Possibilities of utilising perpendicular[1] and oblique photographs of vehicles to determine dimensions[2] and post-crash deformation using photogrammetric transformations

warrant Adam Sikora[1]
ORCID 0009-0008-8189-8022

Forensic Laboratory of the Voivodeship Police Headquarters in Olsztyn, adam.sikora@ol.policja.gov.pl

Abstract

The article presents the issue of measuring traces on vehicles by experts directly from photographs. Tests were carried out, including an analysis of the dimensioning accuracy of perpendicular and oblique photographs, and the possibility of using a photogrammetric transformation of a single oblique photograph to restore its perpendicularity[1] to the photographed object was examined, so that the photograph was cartometric again.

Keywords: dimensioning, straight photography, oblique photography, post-accident deformation, photogrammetric transformation

Introduction

A common situation faced by experts in the field of road accident investigation is the failure to measure significant traces at the scene of the accident, which are necessary to determine the causes of the accident. In situations where such traces can be identified and they were not dimensioned during the visual inspection, experts make efforts to obtain relevant and critical dimensions based on available photographs from the scene. In order to attempt to measure traces from the accident site directly from photographs, the photographs must meet certain criteria. Photographs should include, among other things: as close as possible to the position in which the lens axis is perpendicular to the photographed object. This is technically difficult in the case of inspecting the scene of a road accident, because in order to obtain such an image it would be necessary to take photographs from the air, e.g. using a drone, which is not always possible, for various reasons. In such cases, photogrammetry comes in handy, thanks to which, if appropriate conditions are met, it is possible to use oblique[2] on-ground photographs to convert them into orthophotographs[3] and, on their basis, to measure the traces at the accident site.

Possibility to determine dimensions based on two photographs

This type of research has already been described in the literature, also in Issues of Forensic Science, issue no. 253/2006. The task that was then set in the research work was to determine the entire 3D body of the vehicle based on two photographs. To determine dimensions (such as body deformations) in three-dimensional space relative to the (x, y, z) axes, it is required to have at least two photographs covering the body being processed. In the figure below, taken from the cited article, presents two such photographs with a common coverage area necessary to determine the newly determined 3D points.

1 The optical axis of the lens is perpendicular to the photographed plane of the object.

2 The optical axis of the lens is oblique relative to the photographed plane of the object.

3 A processed photograph, resulting in the image obtaining a uniform scale and perpendicularity to the photographed object.

Photograph 1. A mutually oriented pair of photographs with a common coverage area with stereodigitization of body deformations (illustration taken from the article Issues of Forensic Science No. 253/2006; photograph: A. Sikora)

In such a case, using photogrammetric software, it is possible (Żelazek & Sikora, 2006) to determine the deformation of the body in relation to the adopted axes of the coordinate system (x, y, z). Determining the deformation length is possible in any direction through any rotation of the vehicle body and damage obtained in this way. If two photographs are not available, determining the third dimension, i.e. the Z coordinate, is not possible using photogrammetry methods.

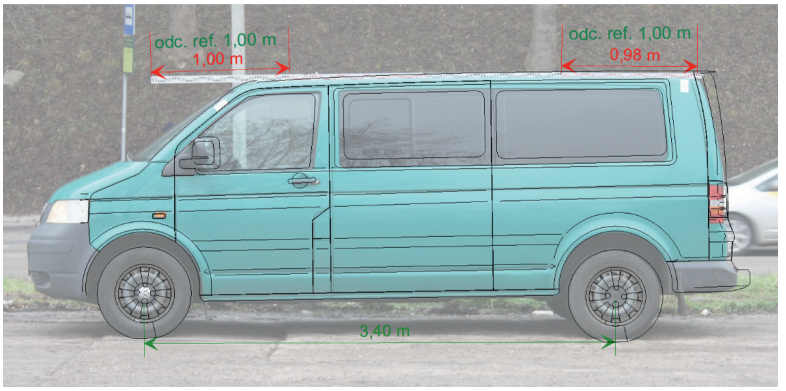
Possibility to determine dimensions based on a single photograph

What if the expert does not have two photographs with a common coverage area, but only one photograph, which is undoubtedly the most common case in the practice of road accident reconstruction?

In order to answer this question, in the first stage, photographs of the vehicle recorded in accordance with the correct technique for preparing such documentation, i.e. perpendicular ones, will be analysed. The impact of incorrectly taken photographs on the possibility and accuracy of dimensioning will also be examined. The increase in the non-parallelism of the plane on which the image is recorded (in the past camera film, today digital sensors) in relation to the conventional plane of the photographed object causes a proportional increase in the scale change factor, which depends on the angle of deviation of the lens axis from the straight line perpendicular to the photographed plane. It must be also taken into consideration that camera lenses have imperfections, including: distortion, and the image created as a result of photographing is the result of symmetry relative to a point (the main point of the lens), and not symmetry relative to the plane, which is necessary to obtain a uniform scale. As a result, the scale of the object in the photograph changes in the directions from the projection of the main point of the lens to the edge of the photograph. With the above in mind, photographs should be taken in such a way as to minimize unfavourable geometric and optical properties as much as possible. The focal length should, if possible, correspond to the standard focal length for a given format (in the case of the full-frame format, the standard focal length is 50 mm). The axis of the lens should be approximately perpendicular to the object being photographed. An example of a photograph taken in this way is presented below.

