THE FUTURE OF TRANSPORT

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Crush measurements obtained from two dimensional photographs using Photogrammetry.

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1 Introduction

Photogrammetry involves the use of multiple two dimensional images to create a three dimensional model from which measurements can be taken.

Photogrammetry is used widely in the United States of America in accident investigations when limited data is available (e.g. photographs, but no vehicles and no scene measurements) to determine vehicle deformations and dimensions of scene features such as skid marks which may have worn away. For some unknown reason it has not been adopted more widely within Europe and the UK.

To help decide whether or not Photogrammetry should be used by accident investigators at TRL, this project was performed. The objective of the project was to trial the use of photogrammetry at TRL with a focus on its use to estimate vehicle deformations or crush.

Analysis of the deformation or crush created on a vehicle during a collision is an accepted method for estimating its delta-V or equivalent barrier speed (EBS). Its use has been described in a large number of technical documents as listed in the, 'Reference List', appended to this report

The conventional way of obtaining external crush values and profiles is to set up a datum line at a known position along the damaged region, and then take measurements perpendicular to this at defined separation distances. This operation is repeated using an identical datum line on an undamaged vehicle, the deformation measurements being the difference between these two profiles measured. The measurements can be taken at different heights to show how an impacting profile can generate significant variations in crush damage.

When instructions are received at TRL to perform an accident investigation, it is very often the case that the damaged vehicles have been scrapped or repaired and hence not available for inspection. In these cases, TRL may be presented with photographs of the damaged vehicles without knowledge of any damage dimensions. To date, accident investigators have had to resort to making estimates or subjective assessments of vehicle damage extent to derive values of impact severity, either from experience, or by reference to documented crash test results. Clearly, the ability to use Photogrammetry in these cases could allow vehicle deformations to be estimated more accurately and in turn enable an improved investigation.

The objective of the work performed was to trial the use of Photogrammetry at TRL by investigating the accuracy of photogrammetric crush measurements compared to manual measurements of vehicle collision deformation.

2 Methodology

Accurate deformation measurements from a previous crash test of a Vauxhall Corsa were taken using a Faro Arm measurement machine with a tolerance about ±0.05mm. The vehicle had been struck in the side by another Vauxhall Corsa at 53 kmh.

The methodology used for the project was to:

- Take deformation measurements of the Vauxhall Corsa impacted in the side using photogrammetry and manual techniques.
- Compare photogrammetry and manual measurements with accurate Faro Arm measurements.

Several digital photographs of a subject vehicle that had previously been crash tested at TRL were taken with a calibrated Nikon D5100 camera fitted with a fixed 50mm lens. The vehicle was marked with several targets as illustrated in Figure 1. These target markers were arranged in rows labelled from A to G on the nearside. There were further target references but they were located outside of the area of interest. Target marker A1 was attached to the front nearside wing below the small quarter light window.

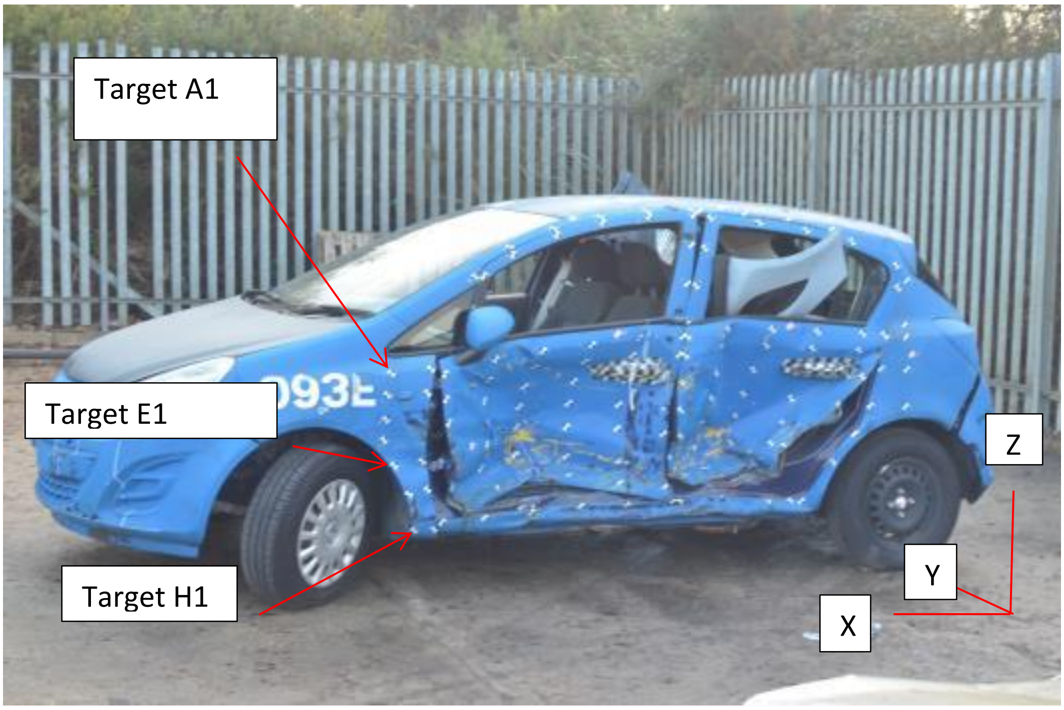

Figure 1 – Subject vehicle with target points measured shown in rows A, E and H

For the purposes of this project, 22 photographic images were taken from different positions around the whole of the vehicle. In a real world case, we are often provided with only two or three images. Even with this small number of photographic images it is still possible to use photogrammetry to resolve the camera views and therefore create a three dimensional model of the damaged areas. Any photographs that are used for this process must contain information about the undamaged parts of the vehicle in order to be able to calculate the camera parameters.

