle hits a rigid wall, the ETS is identical to the change in speed Δv during the impact process. Assessing damage in real central collisions is not difficult, as there are many attempts to record all types of collisions in the automotive industry.

In the papers stating the conformity of ETS and Δv in the case of real central impacts of two passenger cars, in which the deformations are approximate, there are deviations between the lost speed Δv in the impact process and the size of ETS. Therefore, the impact estimation based on deformations in central impacts has a larger area of scatter in the value of the results. [4]

According to Zeider, F. Deformationsverhaiten von Kraftfahrzeugen bei Autprallversuchen unter praxisegerechen Verscuchsbedingungen from 1979, the ETS designation was associated with equivalent speed in testing, but this proved to be a disadvantage because the energy of equivalent speed may deviate from the speed in the test. To avoid this shortcoming, a new expression was introduced - EES. Expressing the speed is done according to the expression:

$$W_d = E_d = \frac{1}{2} m\, EES^2 \tag{1}$$

where W_d work is spent on deformation [J], E_d - deformation energy [J], m - vehicle mass [kg], EES - energy of equivalent speed [km/h].

In oblique collisions of two vehicles, a part of the kinetic energy of the vehicle is converted into rotational energy. The second part of the kinetic energy is expended on the path of calming during translational motion. Experiments have shown that part of the kinetic energy of vehicle deceleration is less than the part of energy expended on vehicle deformation. [4]

During a collision of a vehicle, permanent deformations of the vehicle occur, for which it is necessary to consume a certain amount of vehicle energy. Energy consumption is the kinetic energy of the vehicle that can be displayed using a virtual amount of speed from the EES. For an authentic assessment of the EES, it is necessary to perform several different crash tests of vehicles in different conditions, because the depressions formed on vehicles by the action of deformation energy depend on different parameters. The amount of deformation energy changes during the collision so that it increases to the maximum value in the compression phase, and in this phase the greatest damage to vehicles occurs, while in the restitution phase the deformation energy decreases and, in this phase, there is a return of partially elastically deformed vehicle material. respectively the return of part of the consumed energy, which causes permanent damage to the vehicle. [5]

The EES value depends only on the bulk energy E_d and the mass of the vehicle m. If the EES value of one of the vehicles involved in the collision of two vehicles is known, then it is possible to determine the EES value of another vehicle if it is unknown. reaction. This can be represented by the following equation: [7]

$$\frac{EES_1}{EES_2} = \sqrt{\frac{m_2 S_{Def\,1}}{m_1 S_{Def\,2}}} \tag{2}$$

where m_1 is vehicle 1 mass in [kg], m_2 - vehicle 2 mass [kg], S_{def1} - the depth of the recess of the vehicle 1 caused by the deformation force during the collision of the vehicle in [m], S_{def2} - the depth of the recess of the vehicle 1 caused by the deformation force during the collision of the vehicle in [m], E_d - the energy spent on damage of two vehicles that collided in [J].

If data to determine the deformation energy of colliding vehicles are not available, then the deformation energy of the collided vehicles may be calculated either using a velocity deformation curve based on multiple tests of different vehicle collision speeds or a force displacement curve based on a single impact test. In addition to the above methods, there are other methods for calculating the EES value, namely: the energy grid method (energy grid), approximate equations and algorithms based on damaged vehicles. [5]

When calculating the EES value, the data contained in the EES value catalog, which were obtained from various crash tests of different vehicle models, are most often used. The EES value catalog contains photographs of vehicle damage, which are arranged according to vehicle models and types of collisions. This allows catalog users to calculate the impact strength quickly and reasonably, i.e., the collision speed of the vehicle, based on the EES value, which is based on a visual comparison of the actual damage to the vehicle with those in the EES value catalog. [5]

Delta-V (Δv) is a common notation used in mathematics, and especially in physics to denote a change or difference in velocity. In the context of a motor vehicle collision, Δ specifically refers to the change in speed between the trajectory of the vehicle before and after the collision. [6]

$$\Delta v = v_2 - v_1 \tag{3}$$

where v_1 vehicle speed before collision [m/s], and v_2 - vehicle speed after collision [m/s].

