

**TECHNICAL PAPER FOR STUDENTS AND YOUNG ENGINEERS**  
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TITLE:

**The Suitability of Digital Photogrammetry with PhotoModeler Software for Accident Investigation**

Topic:

- FUTURE AUTOMOTIVE TECHNOLOGY       INTELLIGENT TRANSPORTATION SYSTEMS  
 USER FRIENDLY AUTOMOBILE       ADVANCED PRODUCTION AND LOGISTICS  
 VEHICLES & THE ENVIRONMENT

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Abstract:

In this paper the results are presented of an experiment to evaluate the accuracy of digital photogrammetry with PhotoModeler as a measurement technique and to determine if the technique is suitable for measuring the typical depths of crush found in low speed collisions.

The results of a photogrammetric study of a staged T-style 30-mph collision are also presented. The vehicles involved were photographed, modelled in PhotoModeler, and the pre-impact speed was then found using the crush measurements from the models and empirical equations developed by Dr. D. P. Wood, which relate crush and energy absorbed.

Place / Date:

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## **Introduction**

Photogrammetry is defined as the process of deriving information about an object through measurements made on photographs. Its earliest use can be traced back to Leonardo da Vinci who studied the principles involved in the geometric analysis of paintings in the late 1400s (1). PhotoModeler is a Windows program, a tool for performing close-range photogrammetry. Two or more photographs are opened in the software package and the operator marks each photograph with the mouse, tracing and tagging features and points of interest. These points and features are cross-referenced on all photographs in which they appear; PhotoModeler orientates the photographs and locates the marked features/points in three dimensions (2).

There are a number of papers, which discuss the use of photogrammetry in the reconstruction of an entire accident scene, for example Pepe et al. (3) mapped a scene using different photogrammetry techniques and compared them. There are also papers on vehicles with large amounts of damage. Knott laboratory studied the Princess Diana crash using photogrammetry (4), whereas my work examines the use of photogrammetry in low speed collisions, therefore testing the limits of accuracy of the technique as relatively small amounts of residual crush damage are involved. The speed of the collision presented here was 30.7mph and the average residual crush depth on the bullet/striking vehicle was 3.6cm and on the target/struck vehicle was 16.5cm.

Experiments with pipes of known lengths were carried out to see if the technique of measuring through photogrammetry with PhotoModeler is capable of measuring crush depths in the order of magnitude associated with low speed collisions, and to help develop the best method of gathering the data required by the technique.

## **Pipe Experiment**

Plastic pipes of varying lengths were supported and arranged as in figures 1 and 2. A triangular target was placed at each end of the pipes, to provide a distinct point for tagging during the modelling process. Figure 1 shows the pipes within a metal frame, which has a circular target at each corner; the centres of these circles can be automatically found and tagged by PhotoModeler. The corners of the frame around the pipes being modelled help to orientate the photographs. The length of the longer side of the frame was used to scale the model. Figure 2 shows the pipes with a longer metal pipe above them, which was used to scale the model; triangular targets were also placed at the ends of this pipe.

Tables 1 and 2 show the results of the models made. The actual lengths were measured using a metal tape measure. Four photographs taken from around the pipe set up were imported into PhotoModeler. The tips of the triangular targets at the ends of the pipes or the centres of the circular targets at the corners of the frame were tagged and cross-referenced between the photographs. The project was scaled as explained above. This was repeated ten times, giving tens sets of results for each pipe set-up. The lengths obtained from these models were then averaged and a standard deviation was found.



**Figure 1. Plastic pipes within frame.**

	<b>m</b>	<b>m</b>	<b>m</b>	<b>m</b>	<b>m</b>	<b>m</b>	<b>m</b>
<b>Actual</b>	3.999	3.96	3.9	2.00	1.504	1.028	1.006
<b>PhotoModeler</b>	4.009	3.976	3.91	2.013	1.368	1.018	0.93
	4.008	3.975	3.906	2.019	1.368	1.022	0.918
	4.008	3.981	3.907	2.016	1.369	1.021	0.934
	4.01	3.973	3.904	2.017	1.373	1.017	0.934
	4.008	3.973	3.903	2.015	1.373	1.017	0.899
	4.011	3.975	3.905	2.015	1.368	1.018	0.918
	4.009	3.975	3.905	2.012	1.368	1.023	0.925
	4.008	3.975	3.904	2.019	1.365	1.023	0.925
	4.011	3.975	3.908	2.015	1.37	1.017	0.923
	4.008	3.976	3.905	2.016	1.37	1.022	0.925
<b>Average</b>	4.009	3.975	3.906	2.016	1.369	1.020	0.923
<b>Standard Dev.</b>	0.001	0.002	0.002	0.002	0.002	0.003	0.010
<b>Range</b>	4.008	3.973	3.904	2.014	1.367	1.017	0.913
	4.010	3.977	3.908	2.018	1.371	1.023	0.933