Using the Photomodeler product (US spelling) about 11 of the 22 photographic images were loaded into the program and referenced to each other using uniquely definable points on the exterior of the vehicle. This process solves the camera positions and is called inverse camera, where the objective is to identify where the camera was positioned for each photograph. The image in Figure 2 below illustrates the camera positions derived by the reverse camera process in this particular project.

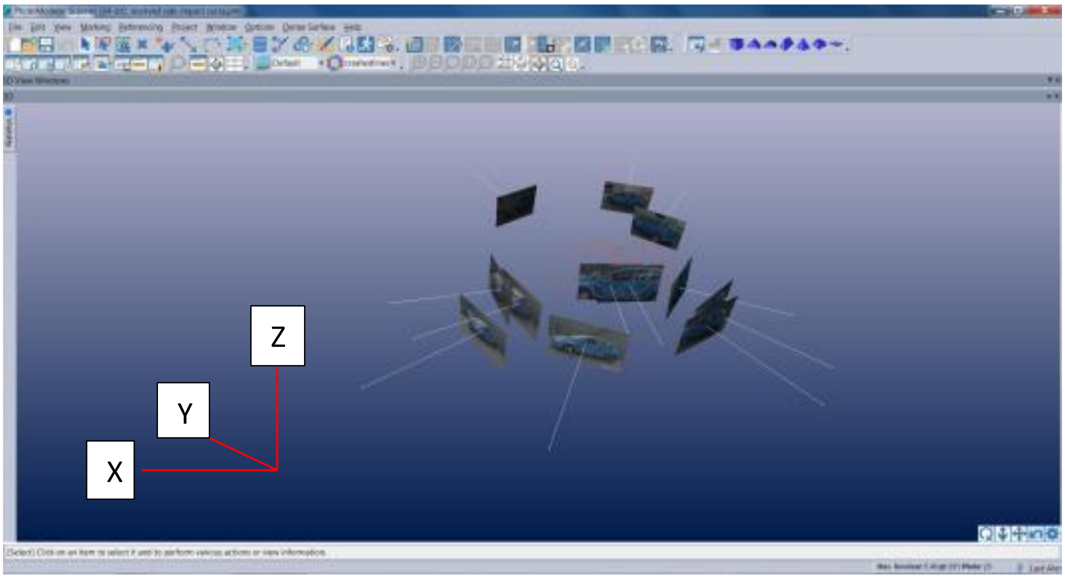

Figure 2 – Photomodeler program showing camera positions identified

The software identifies the residual errors, which is where a referenced set of points have not been placed correctly. These residuals are easily resolved, allowing the model to be completed and exported. Residual errors are calculated within the program by analysing the spacial difference between where the camera shows where any of the uniquely definable points lies and where it is predicted to lie based on the developing three-dimensional image.

The image in Figure 3 below shows the crushed side of the vehicle with the referenced points and crush profile lines visible.

Figure 3 – Showing the Corsa with the referenced pohotogrammetry points

The model is then scaled based on the determination of one or more undamaged lengths within the model and rotated to calibrate the co-ordinates.

For the purposes of this exercise, a 3D exemplar model of the vehicle was purchased (Figure 4) and was loaded into the Rhino 3D CAD software. This method was adopted as an alternative to measuring profiles of the side structures of an undamaged vehicle. This computer model is used to create an outline, which is then exported as a dxf.