The utility Δ for characterizing collision severity emerged in the 1970s, in the context of collision reconstruction analysis. The National Highway Traffic Safety Administration (NHTSA) has commissioned the development of a collision reconstruction program called CRASH. This program is used to estimate ΔV vehicles involved in a collision based on measurements of their structural deformation. The original version of the CRASH tests was able to estimate the impact speed of the vehicle to an accuracy of about 12% of the actual collision speed. [6]

The EES value reconstruction method is usable only if the value of the EES can be determined from the remaining deformations. A prerequisite for this is good documentation of vehicle damage, which can be seen in the pictures of photo documentation of mostly every traffic accident. Comparative images for determining the EES value are available today from crash tests, and from the automotive industry for comparison. There are several ways of testing that are usually performed at different speeds and for different types of collisions and impacts. There are the following types:

- frontal impact, i.e., a collision of a vehicle with a solid obstacle
- frontal impact into one of the 30 ° oblique obstacles
- frontal impact in a stepped obstacle with 50% coverage
- frontal impact in a stepped obstacle with 30% coverage
- side impact at right angles with a solid impact vehicle
- side impact below 45 ° from the front with a solid impactor
- side impact below 45 ° rear with solid impact vehicle
- impact at the height of the rear window glass with a solid impact vehicle.

For these tests, test speeds (ETS) are known, which means the speeds at which the tests are performed. These ETS data do not always and in all cases correspond to the EES, which should be considered in the assessment. Also, the weight of the tested vehicle and the weight of the test load (hard hit vehicle) should be considered. The results of test values are regularly published in professional journals. [5]

If it is assumed that the vehicles partially penetrate each other, then there is no difference, [5]. If, for example, in the event of a full collision of two vehicles, a thin steel plate is placed between them, the plate would remain in the same place during the collision and can be removed after the collision. The plate has virtually no impact on the collision. If the board is big enough so that drivers can't see it, they would have the impression that they have crossed a solid obstacle. To protect passengers, the crash test determines the maximum values of vehicle deceleration that must not be exceeded (Figure 3). The kinetic energy possessed by the vehicle when hitting an obstacle is converted into deformation work. [7]

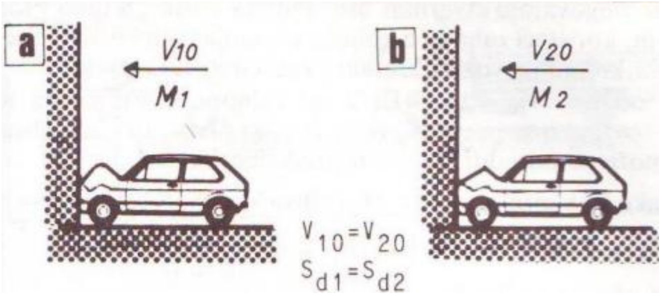

Fig. 3 *Vehicle collision with an obstacle [5]*

If vehicles have the same dimensions, strike an obstacle at the same speeds, and have the same deformation path (Figure 3), then the following equation holds, [5]:

$$E_{k1} = \frac{M_1 \cdot v_{10}^2}{2}; E_{k1} = \frac{M_2 \cdot v_{20}^2}{2} \tag{4}$$

To facilitate the assessment of vehicle damage and the calculation of energy consumption during vehicle collisions, a catalog has been prepared that includes a wide range of vehicles and their damage. This catalog is updated daily with new examples and results of accidents for each vehicle, thus reducing error and increasing accuracy in the calculation. For the time being, when using EES, optical comparison is preferred over computer comparison, due to a better assessment of the damage in the photographs of the damaged vehicle. Collision tests are used as a basis for computational analysis, from which impact forces are measured, and quantities such as impact speed, vehicle mass, etc. are known. In addition to the reconstruction of traffic accidents, the EES is also used in insurance companies in the analysis of collisions.

