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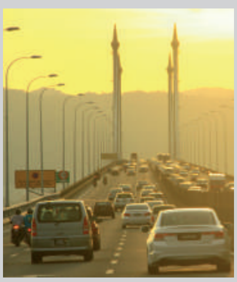
Research Report

Development of Photogrammetry Method in Measuring Damaged Vehicle



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Abstract

Crash reconstruction usually requires the detail on vehicle damage to establish the vehicle dynamics and kinematic during the occurrence of the motor vehicle crash. The conventional way of obtaining these measurements is through using measurement tape and flexible ruler. The conventional method requires appropriate training for a crash reconstructionist to ensure accurate measurement being taken. Nevertheless, the conventional method is still highly exposed to human error while measuring damaged vehicle especially while it is required to measure complex damaged surface. Thus, to prevent such problem, this study proposed using photogrammetry method to replace the conventional method in obtaining measurement from damaged vehicles.

In this study, two (2) damaged vehicles with different impact configuration were used to evaluate the performance of photogrammetry measurement. Four (4) different groups consist of two (2) experienced crash investigators were assigned to use the conventional method to measure the basic dimension and crush profile of both damaged vehicles. A coordinate measuring device (CMM) was used as a benchmark to evaluate the accuracy of photogrammetry measurement. From the results, it was found that the mean residual of photogrammetric was as low as 7.5 mm. The findings also revealed that number of photos used in photogrammetry can reduce the variance of residual and can help to achieve lower residual error. On the other hand, the findings showed that the conventional method was not consistent and was having high residual if compared with CMM measurement. Thus, photogrammetry method is a more reliable option to replace the conventional method in measuring damaged vehicle.

1. Introduction

This section shall explain the background of the current study. The problem statement, objectives and expected outcomes of this study shall also be clearly stated here.

1.1 Background

Accident reconstruction requires the details of vehicle damage to establish the vehicle dynamics and kinematics during the occurrence of the crash. Based on the vehicle damage, the impact energy during the crash event can be estimated. The impact energy can be further translated into impact speed, delta V and equivalent barrier speed. Besides, deformed surfaces on a crashed vehicle are crucial physical evidence to identify which objects have contacted with the vehicle during the event. According to (Campbell, 2010; Emori, 2010), the methodology of accident reconstruction based on vehicle damage has been very well established.

While the theory of accident reconstruction has been around for years, a conventional or manual method is still widely used as the primary method in measuring the important parameters of a damaged vehicle (Fricke, 2010). The conventional method only requires simple equipment including measurement tape, string, plump-bob and flexible ruler to take measurement to acquire accurate results in crash investigation (Fricke & Baker, 2014). However, the conventional "hands-on" method requires appropriate crash reconstructionist training in order to ensure proper method has been applied while taking measurement.

In recent years, photogrammetry has emerged as a new measuring method to produce accurate measurement using photographs. By using multiple two-dimensional photos, the photogrammetry method can create a three-dimensional model to represent an object. Some experiments have been conducted to examine the accuracy of photogrammetry in measuring vehicle dimension. It was reported that the photogrammetry measurement method only showed 1% - 2% error in vehicle dimension measurement in comparison to the published vehicle dimension (Fenton & Kerr, 2010). In another study, the measurement result of photogrammetry was compared with total station on crush vehicle and it was found that the average difference between the two (2) methods were only 1.1 to 1.2 cm (Pepe, Sobek, & Zimmerman, 1993).

1.2 Problem Statement

Three (3) main problems of the current conventional measuring method in crash investigation are as follows:

i. The conventional method is highly susceptible to human error while measuring damaged vehicle especially when it is required to measure complex damaged surface;
ii. The method may miss out on some important measurements especially of heavily deformed surface; and
iii. The method is not time efficient when complex measurement is required.

1.3 Objectives

The general objective of this study is to develop a photogrammetry method to replace the conventional measuring method. The following are the specific objectives of this study:

i. To evaluate the accuracy of the developed photogrammetry method;
ii. To evaluate the efficiency of the developed photogrammetry method in terms of time;
iii. To compare the accuracy of measurement between photogrammetry and the conventional method; and
iv. To determine the optimum method in implementing photogrammetry analysis.

1.4 Expected Outcomes

This study is expected to deliver the following outcomes:

i. A set of photogrammetry tools including markers and scales; and
ii. A more effective method to obtain measurement from damaged vehicles.

2. Literature Review

This section shall briefly discuss the basics of photogrammetry and application of photogrammetry in measuring damaged vehicles.

2.1 The Basics of Photogrammetry

Photogrammetry is a combination of methods in image measurement and interpretation for estimating the shape and location of an object based on one (1) or more photographs of that object (Luhmann, Robson, Kyle, & Boehm, 2013). In general, photogrammetry can be applied to any objects as long as the object can be documented in photograph form. The outcome of photogrammetry measurement is the 3-dimensional reconstruction of a specific object in coordinates and geometric elements form or in graphical form. In photogrammetry, a photograph is treated as a store of information on each of the pixel.

A photography is a reduction of a 3-dimensional object to a 2-dimensional image which would involve loss of information in the process of conversion. To reconstruct the 2-dimensional image into a 3-dimensional object, it is necessary to fully understand the optical process by which an image is created. The radiometric data such as intensity, grey value, colour value and geometric data can be extracted from an image point which is the critical information in the process of reconstructing the 3-dimensional structure. With the available information, photogrammetry uses central projection imaging as its fundamental mathematical model to apply 3-dimensional measurement technique on an object.