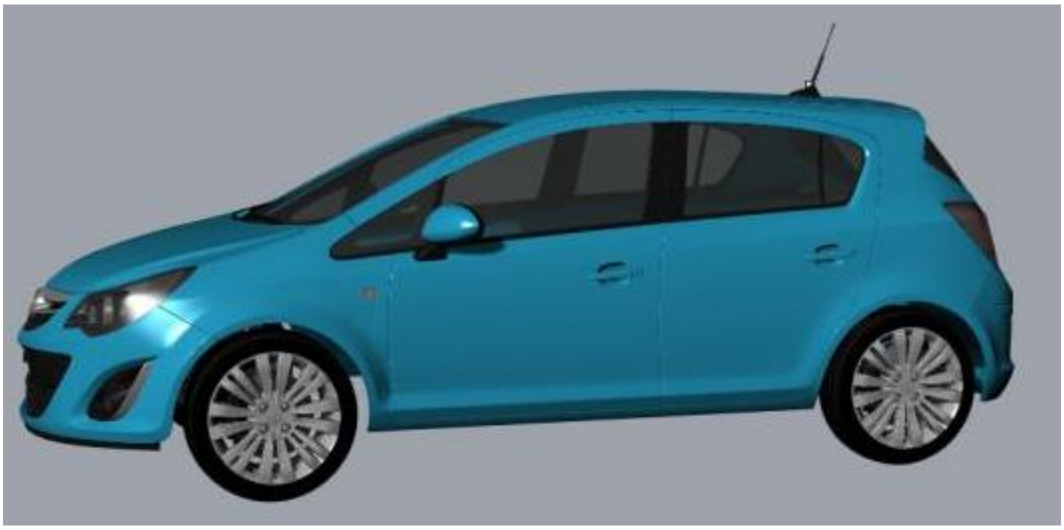

Figure 4 – Image of the 3D model in Rhino

The exemplar outline was imported into the PhotoModeler program and then merged with the damaged profile that was created earlier, as shown in Figure 5.

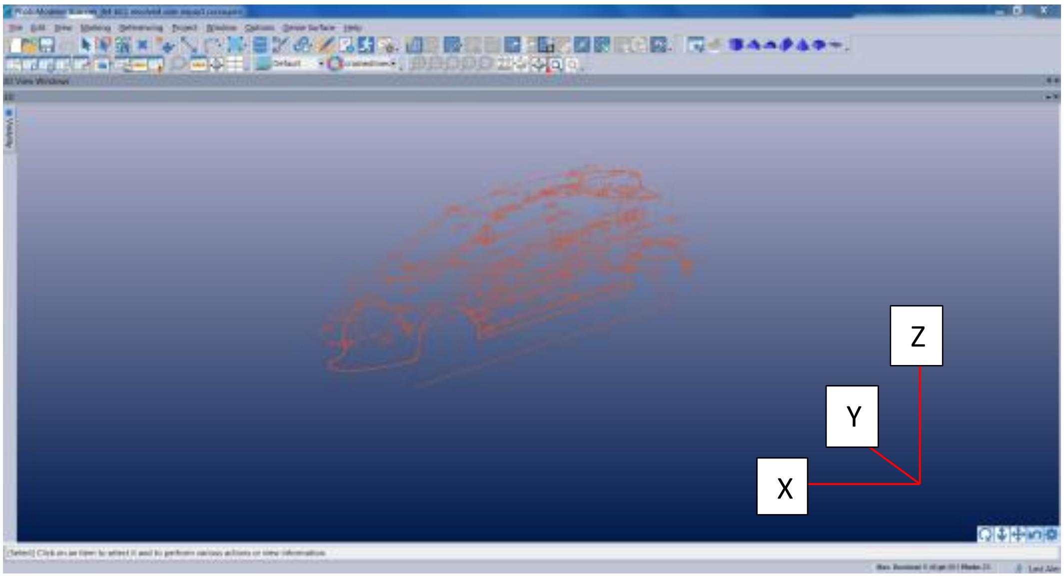

Figure 5 – PhotoModeler with the two models merged together

The model is then exported from PhotoModeler as a dxf file and re-imported back into Rhino. The image in Figure 6 shows the completed model as a three dimensional point matrix after it has been imported into Rhino.

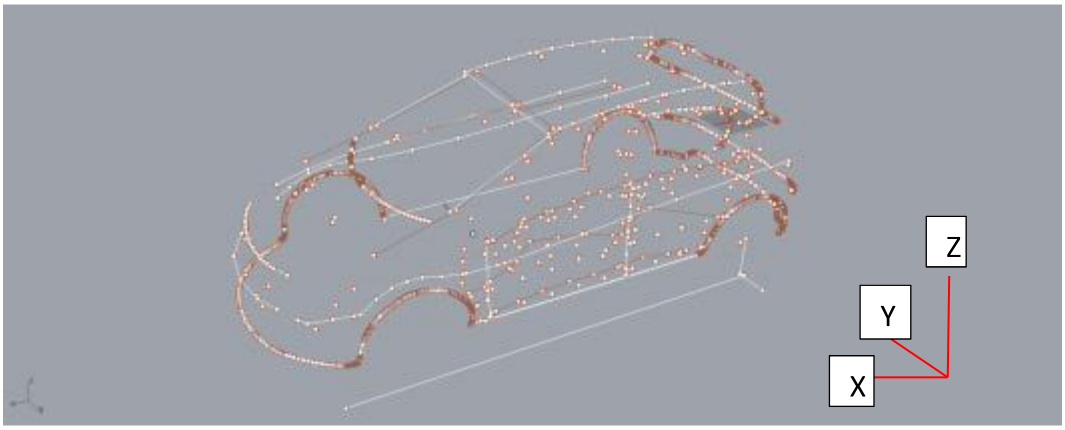

Figure 6 – View of the merged models in Rhino following export from PhotoModeler

The imported models are then merged with the 3D model of the Corsa as shown below.