3.1. Energy grid for collision analysis purposes

According to Campbell's work, the starting point is that during a frontal impact, i.e., a collision with a solid obstacle, a certain deformation of the vehicle occurs, which is a function of the impact speed (EBS - Equivalent Barrier Speed). [5] The procedure of reliable determination of deformed energy is based on a new model which involves the construction of specific energy raster diagrams for each make, type and model of vehicle. At the very beginning of this procedure, it is necessary to perform the percentage and geometric redistribution of deformed energy over the entire width of the vehicle.

Vehicle impact tests on a fixed obstacle can establish a relationship between deformation and known speed in the test. Based on the known impact speed of a solid fixed obstacle, the degree of strength of the vehicle can be determined, and on the basis of the measured values of deformations. The strain width w_0 is divided into six equal areas in which the strain depth is measured from C_1 to C_6 (Figure 4). For the known width of the vehicle, the weight of the vehicle, the amount of speed up to which there are no visible deformations b_0 and the test speed of impact on the obstacle V_t, the vehicle strength is obtained as follows: [8]

$$S = B \cdot (vehicle\,width) \tag{5}$$

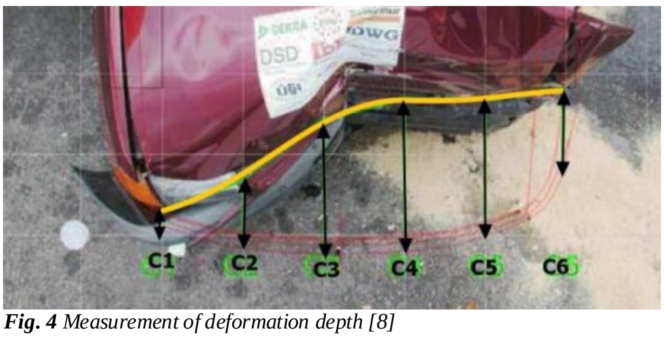

Fig. 4 *Measurement of deformation depth [8]*

During the investigation of the traffic accident, the technician photographs the deformations of the vehicles involved in the traffic accident. The way the photo documentation of deformed vehicles is carried out is very important and should be carried out according to the rules of the profession. It is important that when photographing certain parts of the vehicle that have suffered deformations, a meter is also photographed so that the depressions can be read later from the photographs. With the help of software tools, recesses can later be displayed in scales from which the work consumed for this deformation can be calculated, and the impact speed can be calculated using expression (6).

$$EBS = \sqrt{\frac{2 \cdot W_{def}}{m}} \qquad (6)$$

where W_{def} is the total value of the deformed work on the vehicle [J], and m - total vehicle mass [kg].

4. Research methodology and equipment

For photographing a damaged vehicle from all angles, the use of an unmanned aerial vehicle, the so-called drone, because it is not possible to cover all corners of the vehicle with a classic camera. When shooting with a handheld camera, it is not possible to take photos above your height, and there is a need to use a drone. For the end result to be as accurate as possible, it is necessary to shoot the damaged vehicle from all angles and with sufficient folding of photos for easier processing in software tools for photogrammetry.

4.1. Drone DJI Phantom 4 PRO photography

For photography, the Phantom 4 PRO drone (Figure 5) was used, which provides the possibility of stable flight and shooting in high resolutions. The drone has four engines located on the edges of the aircraft, which allows it a stable flight and easy handling. A remote control is required to operate the drone. For safer control and flight of the drone, it has built-in sensors that prevent the drone from colliding with obstacles around it. The Phantom 4 PRO drone has a built-in 1-inch camera and a 20-megapixel CMOS sensor. The drone camera has a mechanical shutter that eliminates distortions that occur when shooting objects when the camera is moving, and this feature is very important in photogrammetry and therefore this drone with a built-in camera has an advantage over others that do not have this feature.

***Fig. 5** DJI Phantom 4 PRO drone [9]*

4.2. Agisoft Metashape software tool

Agisoft Metashape is a software tool for photogrammetry and one of the most popular in the sector. Using high-resolution photographs, the program can use the photogrammetry technique to generate 3D models of photographed objects. The application of this software tool is in various industries, e.g., in the computer game industry, in construction, in traffic, geodesy, etc.