In a more technical term, points, shapes and position of a target object are determined by reconstructing the sources of rays from each camera at each image point P' with a corresponding perspective centre, O', to define the spatial direction of the ray to the object point P (Luhmann et al., 2013). This technical explanation is illustrated in Figure 1. An object point can be located in 3-dimensional space through intersection of at least two (2) corresponding spatially separated image rays. Further extending concept for all image points, bundles of rays from multiple images are intersected and would form a dense network. Using the method of bundle triangulation, the intersection points associated with the 3-dimensional object point locations can be simultaneously oriented and determined (Luhmann et al., 2013).

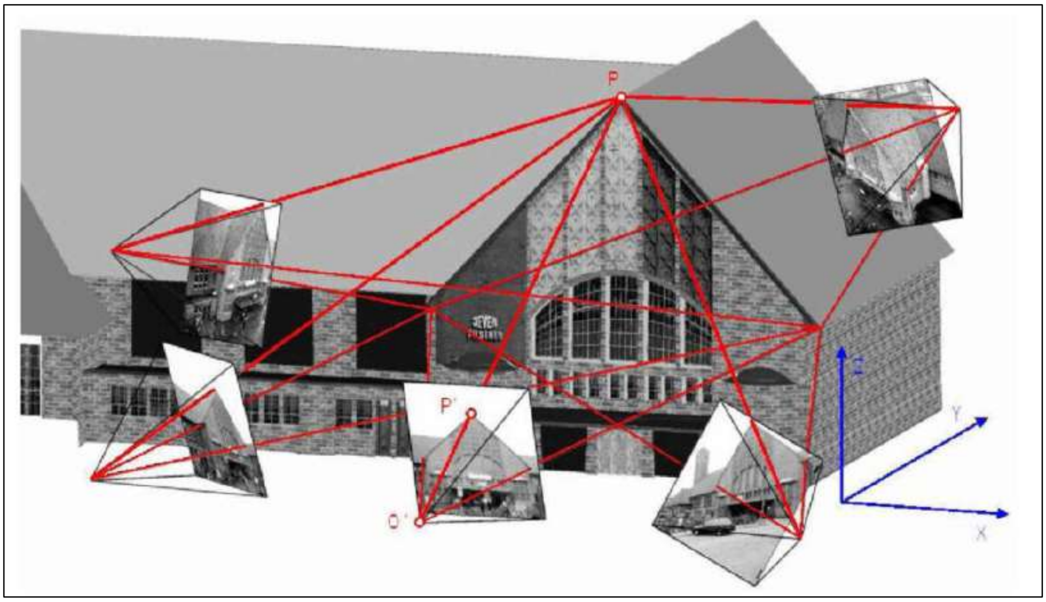

Figure 1 Principle of photogrammetry measurement (*Source*: Luhmann et al., 2013)

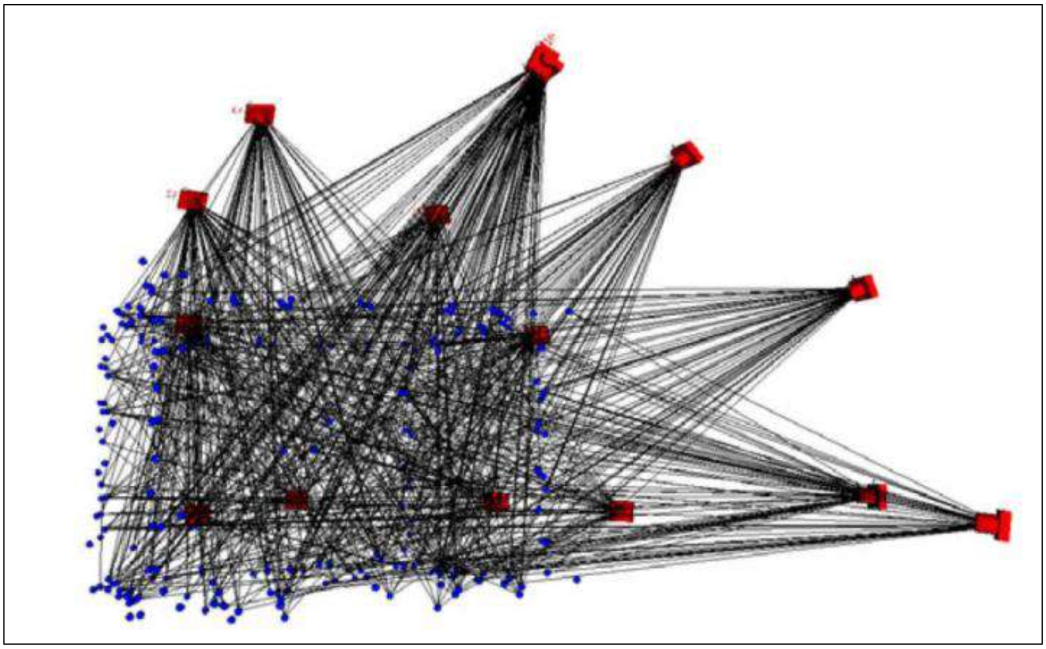

Figure 2 Bundle of rays from multiple images which form a dense network. (*Source:* Luhmann et al., 2013)

2.2 Application of Photogrammetry

In crash investigation, the photogrammetry method is normally used for measuring and determining the location of roadway evidence, and determining the crush profile sustained by a crashed vehicle. In order to create a model of a crashed vehicle, targeted markers with high contrast and highly identifiable points are placed on the vehicle as targeted points of reference. An example of targeted markers is as shown in Figure 3. Under optimal condition, using a calibrated metric camera and high contrast non-retroreflective targets, the photogrammetry method can produce high accuracy measurement, in which the average residual from the measurement of total station is 2.3 mm (Switzer & Candrlic, 2010). Even under the condition with uncalibrated camera and non-targeted vehicles, the accuracy of a photogrammetry method is in between 5 to 56 mm (Fenton et al., 2010). A previous study also showed that using the combination of calibrated digital camera, retroreflective markers, defined scaled and 34 photographs, the accuracy of vehicle model generated using photogrammetry was within the range of ± 1 mm (Rentschler, 1999). The previous work indicated that photogrammetry method was a reliable method which could generate highly accurate vehicle model.