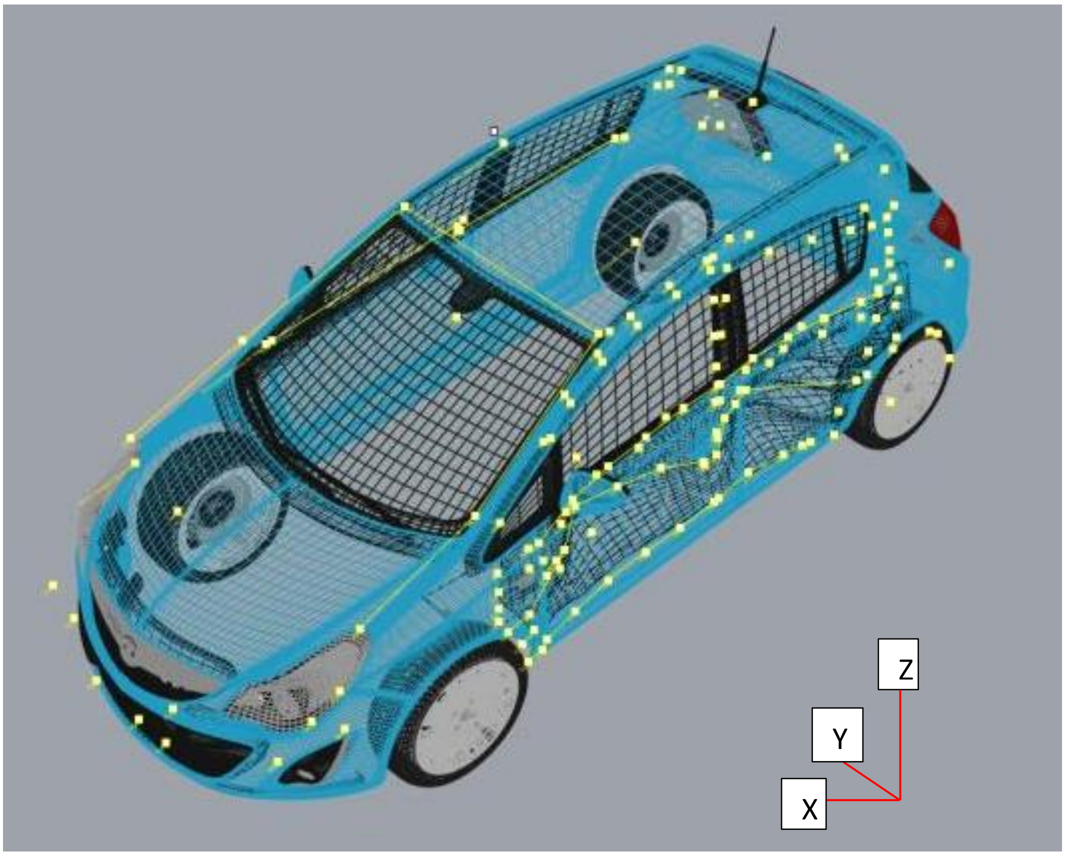

Figure 7 – Image showing the photogrammetric points and Faro profile with the 3D model

3 Results

3.1 Deformation measurements

Measurements of the lateral crush (intrusion) of the damaged vehicle were recorded using three different techniques.

The first was a simple manual measurement approach using tapes and a spirit level; the second data set was derived from Faro Arm data (which had been measured before and after the crash testing for the original project); and the third was using Photogrammetry. The measurements were taken for the defined Rows A, E and H. It should be noted that the Faro Arm measurements have a tolerance about +/- 0.05 mm and therefore they were used to assess the relative accuracy of the manual and photogrammetry measurements.

The graph in Figure 8 below shows the crush profile determined by the three methods for Row A, when viewed from above.