By loading and uploading photos, the photos need to be aligned. The program calculates the position of each photo around the photographed object, and it is possible to determine the accuracy: small (25% of possible), medium (50% of possible) and high (100%). The program requires a lot of working memory on the computer. The more photos, the more working memory is needed.

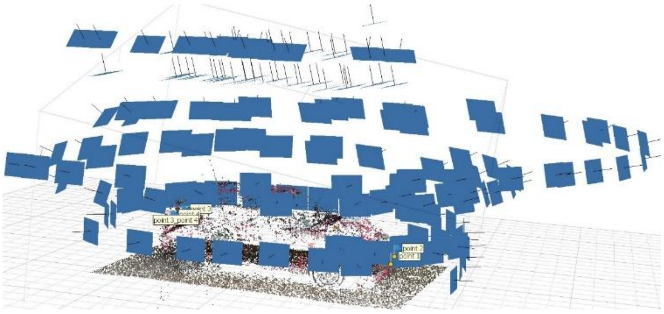

***Fig. 6** Dispaly of the sorting of photos in Agisoft Metashape*

The next step in the Agisoft Metashape software tool is to generate a dense cloud model. After calculating the camera position, the program calculates the depth information of each camera. Depth information is merged into one point called a dense point cloud. In order to make the calculation as good as possible, it is necessary to select the maximum amount in the program that is possible depending on the hardware capabilities of the machine. As with the previous step, this part depends on the amount of working memory, and 32 GB and more is recommended.

***Fig. 7** Building dense points in Agisoft Metashape*

With the data from the previous step, it is possible to create a network, i.e., a polygon - mesh. The program offers several methods for building polygons, and Arbitrary is the option that best suits this model. Before starting this step, it is necessary to determine the maximum number of polygons and points. In the model shown in the figure below, there are 2,239,419 polygons and 1,120,791 points.

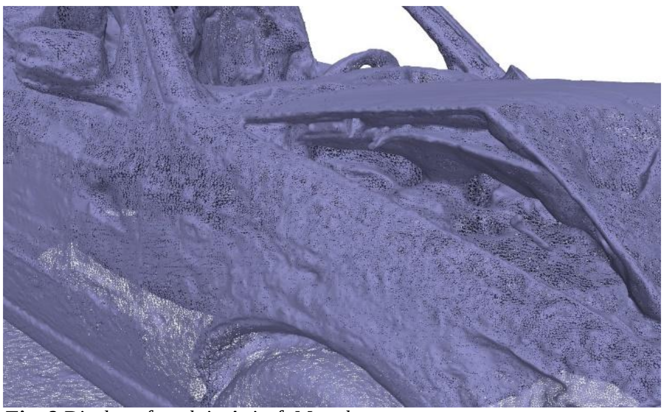

***Fig. 8** Display of mesh in Agisoft Metashape*

In case the model needs to be exported to another program, such as PC-Crash, it is necessary to optimize the model for easier handling in other programs. One of the basic steps of optimization is to reduce the number of polygons and points. Agisoft Metashape offers this feature called Decimate Mesh. The model above in the picture has too many polygons and too many points. The image below is a comparison of the network before and after optimization.

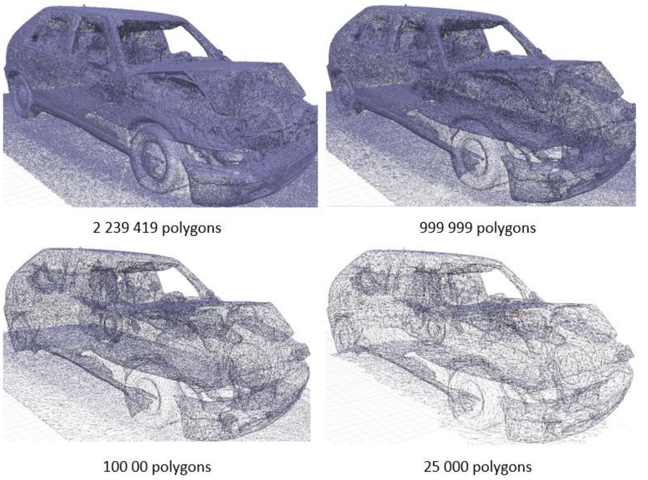

Fig.9 *Display of different numbers of polygons after optimization in Agisoft Metashape*

Building the texture is the last step in the reconstruction of the vehicle, which is not necessary, but in some cases the reconstruction comes in handy because it allows a more realistic view of the vehicle. Agisoft Metashape offers a total of six different ways to create texture. Figure 10 shows the final texture result on a model of 25,000 polygons.