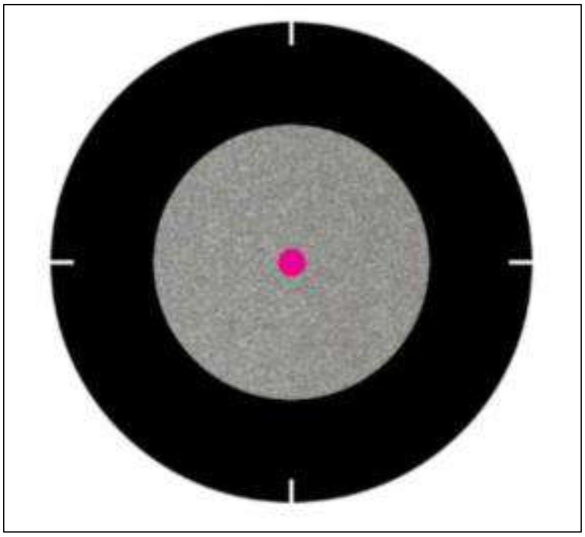

Figure 3 Targeted markers for photogrammetry

2.3 Comparison between Photogrammetry and Conventional Method

A main disadvantage of the use of conventional or physical measuring method on damaged vehicle is that the measurement taken cannot be reviewed after the damaged is repaired. Nonetheless, photogrammetry can convert the captured 2-D photos into 3-D measurements or CAD which contain all of the dimension information of the measured vehicles (Obaidat, 2000). This advantage can help the crash reconstructionist to obtain all the dimensions required for a crash reconstruction process and prevent the problem of revisiting the damaged vehicle to obtain more information.

More importantly, photogrammetry measuring method can significantly reduce the clearance time of traffic crash. It was reported that for every minute reduction in clearing the crash scene, it could result to saving 4 to 5 minutes to other road users (Neudorff, Randall, Reiss, & Gordon, 2003). Typically, it takes approximately 15 – 20 minutes to setup and perform the field photography required for photogrammetry (Cooner & Balke, 2000). On the other hand, the conventional method normally would take 30 - 60 minutes to gather the similar amount of high accuracy measurement.

The accuracy level of photogrammetry is at an acceptable level. A traffic officer without any knowledge in photogrammetry can obtain accuracy of 1 – 1.5 cm (Cooner & Balke, 2000). This is another benefit of using the photogrammetry method. It is because most of the crash data shall be collected by untrained first responders (Kamrén et al., 1993). The possibility of collecting high quality on-site damaged vehicle photos can significantly increase the accuracy of reconstructing a crash.

3. Methodology

In this study, three (3) different measurement methods were used to measure damaged vehicles basic dimension and crush profile. These methods included photogrammetry method, conventional method (using measurement tape and flexible ruler) and optical triangulation method using portable coordinate measuring machine (CMM). The conventional method is the most common method used in crash investigation in Malaysia, whereas the optical triangulation method is an accurate way to measure the coordinates of important points of an object. The details of implementation of these methods shall be explained in this section.

3.1 Details of Damaged Vehicles

In this study, two (2) damaged vehicles were used to evaluate the performance of photogrammetry measurement. The vehicles were labelled as vehicle 1 and vehicle 2, in which the most significant areas of damage for vehicle 1 and vehicle 2 were the frontal and offside, respectively. Both vehicle 1 and vehicle 2 are shown in Figure 4.

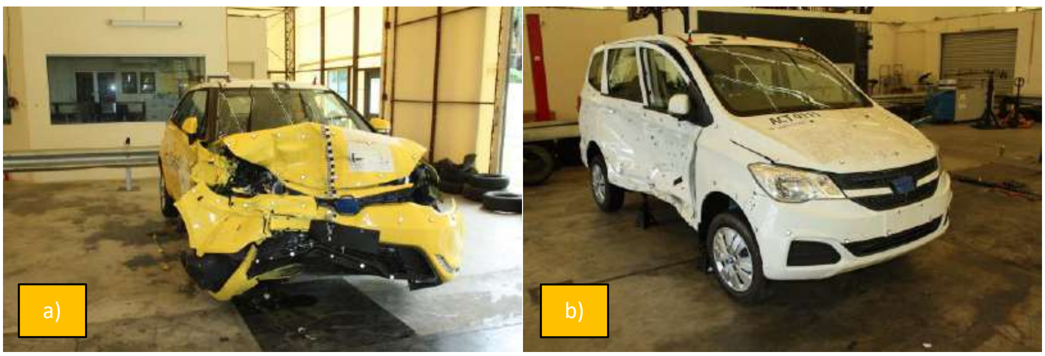

Figure 4 Damaged vehicles used in this study. a) Vehicle 1 – Frontal damage; b) Vehicle 2 – Offside damage

3.2 Measuring Damaged Vehicle with Conventional Method

Normally, in a crash investigation, the conventional way to measure a damaged vehicle is to use the combination of measuring tape and flexible ruler. In this study, four (4) different groups were assigned to measure the basic dimension and crush profile of both vehicle 1 and vehicle 2 using the conventional method. Each of these groups comprised two (2) experienced crash investigators who have investigated crashes for over three (3) years. For the basic dimension, the groups were required to measure length, overhang, width, length of wheelbase and width of both vehicles. As for crush profile, the groups needed to measure the damage width, the six (6) damage depths along the damaged surface (namely C1, C2, C3, C4, C5 and C6) and maximum crush for both vehicle 1 and vehicle 2. The vehicle damage measurement form is as shown in Appendix A. The time taken to measure all the necessary dimension was also recorded in the dedicated form.