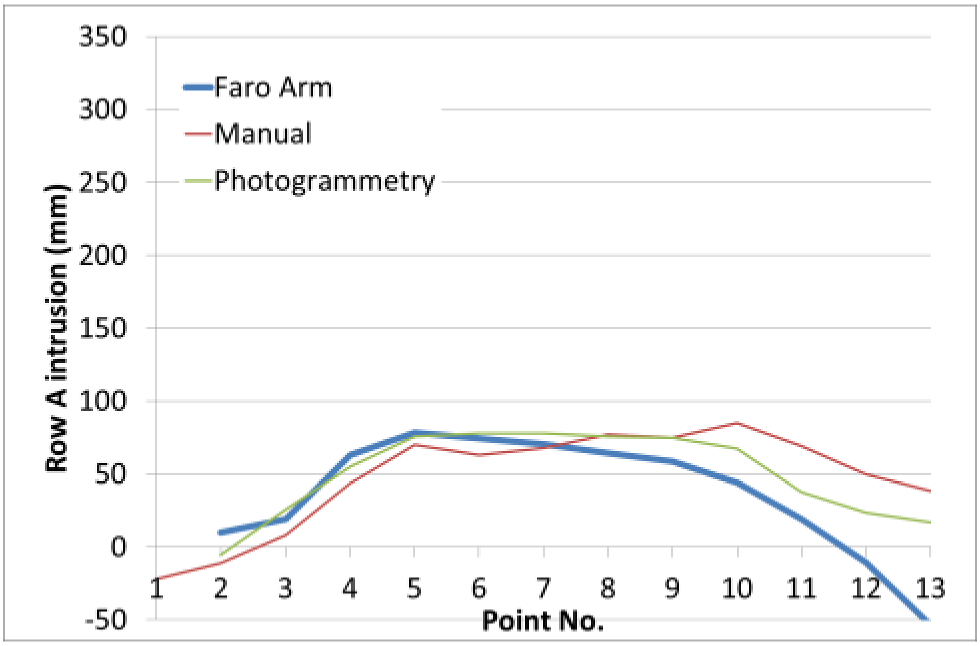

Figure 8 – Image showing the results of the three methods for Row A

The results for Row E are shown in Figure 9 overleaf.

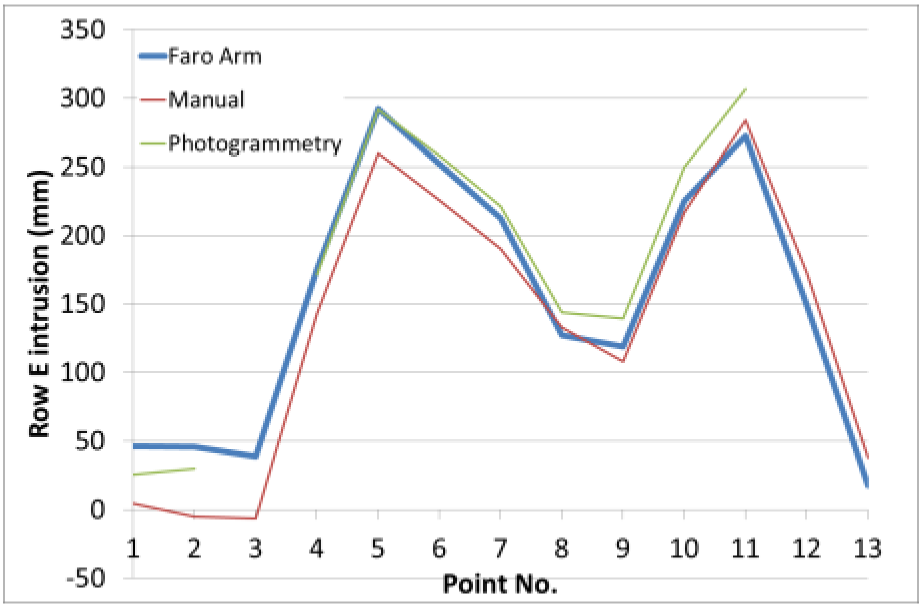

Figure 9 – Image showing the results of the three methods for Row E

The results for Row H are shown in Figure 10 below.

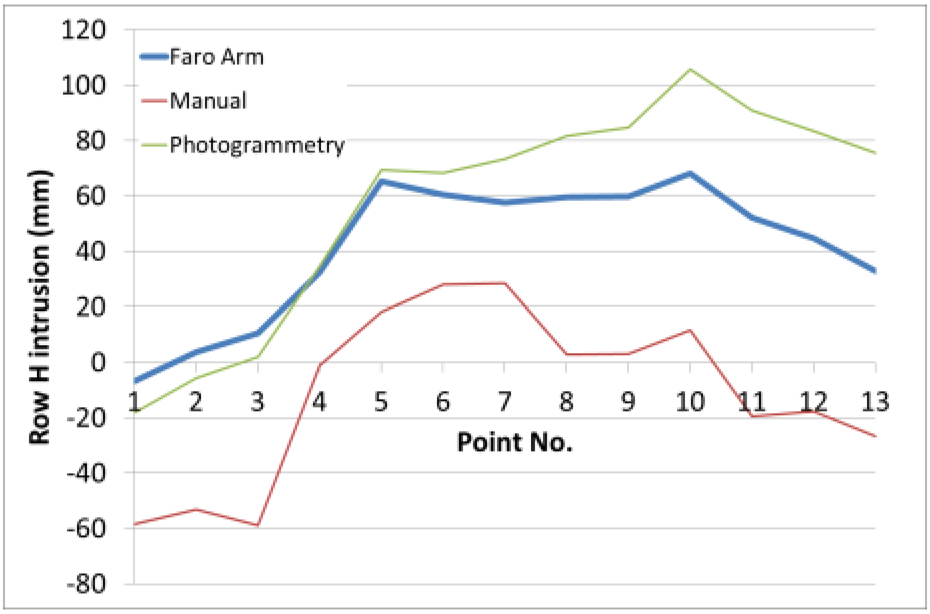

Figure 10 – Image showing the results for the three methods for Row H

It is seen that, in general, the photogrammetry measurements compare better to the Faro Arm measurements than do the manual measurements that were taken for this project.

Table 1 overleaf shows the comparison between the Faro Arm and the manual measurements, presented in mm.