Photograph 2. A photograph with a focal length of 50 mm of a Volkswagen T5 vehicle taken according to the rules, i.e. perpendicular to the side of the vehicle

The above photograph was scaled based on the vehicle's wheelbase (Photograph 3), which is 3.40 m[4] (marked with a green line), then this image was placed in the background of the *reference silhouette*[5] of the Volkswagen T5 vehicle (black lines). On this basis, it was possible to initially analyse the accuracy of the photograph taken in this way in relation to the reference model, which is presented graphically in the illustration below.



Photograph 3. A photograph of a Volkswagen vehicle taken in accordance with the rules, i.e. perpendicularly with a focal length of 50 mm, scaled based on the wheelbase = 3.40 m of the reference silhouette (black lines) and with marked control sections (red), which should correspond to a length of 1 m on a level staff

A detailed analysis of the accuracy of the photograph taken in this way in relation to the reference figure will be presented in a table later in the article, while at this stage the lengths of the reference sections were checked on a level staff placed on the vehicle's roof. As a result of the study, it was found that for the left side of the photograph, the reference section with a length of 1.0 m corresponds to exactly the same value on the photograph scale, and the section at the right edge corresponds to 0.98 m. This tentatively shows that when the appropriate conditions are met, the photograph, which has not been photogrammetrically processed in any way, coincides with a high degree of accuracy with the reference figure and may be useful for determining the position and dimensions of traces on the vehicle during the road accident reconstruction process.

In practice, unfortunately, it is often the case that the evidence does not include photographs taken in this way, which may also result from objective reasons (e.g. terrain obstacles at the site of the accident, making it impossible to take perpendicular photographs). Below is an oblique photograph with a slight, 10-degree angle deviation from the straight line perpendicular to the side of the vehicle.

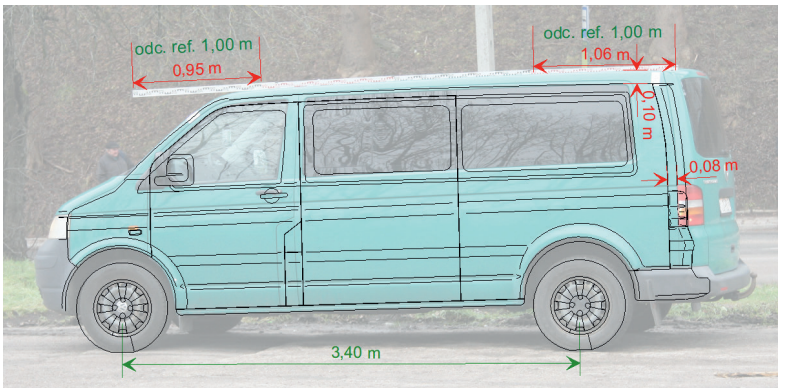
Photograph 4. The photograph was taken obliquely at an angle of 10° to the side of the Volkswagen T5 car

In a similar way as in the case of a photograph taken perpendicular to the vehicle, a preliminary analysis of its suitability for determining dimensions was carried out. The photograph was also scaled based on the vehicle's

4 The parameter is determined on the basis of information contained on publicly available websites regarding technical data of vehicles.

5 Model vehicle profiles are offered by various entities. They can also be developed individually, e.g. photogrammetrically or using a laser scanner.

wheelbase, then the image was placed against the background of the reference silhouette of the Volkswagen vehicle (black lines), and then one-meter sections of a level staff placed on the vehicle's roof were measured – the illustration below.



Photograph 5. The photograph presented in Photograph 3 scaled based on the wheelbase = 3.40 m in the background of the reference silhouette (black lines) and with marked reference sections on the vehicle roof covering (red dimensions), which should correspond to a length of 1.00 m

As can be seen, even with such a small angular deviation, the accuracy of dimensioning directly from the photograph has significantly deteriorated. The silhouette of the vehicle recorded in the photograph differs from its real shape. It can be seen that the measurement of one-meter reference sections of the level staff at the left edge is 0.950 m, and the measurement of such a section at the right edge is 1.060 m. This means that even such a minor angular deviation of the lens axis from the straight line perpendicular to its side, as in the case of the photograph in question, results in significant scale variability in different areas of the photograph. Objects are shorter in the left part of the image and longer in the right part. The silhouette of the vehicle is also 0.10 m higher than the reference silhouette. Such discrepancies when determining the deformation may contribute to questioning the calculations made on this basis, e.g. regarding energy loss during an accident, and, consequently, the conclusions of the entire reconstruction of the road incident.