3.3 Benchmarking with CMM

The coordinate measuring machine (CMM) is a device for measuring the physical geometrical characteristics of an object. The single point accuracy of CMM is ± 0.1 mm. Therefore, it can measure the coordinates of marked points placed on both vehicle 1 and vehicle 2. The CMM was used to measure 70 points located on the damaged vehicles. The coordinates of these 70 points were compared with the coordinates estimated using the photogrammetry analysis method. The residuals between the coordinates estimated by CMM and photogrammetry analysis were computed to determine the accuracy level of photogrammetry.

3.4 Photogrammetry Analysis

This section shall explain the overall setup of photogrammetry analysis. This includes the specification of camera, calibration, setup of photogrammetry marker and setup of photogrammetry.

3.4.1 Specification of Camera

Two (2) different types of cameras were used in this study, namely a DSLR Camera (Canon EOS 550D, 20 mm f/2.8, super wide-angle lens) and a smartphone camera (iPhone 5S Plus, 8-megapixel, f/2.2). The photos taken by both cameras were analysed by the photogrammetry method to compare the accuracy between the different types of camera.

3.4.2 Calibration of Camera

In photogrammetry, calibration of a camera is referred to as the process of determining the parameters of interior orientation of a camera. These parameters include principal distance, image coordinates of principal points, distortions and sensor corrections. To determine these parameters, both the cameras took 12 photos of calibration sheets from different angles and camera orientations. An example of calibration sheets is as shown in Figure 5. The interior parameters of a camera were determined using a photogrammetry software, namely Photomodeler 2018. The same software was used to conduct photogrammetry analysis to determine the 3-d coordinates of the points placed on the damaged vehicles. The reported accuracy of Photomodeler was ± 1 cm.

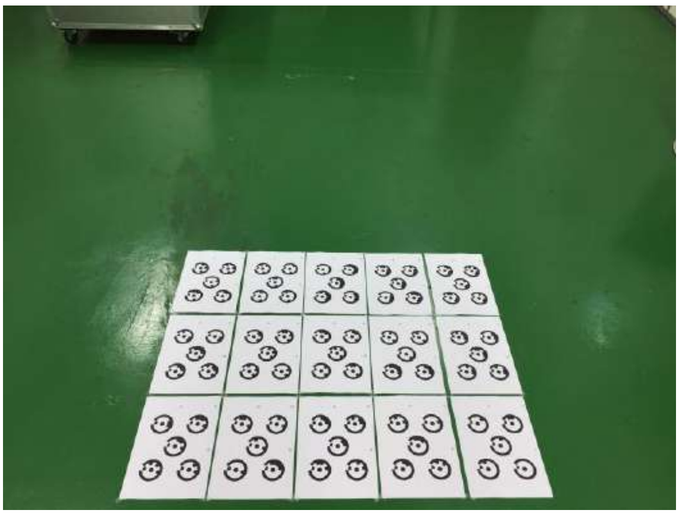

Figure 5 An example of calibration sheet for camera calibration

3.4.3 Setup of Photogrammetry Marker

The targeted markers for photogrammetry was fabricated and used in this study. Magnetic reflective markers were used as reference points to conduct photogrammetry analysis. The reflective nature of the markers can create sufficient contrast to differentiate the markers and background. It was essential to increase the appearance of the markers to be identified as a point from any angles of view. The placement of markers was evenly distributed on the body of the damaged vehicles to ensure coordinates of every components could be obtained. Nonetheless, more markers were required on complex surface such as damaged surface in order to accurately outline the dimension of the complex surface. The reference sheet of marker placement is included in Appendix B. All the markers were placed in accordance with the reference sheet for both vehicle 1 and vehicle 2. Additional markers were placed at the frontal structure of vehicle 1 and the offside structure of vehicle 2.

3.4.4 Setup of Photogrammetry

To estimate the 3-dimension coordinates of the points marked on the damaged vehicles, a minimum of eight (8) photos were required to cover all angles of view of the damaged vehicles. The basic setup of multiple photo photogrammetry is shown in Figure 3. All of these photos must be interacted with other adjacent photos to determine the position of points. To further increase the reliability and accuracy of photogrammetry, increasing the area of intersection between photo was an option. In this study, besides using the basic 8-photos setup, the photogrammetry analysis also used 10, 12 and 14 photos which enabled more area intersection between photos. The example setup for 12-photos set is illustrated in Figure 7. The outcome of the photogrammetry analysis is the 3-dimension locations of the points. The example of 3-dimension points generated by photogrammetry analysis for vehicle 2 is shown in Figure 8.