Table 1

	1	2	3	4	5	6	7	8	9	10	11	12	13
Faro Row A		10.10	19.37	63.15	78.10	74.44	70.22	64.45	58.68	43.96	19.11	-10.41	-53.70
Manual Row A	-21.94	-10.85	8.28	43.64	70.09	63.04	67.86	77.15	74.7	84.88	69.08	49.73	38.45
Absolute diff		-20.95	-11.09	-19.51	-8.01	-11.40	-2.36	12.70	16.02	40.92	49.97	60.14	92.15
% diff		-207.43	-57.26	-30.89	-10.26	-15.31	-3.35	19.71	27.29	93.09	261.54	-577.58	-171.59
Faro Row E	46.35	45.56	38.84	175.12	292.12	251.87	212.36	127.10	118.99	225.36	272.32	148.95	17.68
Manual Row E	4.37	-4.97	-6.44	142.94	260	225.67	190.22	132.64	107.88	217	283.86	172.59	37.71
Absolute diff	41.98	50.53	45.28	32.18	32.12	26.20	22.14	-5.54	11.11	8.36	-11.54	-23.64	-20.03
% diff	90.57	110.91	116.58	18.38	11	10.4	10.42	-4.36	9.34	3.71	-4.24	-15.87	-113.24
Faro Row H	-6.80	3.82	10.51	32.48	65.23	60.36	57.60	59.49	59.85	68.15	52.17	44.67	32.98
Manual Row H	-58.5	-53.25	-58.76	-1.11	18.28	27.95	28.45	2.99	3.01	11.58	-19.4	-17.78	-26.64
Absolute diff	51.70	57.07	69.27	33.59	46.95	32.41	29.15	56.50	56.84	56.57	71.57	62.45	59.62
% diff	-760.55	1492.89	659.09	103.42	71.97	53.7	50.61	94.97	94.97	83.01	137.19	139.8	180.78

The data in Table 2 below shows the difference between the photogrammetry and Faro Arm measurements.

Table 2

	1	2	3	4	5	6	7	8	9	10	11	12	13
Faro Row A		10.10	19.37	63.15	78.10	74.44	70.22	64.45	58.68	43.96	19.11	-10.41	-53.70
Photogrammetry Row A		-5.38	25.60	54.91	75.67	77.61	77.67	75.62	74.64	67.36	37.49	23.41	17.18
Absolute diff		15.48	-6.23	8.24	2.43	-3.17	-7.45	-11.17	-15.96	-23.40	-18.38	-33.82	-70.88
% diff		153.27	-32.15	13.05	3.11	-4.26	-10.62	-17.34	-27.19	-53.24	-96.21	324.82	131.99
Faro Row E	46.35	45.56	38.84	175.12	292.12	251.87	212.36	127.10	118.99	225.36	272.32	148.95	17.68
Photogrammetry Row E	25.65	30.08		171.32	291.89	257.97	221.30	143.69	139.27	249.59	306.49		
Absolute diff	20.70	15.48	38.84	3.80	0.23	-6.10	-8.94	-16.60	-20.28	-24.23	-34.17		
% diff	44.66	33.97	100.00	2.17	0.08	-2.42	-4.21	-13.06	-17.04	-10.75	0.67		
Faro Row H	-6.80	3.82	10.51	32.48	65.23	60.36	57.60	59.49	59.85	68.15	52.17	44.67	32.98
Photogrammetry Row H	-18.04	-5.68	2.03	34.64	69.41	68.34	73.28	81.71	84.78	105.81	90.81	83.38	75.57
Absolute diff	11.24	9.50	8.48	-2.16	-4.18	-7.98	-15.68	-22.23	-24.93	-37.67	-38.64	-38.71	-42.59
% diff	-165.37	248.57	80.69	-6.66	-6.41	-13.21	-27.22	-37.36	-41.66	-55.27	-74.07	-86.66	-129.16

The greyed out cells in columns 11 to 13 on Row A, and columns 12 and 13 in Row E were not compared as these were located on the rear door, where the outer skin had moved away from the vehicle. The target Column 3 in Row E was missing at the time of this study of the vehicle so no comparison could be made.

The mean values of the differences between the Faro Arm measurements and those of the photogrammetry and manual measurements, respectively, for rows A, E and H, were calculated to assess the relative accuracy of the photogrammetric and manual techniques. Note that greyed out cells were not used in this calculation. The results are shown in Table 3.

Table 3: Means of differences to Faro Arm measurements.

Table Row	Technique	Means (Average) of differences to Faro Arm measurement (mm) Note: A positive difference indicates intrusion under-estimated.
Row A	Photogrammetry	-4.58
	Manual	16.55
Row E	Photogrammetry	-7.01
	Manual	16.09
Row H	Photogrammetry	-15.81
	Manual	52.59

The results show that on average there are smaller differences between the Faro Arm and the photogrammetry derived measurements as compared to the Faro Arm and manual measurements. This indicates that the photogrammetry measurements are more accurate than the manual measurements.

It is noticeable that, on average, the photogrammetry process slightly over-estimated the crush values, whereas the manual measurements under-estimated them, particularly for Row H.

3.2 Important points to note

To be able to use the photogrammetry process successfully, photographs showing particular types of view of the deformed vehicle must be available. The position of the camera and the quality of the images must be optimised to allow the program to model and match as best possible.