**Table 1. Results of experiment with pipes within frame.**



**Figure 2. Pipe with scaling pipe**

	<b>m</b>	<b>m</b>	<b>m</b>	<b>m</b>	<b>m</b>	<b>m</b>	<b>m</b>
<b>Actual</b>	4.492	3.999	3.96	3.9	3.048	2.00	1.028
<b>PhotoModeler</b>	4.492	3.98	3.951	3.897	3.042	1.998	1.025
	4.492	3.98	3.951	3.897	3.042	1.998	1.025
	4.492	3.985	3.955	3.897	3.046	2.00	1.024
	4.492	3.985	3.957	3.902	3.044	2.008	1.028
	4.492	3.995	3.957	3.897	3.043	2.001	1.025
	4.492	3.987	3.959	3.901	3.049	2.003	1.03
	4.492	3.986	3.953	3.896	3.043	2.004	1.033
	4.492	3.99	3.956	3.897	3.041	2.003	1.028
	4.492	3.991	3.951	3.894	3.044	1.999	1.03
	4.492	3.995	3.958	3.9	3.046	2.00	1.03
<b>Average</b>	4.492	3.987	3.955	3.898	3.044	2.001	1.028
<b>Standard Dev.</b>	0.000	0.005	0.003	0.002	0.002	0.003	0.003
<b>Range</b>	4.492	3.982	3.952	3.896	3.042	1.998	1.025
	4.492	3.993	3.958	3.900	3.046	2.004	1.031

**Table 2. Results of experiment with scaling pipe (4.492 is the scale pipe).**

### Collision Study

On the 26<sup>th</sup> of September 2003, the Institute of Traffic Accident Investigators (ITAI) staged a number of collisions at the Jaguar proving ground in Warwick, UK. The following are the resulting measurements and speeds calculated from photographs taken before and after one of the collisions. The formulae used to find the energy equivalent speed and the total energy in a T-style collision were developed by Dr. D. P. Wood (5).

The collision was a T-style collision between two vehicles, a Jaguar S-Type V8 and a Jaguar XJ V8. The XJ was stationary and the S-Type, with the use of a pulley system, was driven into the side of the XJ at a recorded speed of 30.7mph. Both vehicles had a driver and front seat passenger.

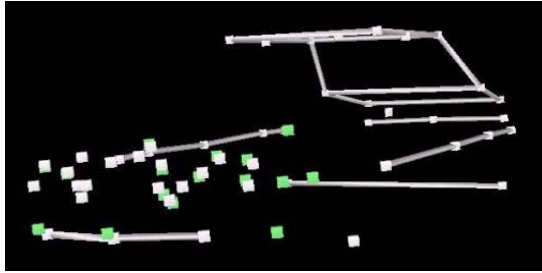
Reference markers/stickers were placed on both vehicles before the collision, extra markers should have been placed on the vehicles after the collision to hi-light the areas of damage but there was not enough time for this.



**Figure 3. The Jaguar S-Type, before the collision**



**Figure 4. The Jaguar S-Type, after the collision**



**Figure 5. The merged before and after models of the S-Type.**



**Figure 6. The collision**

The before and after models were created by tagging and cross-referencing the targets/stickers, which were placed on the vehicle, on all the photographs they appeared in. The two models were then fitted together at the points of the models that were undamaged, as these had not moved relative to their original positions on their respective vehicles.

The residual crush depths were then measured from the merged model by measuring the distance between the new locations of the targets (green points) that were displaced during the collision and their original positions.

The crush depths measured were 0.015m, 0.006m, 0.038m, 0.085m, 0.062m, 0.022m, 0.038m, 0.022m. The average residual crush depth,  $C_{res} = 0.036m$ .

Pre-impact length,  $l = 4.877m$ , as provided by the vehicle specifications and used to scale the model.