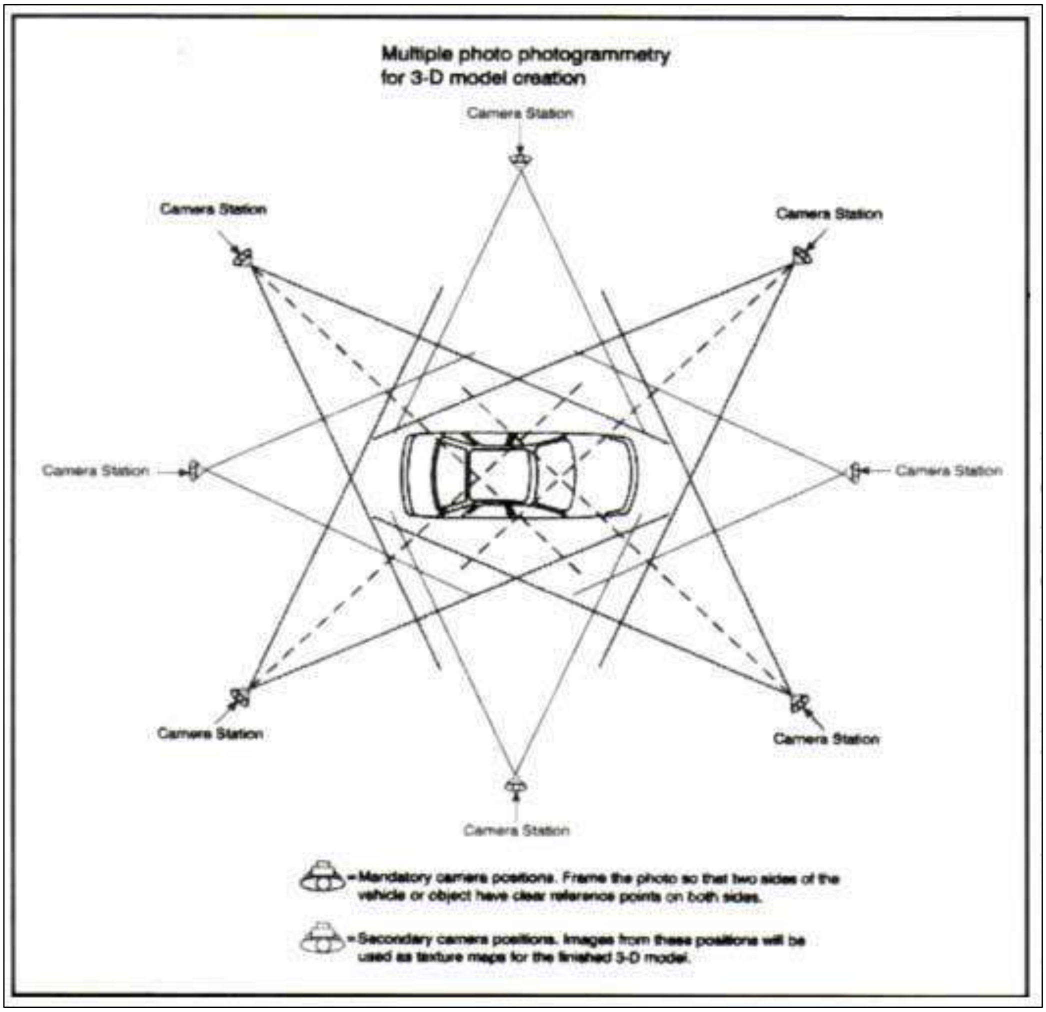

Figure 6 The basic setup for multi-photo photogrammetry

Figure 7 An example of photogrammetry setup for 12-photos set

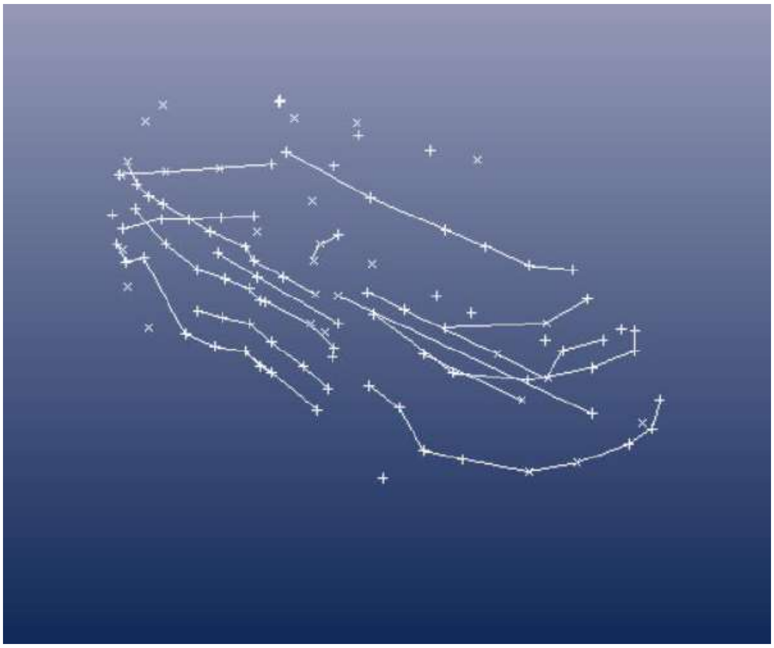

Figure 8 3-dimension points generated with photogrammetry analysis (vehicle 2)

4. Results and Discussion

In this chapter, the findings and results of the photogrammetry analysis are presented. The first section shows the comparison between the measurement of CMM and photogrammetry. In the second section, the conventional method is compared with the photogrammetry in terms of accuracy and efficiency.

4.1 Comparison between Photogrammetry and CMM

A CMM was used as the benchmark to measure the accuracy of the implemented photogrammetry analysis. The tolerance of CMM was ± 0.1 mm. The distance between 70 points and a pre-defined origin marked on the damaged vehicle were measured by both CMM and photogrammetry analysis. In particular, for photogrammetry analysis, two (2) different factors were considered before making the comparison. These factors were type of camera (Canon EOS 550D 20 mm f/2.8 and iPhone 5S Plus) and number of photos taken (8, 10, 12 and 14) in the photogrammetry analysis.

The descriptive statistics of the residual between CMM and photogrammetry measurement for both cameras was tabulated in Table 1 and Table 2. From Table 1, it showed that the residual decreased as the number of photos used in photogrammetry increased. A reduction pattern in residual variation can also be observed in the boxplot in Figure 9, in which the size of the band and whisker of the boxplot decreased while the number of photos used increased. With 14 photos used for analysis, 75% of the points were within the residual of 22.9 mm and average residual of 7.45 mm.

Table 1 The residual between the measurement of CMM and photogrammetry measurement with Canon EOS550 camera

Statistics	Residual for number of photos taken (mm)			
	8	10	12	14
Mean	11.332	-14.154	-10.854	-7.451
Std	45.987	19.754	19.436	15.554
Min	-51.757	-56.504	-53.026	-41.739
25%	-22.383	-33.209	-28.756	-22.920
Median	-4.381	-4.562	-0.006	-0.322
75%	42.967	-1.394	1.702	2.223
max	110.343	24.547	26.598	24.939

Table 2 The residual between the measurement of CMM and photogrammetry measurement with iPhone 5S smartphone camera.