- The photographs of the damaged vehicle must contain information about the uncrushed part of the vehicle. This known information is used to calculate the camera parameters.
- At least two photographs are required, although three or more photographs would be ideal as it reduces redundancy.
- The photographs of the damaged vehicle must be taken from different positions providing good intersection angles. Photographs taken from a range of heights are advantageous.
- Four undamaged points must be identified on both the damaged and undamaged models.
- There must be a reasonable degree of overlap between the photographs. An overlap of about 30% between adjacent images is a good working guide.
- The photographs should provide clear, sharp edges. The program requires these for matching and comparison purposes.

Additional work was conducted to show how the data from the PhotoModeler software could be imported into other software used within the EIN group at TRL, specifically Rhino, and manipulated for presentation.

The Faro laser arm crush data obtained immediately after the crash test was used to generate a 3D model net of the crush damage, as shown in Figure 11. The model was created from FARO Arm Measurement data. Within it can be seen the coloured points that represent the targets attached to the vehicle.

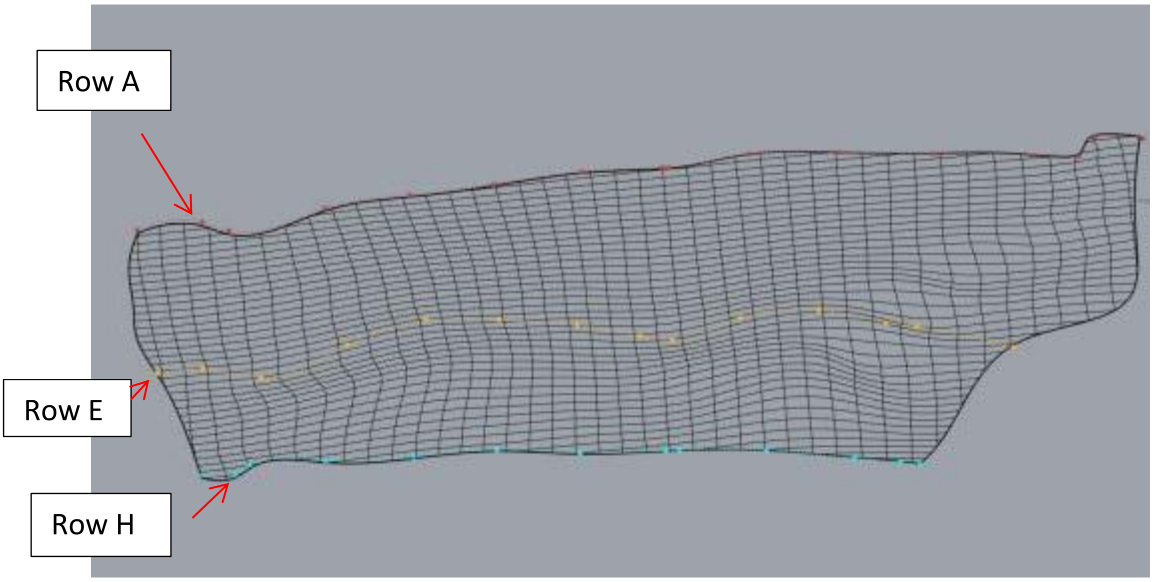

Figure 11 – Image showing the Faro Arm damage profile with rows A, E and H

The FARO arm and the PhotoModeler profiles have been merged together to show that the target points match closely, as shown in Figure 12 overleaf. The white squares are the points created in PhotoModeler. It can be seen that they closely match the majority of the FARO Arm measured points.

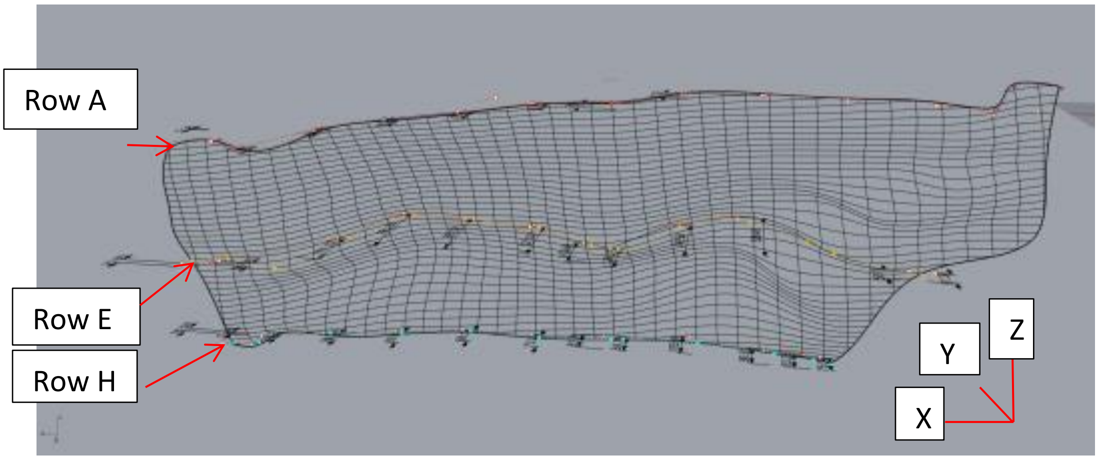

Figure 12 – Image showing the Faro Arm profile with the Photomodeler profiles for Rows A, E and H

4 Conclusions

The use of photogrammetry, and in particular the PhotoModeler product, has proved to be of use where the vehicles are no longer available for inspection. It is a tool that offers the investigator a means of determining values of crush, to calculate collision severity where this cannot be derived from other physical approaches.