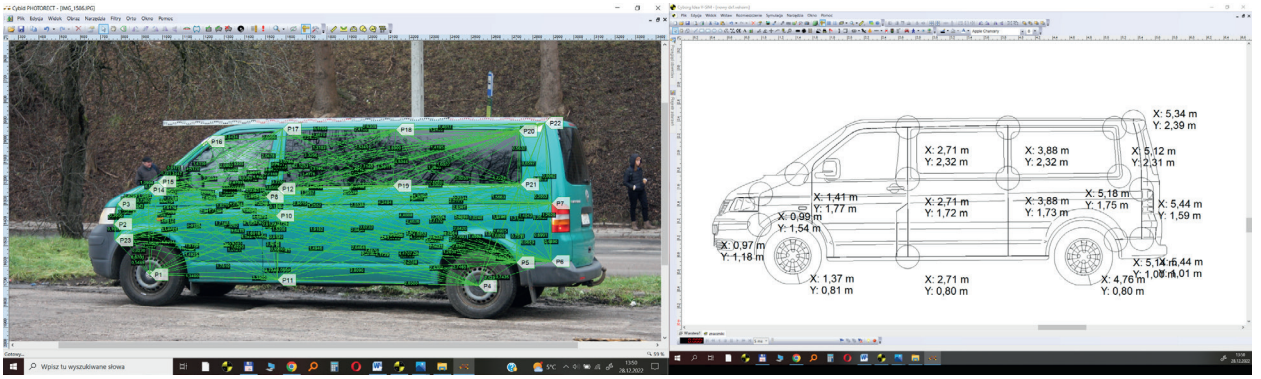
Orthorectification of an oblique photograph

Below, the case of orthorectification of a single photograph taken obliquely is examined.

Assuming that a given dimensioning area represents a plane, it is possible to apply a 2D "plane-to-plane" transformation. In order to answer the question whether it is possible to apply such a transformation to the side of a vehicle, the possibilities of photogrammetric processing of single photographs into such a form will be examined to restore perpendicularity and cartometricity[6] even to photographs taken at an angle (obliquely to the photographed plane). What needs to be explained is that the challenge at the basis of this experiment is the use of a 2D ("flat") transformation when processing the image of the side of a vehicle, which is not actually a plane. It would be normal for such an image processing process (vehicle side) to use 3D transformations, which would allow determining the coordinates (x, y, z) on the curvature of the body, and not only (x, y), and thus the possibility of appropriate reduction of diagonal measures . However, due to the research assumption that we have only one photograph of the object (vehicle) and not two (which are necessary to apply the spatial transformation), the research will be carried out based on the flat transformation, which in this situation is the only potential chance to restore the cartometricity of oblique photograph. The results of this experiment are intended to answer whether it is possible to use a 2D transformation and obtain sufficient accuracy to dimension traces on the side of the vehicle. Since the side of the vehicle is not a plane, discrepancies between the newly determined image resulting from the 2D transformation and the corresponding points of the reference silhouette should be expected, which will be subject to a detailed accuracy analysis in tabular form and initially in the photographs below. The photograph presented in Photograph 4, i.e. Volkswagen Transporter T5, will be subjected to photogrammetric processing. For this purpose, Photorect 4.0 software from CYBID will be used, which features a 2D image transformation tool. Image processing is possible based on any number of reference points, as shown in

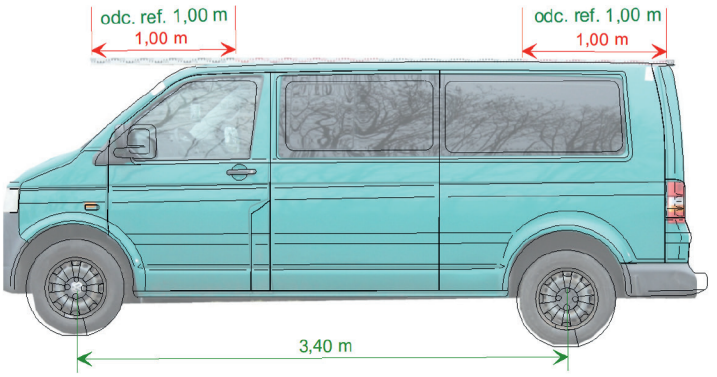
6 The image can be used to perform measurements.

Photograph 6. Based on the reference silhouette, reference points were determined, which served as reference points for the photography in relation to reality.



Photograph 6. Points on which the image was orthorectified

As a result of the transformation of the image from Photograph 4, the rectified image presented in Photograph 7.