Statistics	Residual for number of photos taken (mm)			
	8	10	12	14
Mean	-10.850	-12.781	-11.564	-10.641
Std	20.617	19.160	19.404	19.290
Min	-53.277	-54.897	-49.525	-50.859
25%	-29.427	-32.978	-32.179	-29.817
Median	0.053	-2.160	-0.501	-0.304
75%	1.713	-0.998	1.724	2.633
max	27.590	23.595	22.501	23.828

A similar pattern was also observed for the iPhone 5S Plus camera. The variation of the residual also decreased as more photos were used for photogrammetry analysis. This downward pattern is shown at the boxplot in Figure 10. When the number of photos taken increased from 8 to 10, the length of the band and whiskey were reduced. Nonetheless, further increment in the number of photos did not reduce the variation in residual. In terms of accuracy, the residual for the iPhone 5S Plus camera was slightly higher compared to the Canon D500, in which 75% of the points were within the tolerance of 33 mm and average residual of 10.64 mm. The coordinates of the points generated using the photo captured by the smartphone camera were reasonably well and the residual was slightly greater than the DSLR camera by ± 10 mm. Therefore, a slightly older smartphone camera such as iPhone 5S Plus still can produce highly accurate photogrammetry analysis.

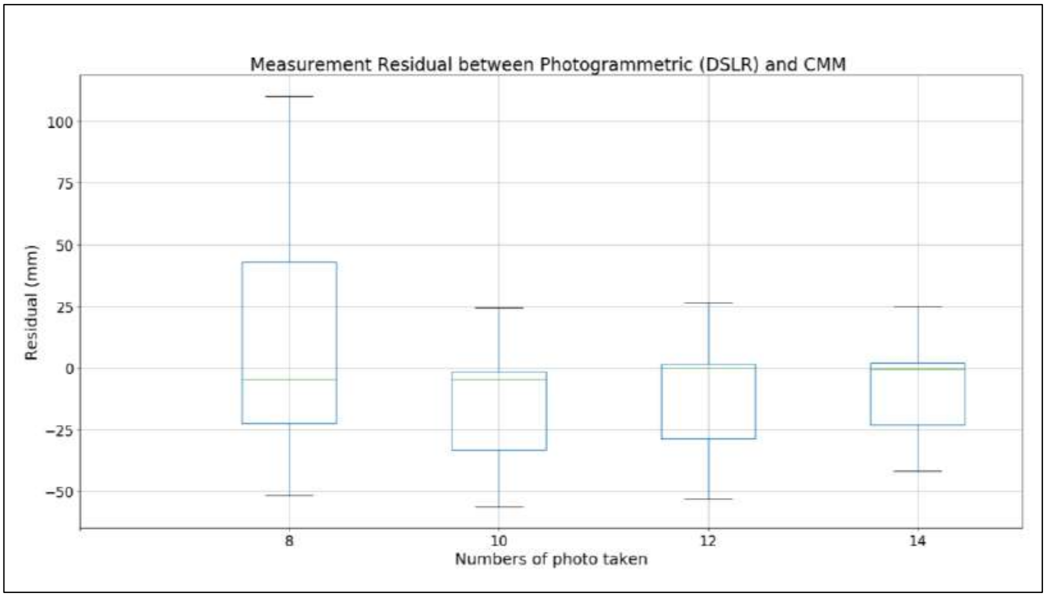

Figure 9 Boxplot of measurement residual between CMM and photogrammetry measurement with DSLR

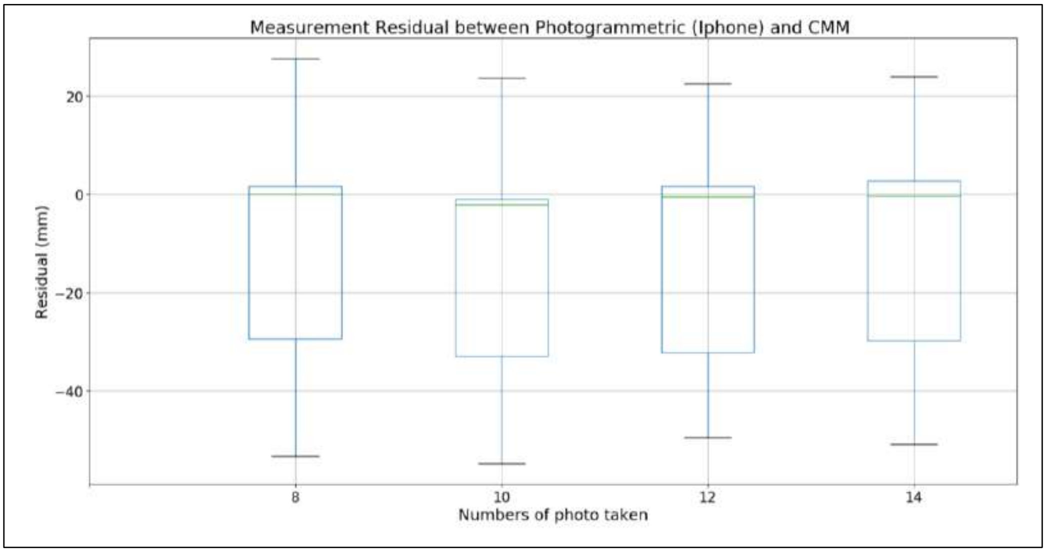

Figure 10 Boxplot of measurement residual between CMM and photogrammetry measurement with smartphone camera

4.2 Accuracy of Conventional Measurement Method

Four (4) groups comprising two (2) members were tasked to measure the dimensions of two (2) damaged vehicles using the measuring tape (conventional method). The measured dimensions were front overhang, wheelbase, rear overhang, length, width and height for each side of the damaged vehicles. The measurement result from conventional method was compared with photogrammetry and CMM. The result of the comparison is tabulated in Table 3 and Table 4 for vehicle 1 and vehicle 2, respectively.