$V_{EES}$ , is the **energy equivalent speed**, the speed at which an unloaded car of this type would be travelling to cause the same amount of damage (5).

$$V_{EES} = 4.6 + 119.1 \left( \frac{C_{res}}{l} \right)^{2/3} = 4.6 + 119.1 \left( \frac{0.036}{4.877} \right)^{2/3}$$

$$V_{EES} = 9.1mph = 4.067m/s$$

Loaded mass of bullet car,  $m_t = 1734kg$  (as given by organisers)

Mass of load = 170kg (mass of two crash test dummies, 85kg each)

Unloaded mass of the bullet car,  $m_k = 1564kg$

**Energy of bullet car,  $E_b$**

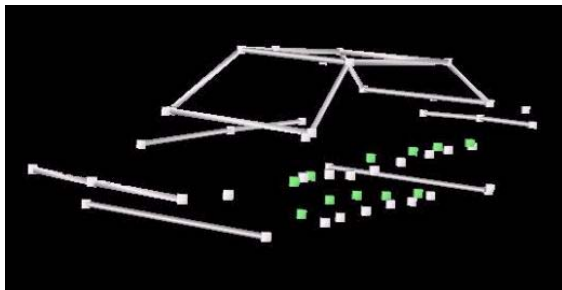
$$E_b = \frac{1}{2} m_k (V_{EES})^2 = \frac{1}{2} 1564 (4.067)^2 = 12934.66J$$



**Figure 7. The Jaguar XJ, before the collision**



**Figure 8. The Jaguar XJ, after the collision**



**Figure 9. The merged before and after models of the XJ.**

The before and after models of the XJ were created and merged in the same way as the models for the S-Type. The residual crush depth was also measured in the same way.

The residual crush depths measured were 0.023m, 0.057m, 0.089m, 0.105m, 0.212m, 0.257m, 0.315m, 0.33m, 0.148m, 0.209m, 0.07m.

Average residual crush depth,  $C_{res} = 0.165\text{m}$

Mass of Target car = 1708kg

### **Total energy in a T-style collision, $E$**

$d_{target}$  is the depth of damage at the point of contact (taken to be at the centre of the vehicle) on the target vehicle = 0.25m

$d_{bullet}$  is the depth of damage at the point of contact (taken to be along the centre line of the vehicle) on the bullet vehicle = 0.052m

$$E = E_b \left( 1 + \frac{d_{target}}{d_{bullet}} \right) = 12934.66 \left( 1 + \frac{0.25}{0.052} \right) = 75021.03J \quad (5)$$

$M_E$ , **Equivalent mass** of energy absorbing structure (central impact).

$$M_E = \frac{m_{bullet} \times m_{target}}{m_{bullet} + m_{target}} = \frac{1734 \times 1708}{1734 + 1708} = 860.45Kg$$

**Speed,  $V$** , corresponding to this amount of energy is given by

$$E = \frac{1}{2} M_E V^2$$

$$V = 13.2m/s = 29.54mph$$

The calculated pre-impact speed of the bullet car is **29.54mph**.

$$V_{Calculated} - V_{Actual} = 29.54 - 30.7$$

$$V_{Calculated} - V_{Actual} = -1.16mph$$

$$\% \text{ Difference} = -3.78\%$$

### Uncertainty Analysis

The standard deviation on the average residual crush depth is 0.026m, therefore the standard error on the mean,  $\Delta C_{res}$  is  $\frac{0.026}{\sqrt{8}} = 0.0092m$ ; this is used to find the standard error on the pre-impact speed, assuming there is no error on any other measured value.

$$\sigma = \frac{2}{3} \left( \frac{m_k \left( 1 + \frac{d_{target}}{d_{bullet}} \right)}{M_E} \right)^{\frac{1}{2}} \left( 119.1 \left( \frac{1}{l^3} \right) (C_{res})^{-\frac{1}{3}} \right) \Delta C_{res}$$

$$\sigma = 2.44mph$$

The 50% probability error (using normal tables) is then  $\pm 0.6745\sigma = \pm 1.65mph$ .

The 95% confidence interval is  $\pm 1.96\sigma = \pm 4.78mph$

So we can be 50% confident that the actual pre-impact speed is within the range 29.54 $\pm$ 1.65mph, and 95% confident that it is within the range 29.54 $\pm$ 4.78mph, which it is.

### Comparison of Crush Profiles

Also at the event the crush depths were measured manually by Robert Sproat, Crash Analyst, Birmingham Automotive Safety Centre, School of Engineering, The University of Birmingham.