Photograph 7. Rectified photograph based on Photograph 6

Preliminary accuracy analysis was carried out in the same way as in the previous cases, by checking the distances of 1.00 m of the reference sections on a level staff placed on the vehicle's roof. As a result of the study, it was found that for both the left and right sides of the photo, the 1.00 m section on the level staff corresponds to exactly the same value of 1.00 m. The scale of the photograph remains constant, and the details of the vehicle visually coincide with the corresponding details of the reference model. It follows initially that with the geometry of the bus body, it is possible to transform an oblique image into a perpendicular one (orthorectification) using a 2D transformation, and the curvature of the body side does not cause significant inaccuracies in the newly determined image points. The image transformation should be completed with an analysis of the accuracy of the control points.

However, it should be kept in mind that the vehicle can only be dimensioned relative to the transformed plane, therefore the elements of the front of the reference model vehicle, which lie in a further perspective in relation to the side of the vehicle, were removed for the purpose of the study. The detailed analysis will be presented below in tabular form.

Accuracy analysis

The accuracy analysis was carried out based on eleven clearly identifiable control points of the body of the reference model, located across the entire width of the vehicle's side in accordance with the sketch marked No. 1 presented below. Then, these points were determined in the photograph in the same coordinate system which in turn allowed for the calculation of the deviation in determining the location of the points.

The accuracy of determining the position of points from the photograph was analysed for all previously discussed variants, i.e.:

- **Variant 1:** A photograph taken in accordance with the correct rules for preparing such documentation, i.e. perpendicular to the photographed side of the vehicle with a lens focal length corresponding to 50 mm for the full frame size;
- **Variant 2:** The photograph was taken obliquely to the side of the vehicle with a small angle of 10° deviation of the lens axis;
- **Variant 3:** Rectified oblique photograph from Variant 2.

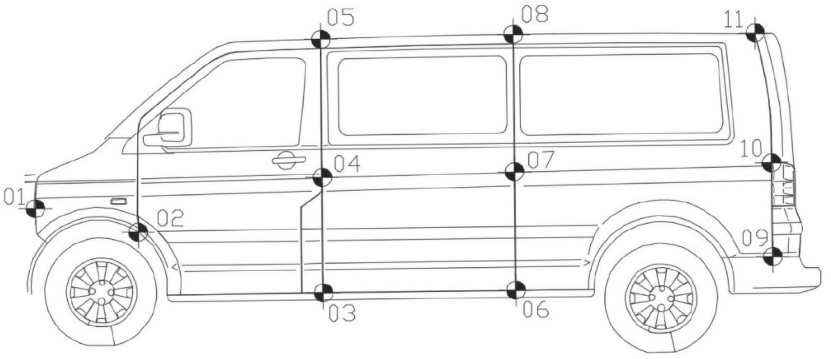


Figure 1. Control points marked on the reference silhouette

The coordinates of the control points were determined based on the reference silhouette model, which in the adopted reference system are as follows:

Point no	X [m]	Y [m]
1	149.999	99.996
2	150.632	99.855
3	151.769	99.460
4	151.729	100.184
5	151.738	101.036
6	152.920	99.493
7	152.915	100.231
8	152.910	101.072
9	154.498	99.699
10	154.471	100.276
11	154.398	101.059

Table 1. Control points marked on the reference silhouette

Control point No	DEVIATIONS FROM THE POSITION OF VEHICLE CONTROL POINTS [mm]		
	PERPENDICULAR PHOTOGRAPH (lens axis perpendicular to the side of the vehicle) [mm]	**OBLIQUE PHOTOGRAPH** (lens axis oblique to the side of the vehicle at a low angle = 10°) [mm]	PHOTO RECTIFIED (photogrammetrically processed oblique photograph) [mm]
1	4	6	4
2	10	58	5
3	18	62	18
4	18	81	18
5	61	50	2
6	5	7	3
7	20	37	8
8	46	54	4
9	9	41	21
10	29	52	4
11	65	94	23

A detailed accuracy analysis confirms previous preliminary findings for each of the tested variants. The accuracy analysis for an oblique photograph was performed for a minor 10° deviation of the optical axis of the lens perpendicular to the object. With larger axis deviations, an increase in dimensioning inaccuracies directly from the photograph should be expected.

CONCLUSIONS:

1. Photographs taken correctly, perpendicularly to the photographed side of the vehicle with a standard focal length for a given matrix format, after scaling allow for direct measuring for road accident reconstruction purposes.
2. In case of photographs taken perpendicularly to the photographed side of the vehicle, it is reasonable to use 3D photogrammetric transformations. In caase of singular perpendicular photographs (as in this case study), using 2D photogrammetric transformations is also reasonable and allows for further use of a transformed photography for road accident reconstuction purposes.