Table 3 Comparison between conventional method, photogrammetry and CMM for vehicle 1

	Measurement (cm)				
	Conventional	Residual	Photogrammetry	Residual	CMM
NS F OH	86	9.1	75.21	-1.69	76.9
	82	5.1			
	87	10.1			
	88	11.1			

NS WB	250	0	249.9	-0.1	250
	251	1			
	253	3			
	250	0			
NS R OH	60	-2.9	62.6	-0.3	62.9
	60	-2.9			
	60	-2.9			
	64	1.1			
NS L	380	0.4	379.4	-0.2	379.6
	377	-2.6			
	NA	NA			
	388	8.4			
OS F OH	42	-2.8	43.51	-1.29	44.8
	26	-18.8			
	42	-2.8			
	56	11.2			
OS WB	242	1.2	241.29	0.49	240.8
	240	-0.8			
	244	3.2			
	244	3.2			
OS R OH	60	-2.9	62.6	-0.3	62.9
	54	-8.9			
	60	-2.9			
	64	1.1			
OS L	330	3.5	326.91	0.41	326.5
	333	6.5			
	NA	NA			
	320	-6.5			
F W	180	1.1	178.1	-0.8	178.9
	157	-21.9			
	178	-0.9			
	150	-28.9			
R W	168	5.5	163.18	0.68	162.5
	160	-2.5			

	156	-6.5			
	156	-6.5			
H	154	-1.1	154.8	-0.3	155.1
	148	-7.1			
	160	4.9			
	162	6.9			

***NS: Nearside, OS: Offside, OH: Overhang, F: Front, R: Rear, W: Width, L: Length, WB: Wheelbase, H: Height**

Table 4 Comparison between conventional method, photogrammetry and CMM for vehicle 2

	Measurement (cm)				
	Conventional	**Residual**	**Photogrammetry**	**Residual**	**CMM**
NS F OH	73	-2.41	75.33	-0.08	75.41
	67	-8.41			
	77	1.59			
	74	-1.41			
NS WB	273	0.59	272.41	0	272.41
	272	-0.41			
	274	1.59			
	274	1.59			
NS R OH	99	10.73	88.7	0.43	88.27
	97	8.73			
	90	1.73			
	97	8.73			
NS L	437	2.76	433.97	-0.27	434.24
	436	1.76			
	441	6.76			
	436	1.76			
OS F OH	66	-8.89	74.37	-0.52	74.89
	67	-7.89			
	72	-2.89			
	72	-2.89			
OS WB	270	0.14	270.59	0.73	269.86
	272	2.14			
	274	4.14			

	272	2.14			
OS R OH	102	14.84	87.58	0.42	87.16
	92	4.84			
	88	0.84			
	97	9.84			
OS L	434	3.16	431.7	0.86	430.84
	431	0.16			
	434	3.16			
	437	6.16			
F W	160	-0.48	160.93	0.45	160.48
	167	6.52			
	160	-0.48			
	158	-2.48			
R W	157	-8.75	165.59	-0.16	165.75
	159	-6.75			
	156	-9.75			
	159	-6.75			
H	175	-0.81	175.6	-0.21	175.81
	178	2.19			
	178	2.19			
	178	2.19			

**NS: Nearside, OS: Offside, OH: Overhang, F: Front, R: Rear, W: Width, L: Length, WB: Wheelbase, H: Height*

It was found that the measurement from the conventional method was inconsistent. On average, the difference between groups were approximately 5 cm. However, the difference in measurement became greater while professional judgment was required to determine where to measure. This problem most often occurred while measuring damaged component and edges with smooth curvature. Measurement difference due to this problem can cause up to 10 cm of residual. Therefore, using conventional method to obtain the dimensions of a damaged vehicle may potentially cause the problem of inconsistency in terms of accuracy.

To further evaluate the accuracy of conventional method and photogrammetry, the measurement obtained from both methods were compared with CMM. The results showed that the standard deviation of the residual for conventional method compared to CMM was 8 cm and 5.4 cm for vehicle 1 and vehicle 2, respectively. On the other hand, the standard deviation of the residual for photogrammetry was much lower which was 0.69 cm and 0.43 cm, respectively. These results clearly showed that photogrammetry could more accurately measure the dimensions of a damaged vehicle. Therefore, in terms of accuracy, the photogrammetry method performed better than the conventional method.

4.3 Crush Profile Analysis

In the crash damage analysis, the crush profile of the damaged vehicle needed to be measured to determine the energy to cause the deformation of the damaged component. This energy can be further converted into kinetic energy to estimate changes of velocity in the impact. In this study, the crush profile of both vehicles 1 and 2 was taken using conventional method and photogrammetry method. The details of a crush profile included damage width, damage depth of six (6) different positions along the damaged component namely C1, C2, C3, C4, C5 and C6, and maximum crush. Four (4) different groups were assigned to measure the crush profiles of vehicle 1 and vehicle 2. The measured crush profiles are tabulated in Table 5 and Table 6.