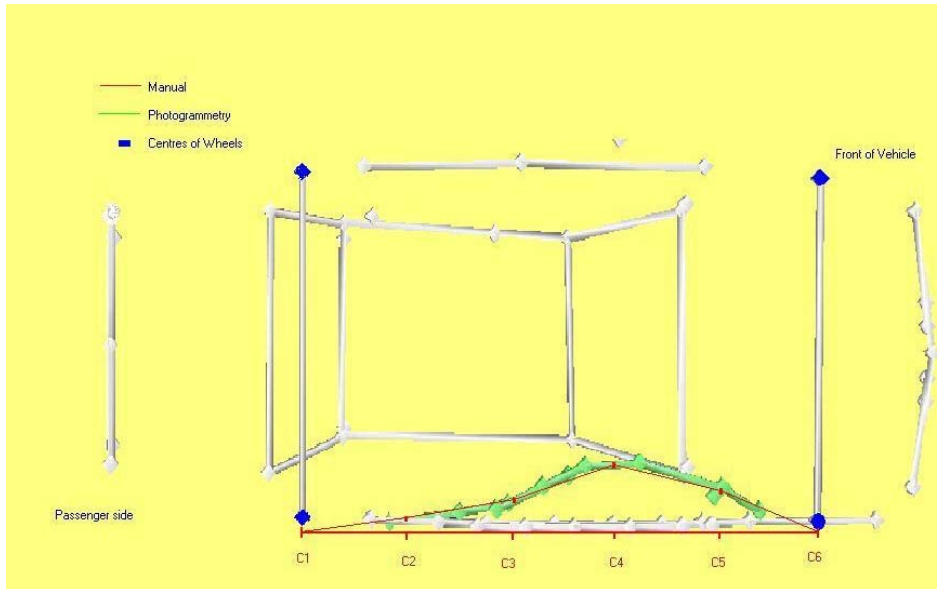
His measurements were taken by placing a grid at the front of the vehicle, with a base line parallel to the axle of the rear wheels or at the side of the vehicle with the base line parallel to the longitudinal axis. The height of the base line was determined visually by estimating the height of the stiff structure of the bullet vehicle (45cm for this collision). The width of the damaged area was divided into five sections, to give six equally spaced points C1 – C6. The distance from the base line to each of these points was then measured.

The crush depths for the target vehicle are given below and figures 10 and 11 show comparisons of the crush profiles of the vehicle as obtained by the photogrammetry method and by the manual method.

Side impacted Jaguar (target vehicle):

Damage width (taken as undamaged wheelbase) 300cm.

C1 (at rear wheel) 0cm, C2 4cm, C3 15cm, C4 37cm, C5 25cm, C6 (at front wheel) 0cm.



**Figure 10. Comparison of crush profiles.**



**Figure 11. Comparison of crush profiles.**

## Discussion

Photogrammetry with PhotoModeler is a very useful method of measuring residual crush depths. However further work is required to determine the best method of gathering the data required to create the models on which the measurements are made. The experiments with the pipes has led to two criteria that must be followed when using this technique; the distance between the points used to scale the project must be very accurately known and points to be included on the model must appear on as many photographs as possible.

A PhotoModeler project is scaled by hi-lighting two points and informing the software of the straight line distance between these two points. For the pipes within the frame, one side of the frame was measured and used to scale the project; however there was some 'sag' on the structure of the frame. The tape measure was allowed to rest on the structure while the distance between the two corners was being measured. Therefore it was not the straight-line distance that was measured. For the other pipe set up the distance from one end to the other

of a long metal pipe was used to scale the project, this pipe was more rigid and therefore the measurement taken was more accurate. With any tape measurement there are errors, either due to the tape itself or due to errors by the person reading it. Bartlett et al (6) found the standard deviation on measuring lengths of 11m and 27m to be approximately 0.0064m and 0.0184m with a measuring tape. In the collision study the vehicle length as provided by the manufacturer was used to scale the models of the vehicles in the collision study and this resulted in a very positive outcome.

The second conclusion from the pipe experiment; points to be included in the model should appear on as many photographs as possible. Two of the pipes within the frame had an end obscured from view by the frame itself in some of the photographs. One end of the 1.504m pipe could only be seen in two out of the four photographs use to create the model and one end of the 1.006m pipe could only be seen in three out of the four photographs use to create the model. The 1.504m and the 1.006m pipes have the worst agreement with their actual / tape measurements of all the pipes. All the other ends of the pipes appeared in all four photographs.

When the manual measurements of the target vehicle were being taken, the base line was located at the side of the vehicle where it was perceived the undamaged vehicle would have been. It contacted the outer walls of the tyres, approximately 22mm further out from the centre points of the hubcaps (the blue points in figures 10 and 11). The main reason for the different crush depths from the two methods is that a different set of samples of the crush depth was taken by each experimenter.

## Reference

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