A number of overlapping photographs of sufficient quality of the damaged vehicle are required as this increases redundancy. They must also contain undamaged areas of the vehicle so that at least four points from the undamaged areas can be matched with the exemplar model.

The results presented in this report show that the crush measurements obtained using photogrammetry compared with the manual method are, on average, much closer to the accurate measurements taken using a Faro Arm, which have a tolerance of less than 1 mm.

The average differences for the photogrammetry measures for Row A, E and H were -4.58 mm, -7.01 mm and -15.81, respectively, whereas for the manual method they were 16.55 mm, 16.09 mm and 52.50, respectively. Note that a positive difference indicates crush under-estimated.

For the limited number of measurements taken in this trial, the results show that photogrammetry is, in general, a more accurate method for obtaining crush measurements than the conventional manual method.

In a technical paper entitled "A Three Dimensional Crush Measurement Methodology using Two-dimensional Photographs", one conclusion was that photogrammetry successfully quantified vehicle crush with differences versus manual methods of less than 25mm. The report states, *"The photogrammetric technique presented has been shown to accurately and reliably quantify the deformation of crash vehicles and its results can be reliably used in accepted crash reconstruction methods."*

Aside from the vehicle measurements that are discussed in this document we have also used the photogrammetry method in a limited number of cases to determine how well it predicts the lengths of road marking and other physical features, where these can be measure manually.

Again the ability of the PhotoModeler program to return values that are comparable to direct measurement relies on the number, orientation and quality of the photographic images.

This is an area that we need to explore in greater depth to develop a level of known accuracy associated with the technique.

5 Way Forward

Photogrammetry has been used widely in the USA as a means of deriving a number of dimensions which were not measured at the scene or elsewhere. For some unknown reason it has not been adopted more widely within Europe and the UK.

The analysis described in this report is based on tests conducted at TRL. The results show that, at its optimum level of performance, photogrammetry is able to return values of vehicle crush to a level of accuracy that is likely to be much greater than a simple manual approach would return.

To extend our competence and knowledge of this method, and of the PhotoModeler product in particular, we need to experiment with the method when the photographic coverage of vehicle damage is less well documented (by way of both number and optical quality) than was the case in this experimental test collision.

We need to determine relative levels of competence when the photographic images are less well defined, or when the medium is of lower quality, as may be the case with images taken by bystanders using mobile phones.

We also need to extend the use of the method to situations where marks on a road, or on other surfaces, are shown in photographs, but were not measured at the scene. Again levels of competence need establishing for a variety of evidential sources.

By extending our knowledge and competence of the method and the product, TRL can provide additional technical evidence in cases where there is a suitable photographic material, as well as a measure of confidence in any dimension derived from this approach.

Appendix A Images of the damaged vehicle used in Photomodeler


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TRL093E


TRL093E

Crush measurements obtained from two dimensional photographs using Photogrammetry.

Other titles from this subject area

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Determination of the collision speed of a vehicle from evaluation of the crush volume using photographs. Inhwan Han and Heejin Kang. IMechE. 2015 Vol 230(4) 479-490

Photogrammetry for documentation of vehicle deformations – A tool in a system for advanced data-collection. Kullgren a et al. Accident Analysis and Prevention, 26(1), 1994, pp99-106.

Image analysis of rollover crash tests using photogrammetry. Chou c et al, SAE Technical Paper Series, 2006-01-0723

Semi-Automated Crush Determination using Coded and Non-Coded Targets with Close-Range Photogrammetry, Mills D and Carty G, SAE Technical Paper Series

http://www.photomodeler.co.uk/applications/documents/MillsCodedTargetsCrush.pdf

Forensic Engineering evaluation of physical evidence in accident reconstruction. Zienicki R et al, in Journal of the National Academy of Forensic Engineers, Vol XXIV, No2, 2007

Determination and Verification of Equivalent barrier speeds (EBS) using Photomodler as a measurement tool Shields L et al. SAE Technical Paper Series, SAE 2004-01-1208

Virginia Dept of Transportation, Research Synthesis Bibliography N08, May 2007 Low Cost 3D Digital mapping and Modelling For Reconstruction. Meinschein G.

Impact, Spring 2016, Vol 2$, No 1 A Survey of Multi-view Photogrammetry Software for Determining vehicle Crush. Terpstra T et al. SAE 2016-01-1475

The Accuracy of Optimised, Practical Close-range Photogrammetry method for Vehicular Modelling. Peck L and Cheng M. SAE 2016-01-1462.

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