Fig.10 *Display of textured model in Agisoft Metashape*

4.3. LIDAR camera Intel Real Sence L515

As part of the experiment, this paper used a LIDAR camera (Light Detection and Ranging), which is a depth camera that uses MEMS mirror scanning technology, providing better laser power efficiency compared to other technologies, with less power consumption of 3.5 W for depth streaming.

Fig.11 *LIDAR camera (RealSence L515) [10]*

The scanning process begins by registering and installing the DOT3D software tool on your smartphone or laptop. By connecting the LiDAR camera L515 with a USB cable and running the DOT3D software tool, you can start scanning a damaged vehicle. The easiest way is to stick the LiDAR camera on the back of your smartphone or laptop so that the camera and smartphone are directed to the scan location, as shown in the image below.

Fig.11 *Display of LiDAR sensor and smartphone before scanning [11]*

When everything is set, scanning is done by looking through the LiDAR camera that is displayed on the smartphone screen. The appearance of green in the place to be scanned indicates that there is enough data so that it can be moved to the next place. Walking around the vehicle with the camera facing it creates a cloud of dots and thus the vehicle is scanned. If the orientation is lost in the process, it is necessary to take a step back for the program to recognize the already scanned parts and continue scanning. The scan result of the two vehicles is shown in the figure below.

Fig.12 *Scanned vehicles Škoda Felicia and Renault Thalia*

5. Research results and discussion

For this paper, the Department of Traffic Accident Expertise of the Faculty of Transport and Traffic Sciences in Zagreb organized a crash test between two vehicles. The Autodesk AutoCAD software tool was used to display the damage. For the purposes of the comparison, it is necessary to have a 3D model of an undamaged vehicle to be able to compare it with a model of a damaged one. The damage display is shown in Figures 12 and Figure 13, and the 3D model of the undamaged vehicle is shown in green. The 3D model after damage is shown in red.

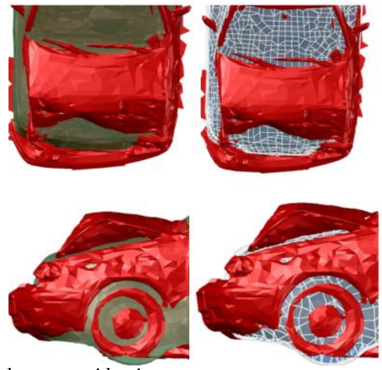

Fig.13 *Vehicle damage - side view*

The collision position of the vehicle was defined using two methods from this paper - photogrammetry, drone shooting and LiDAR camera recording. The vehicles were prepared and scaled in the Agisoft Metashape program to match the actual dimensions. A known measure on the vehicle is taken for scaling, e.g., the length of the license plates. Several more well-known measures have been taken for more accurate scaling. In practice, special markings are used that are placed on the object before taking photos. Figure 14 shows the collision position of the vehicle with satisfactory overlap and the measured collision angle of 123º.

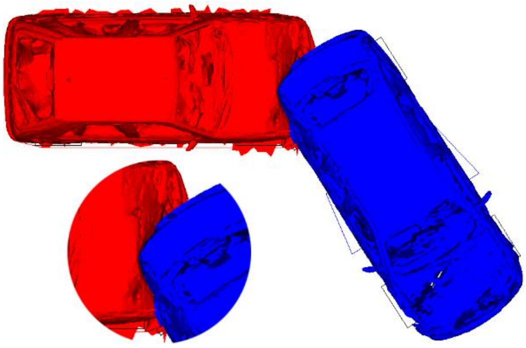

Fig.14 *Display of the collision position - floor plan (photogrammetry)*

When entering vehicles that were scanned with a LiDAR camera and processed in the DOT3D software tool, the format of the output files from that program was considered. Point Cloud scanned models were entered and cut to obtain the outer contour of the vehicle. With the prepared scanned models, the models are manually adjusted to match the damage as well as possible. The measured angle after adjustment was 114º.

Fig.14 *Display of the collision position - floor plan (scanned vehicles)*

5.1. Comparison of photogrammetry with the classic photography method in vehicle deformation assessment

For the purposes of this comparison, the EES catalog of vehicles with similar damages as on the tested Škoda Felicia and Renault Thalia vehicles was searched. The Škoda Octavia found in the EES catalog was involved in a car accident with a Renault Kadjar. A Škoda vehicle collided with the front end of the vehicle in front.

Fig.15 *Photos of the damaged Škoda Octavia vehicle (EES catalog) and the Škoda Felicia test vehicle*

From the photographs collected in the EES catalog, it is difficult to estimate the depth of damage because the photographs were taken from an unfavorable angle for the application of this method. In such a case of determining the depth of damage to the vehicle, only the experience of a forensic expert or the use of some other method to determine the speed of the collision comes to the fore.

For the purposes of this paper, the Department of Traffic Accident Expertise of the Faculty of Transport and Traffic Sciences in Zagreb, organized and performed a "crash" test between two vehicles. A Škoda vehicle (Felicia) collided with a parked Renault (Thalia) vehicle in an organized test. After the test, an investigation was done, and the vehicles were photographed. For the analysis of the traffic accident, in this case of the crash test, the software tool PC-Crash 13.1 was used. This software tool allows the user to reconstruct a traffic accident very accurately and realistically. One of the possibilities of this program is to determine the depth of the damage with the help of a photograph taken on the floor plan (Figure 16).

Fig.16 *Display of the depth of damage to the vehicle in the PC-Crash software*

In the PC-Crash software, it is neccessery to load a photo that was taken from above so that the damage which was caused after the collision can be seen. After scaling the photograph, the deformation line was drawn (green line in Figure 16). Based on this line, the software calculates the difference between the shape of the vehicle before and after the damage and shows the measurement of the depth of damage in eleven points. With these measurements, the program calculates the values of the damaged vehicle (Figure 17). For the program to successfully perform the calculation, a vehicle with similar characteristics is selected from the NHTSA catalog.

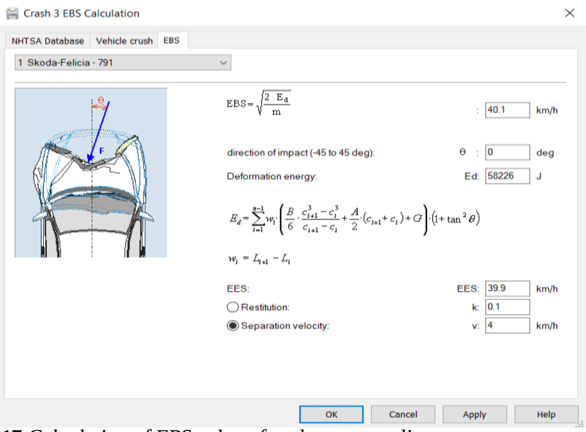

Fig.17 *Calculation of EBS value after damage reading*

According to the photographs obtained after the investigation, it is sometimes difficult to determine the exact damage and the way the collision occurred. As this is a laboratory experiment, the value of the impact speed of the tested Škoda Felicia vehicle is known, in contrast to the vehicle Škoda Octavia from EES catalog, from the beginning of this chapter. New technologies, such as photogrammetry and LiDAR camera recording, have become very accessible and more cost-effective. The application of the mentioned technologies expands the possibilities of the software tool itself, such as PC-Crash, and serves as an additional input parameter for more accurate calculation or estimation. If a forensic expert had a 3D model of a damaged vehicle after a car collision, he could more easily determine the method by which he would calculate the impact speed. This way of looking allows the expert to look at the vehicle from all angles and distances without any loss in image or model quality. By comparing the difference in damage from Chapter 5, it can be also seen how much the geometry of the vehicle itself is disturbed after the collision.

The picture below shows that the front bumper of the Škoda Felicia remained undamaged in the "crash" test, and this damage would not be suitable for the example of the application of the mentioned method in the third chapter. By displaying a 3D model, the estimator can come to this conclusion faster and easier.

Fig.17 *Demonstration of photogrammetry options for determining damage*

Vehicles from the EES catalog that have similar damage are taken for comparison, eg the Škoda Octavia from the beginning of this chapter. The damage assessment itself also depends on the estimator's experience, but such a 3D view of the damaged vehicle would allow the less experienced estimator to determine the damage and observe some other parameters after the traffic accident more accurately.

6. Conclusion

Today's vehicles have changed significantly in the way of construction, design, and technology from vehicles more than twenty years ago. This change affected the behavior of the vehicle in the collision process. Vehicles have become more resilient and can absorb more kinetic energy than before. The properties of today's vehicles are a product of the mentioned ways of designing the structure and using several types of materials to absorb as much kinetic energy as possible during a collision and thus increase the passive safety of drivers and passengers.

A collision of one or more vehicles can have a lot of variations and ways in which it can happen. There are different methods of determining the speed of a vehicle before a collision. Each method has its advantages, disadvantages, and the type of collision to which it can be applied. During each investigation, the vehicles involved in the accident are photographed. By reducing the price of the once expensive technology of digital images and photo processing, the technology of making 3D models from recorded digital photos, photogrammetry, naturally arose.

Photogrammetry is a technology that can generate a 3D model of a captured object from captured photographs using known algorithms and computer processing. The application of this technology in the creation of 3D models of vehicles involved in a traffic accident significantly facilitates the assessment of damage and the level of dents caused by the collision. The symbiosis of this technology with well-known programs, such as PC-Crash, leads to very relevant results in determining the impact speeds and determining the position of the vehicle before the accident.

When the classic method of estimating vehicle deformation after traffic is compared with the new approach via photogrammetry or LiDAR camera, positive shifts in the estimation of deformation depth are obtained. In addition to depth, the estimator has an insight into the 3D model from which you can see many more details of the vehicle, from all angles, which is a significant improvement over classic photography.

This paper shows the possibilities of applying photogrammetry on the example of a collision process between two vehicles in a crash test at the Faculty of Transport and Traffic Sciences in Zagreb. The vehicles were analyzed and photographed after the collision, so that photogrammetry technologies could be applied to create 3D models. The analysis showed that in this case the damage on the vehicle is not reliable to be relevant to the EES catalog. Without photogrammetry technology, such an assessment would be difficult because it would be made from exclusively classic photographs taken during the inspection.

7. References

1. R.P. Wolf, B.A., Dewitt, B.E., Wilkinson, *Elements of Photogrammetry with Applications in GIS*, (2014)
2. B. Ljubenkov, *Modified photogrammetric method in shipbuilding, Doctoral thesis*, (2006)
3. ResearchGate, https://bit.ly/2Kk05Qg, [Accessed: April 2022.]
4. F. Rotim, *Elements of road traffic safety, Volume 3*, Faculty of Transport and Traffic Sciences, Zagreb, (1991)
5. E. Tomasch, *Accident Reconstruction Guidelines*, Graz Univrsity of Technology, Graz, (2004)
6. S. G. Shelby, *Delta-v as a measure of traffic conflict severity*, Indianapolis, USA, (2011)
7. G. Genta, L. Morello, F. Cavallino, The *Motor Car Past, Present and Future*, Springer (2014)
8. F. Kovačević, E. Smajlović, E. Džafić. N. Zdravković, *Evaluation of deformation work on vehicles in the analysis of traffic accidents*, (2016)
9. shorturl.at/fDTW2 [Accessed: April 2022]
10. http://www.infotrend.hr/clanak/2009/5/3d-laserskoskeniranje,38,785.html [Accessed: April 2022]
11. https://store.intelrealsense.com/buy-intel-realsense-lidar-camera-l515.html [Accessed: April 2022]