Table 5 Crush profile measurement from conventional method and photogrammetry for vehicle 1

Measurement (cm)	Group 1	Group 2	Group 3	Group 4	Photogrammetry
Damage width	100	140	125	110	136.9
C1	30	0	0	0	0
C2	38	9	3	8	6.9
C3	40	27	17	33	28.0
C4	43	45	33	6	36.7
C5	55	41	39	54	50.0
C6	73	66	44	56	68.8
Maximum crush	73	66	44	57	68.8

Table 6 Crush profile measurement from conventional method and photogrammetry for vehicle 2

Measurement (cm)	Group 1	Group 2	Group 3	Group 4	Photogrammetry
Damage width	160	200	170	173	191.3
C1	5	2	4	0	3.5
C2	15	8	16	17	18.2
C3	6	25	32	25	26.4
C4	15	30	35	19	21.9
C5	2	24	27	19	22.3
C6	6	15	18	13	8.1
Maximum crush	21	30	36	26	26.9

From the Table 5 and Table 6, it showed that the measurement between the four (4) groups was inconsistent. One (1) of the main reasons for this difference was that professional judgement on where to take measurement was very subjective and could lead to taking different points as part of the crush profile. This subjectivity could possibly cause inconsistency and inaccuracy while analyzing the crush profile with the data obtained from the conventional method.

The same inconsistency problem due to subjectivity can be avoided or reduced using the photogrammetry method. This is because photogrammetry method only collects relative coordinates of points indicated by reflective markers placed on the damaged vehicles. These points can be used to outline the shape of the vehicles and visualise the damage surface of the crashed vehicle using a CAD software. The visualisation outcome is illustrated in Figure 3 and Figure 4.

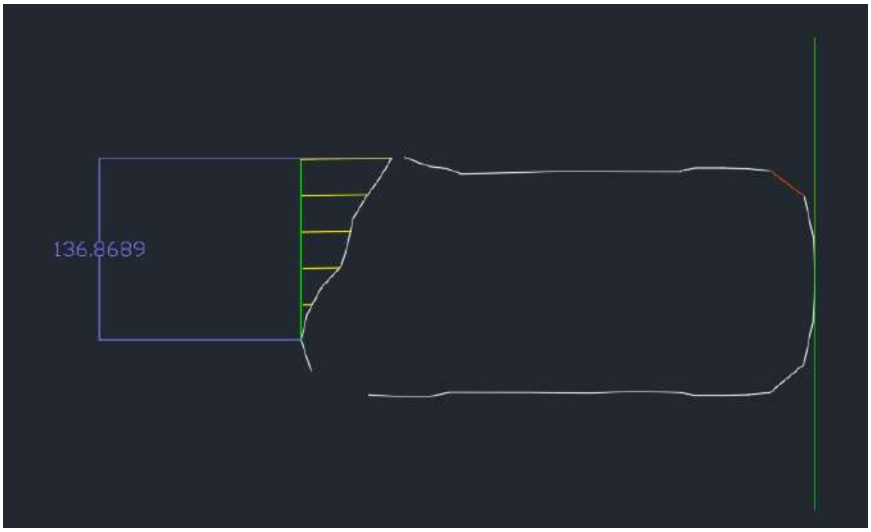

Figure 11 Visualise of the damage profile at top view for vehicle 1 using points generated using photogrammetry method

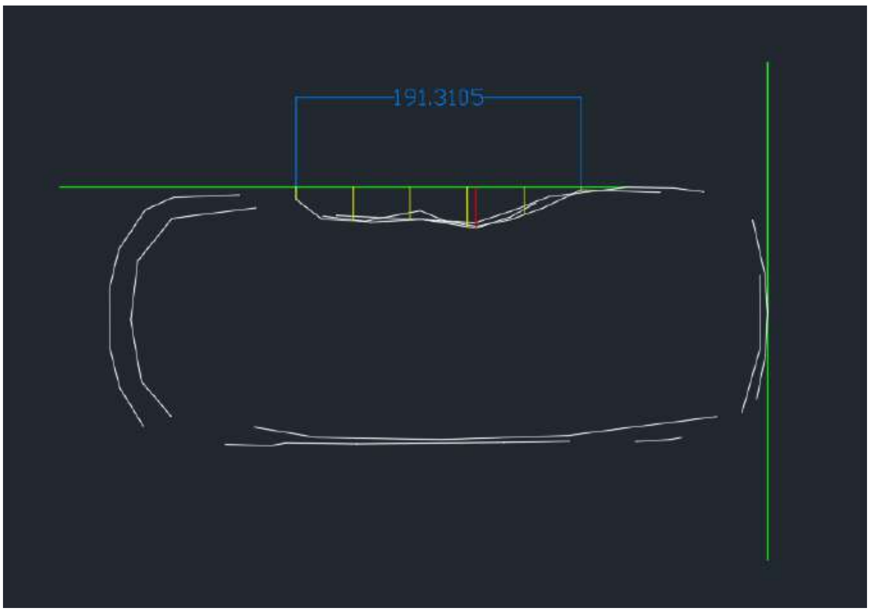

Figure 12 Visualise of the damage profile at top view for vehicle 2 using points generated using photogrammetry method

Unlike conventional method where all of the professional judgment must be conducted on-site, photogrammetry method could provide accurate documentation of damaged vehicle dimension which can be analysed by a group of experienced crash reconstructionist, where collective decision can be made on taking the measurement of the damaged surface. Both Figure 3 and Figure 4 showed that the damage width and damage depth along the damaged surface could be measured with ease when top view of the damaged vehicle was available. This meant that photogrammetry method could produce more reliable and consistent crush profile analysis compared to the conventional measuring method.

4.4 Time Efficiency of Photogrammetry Method

The required time for conventional method to obtain the basic dimension of a damaged vehicle and crushed profile was recorded. To evaluate the time efficiency of photogrammetry method, the time required to place and remove all reflective markers was recorded for comparison purpose. The time in seconds taken for both methods is tabulated in Table 7.

Table 7 Time taken for conventional method (4 groups) and photogrammetry method for data collection at site for vehicle 1 and vehicle 2

Method	Time (s)	
	Vehicle 1	Vehicle 2
Conventional method	666	663
	408	321
	409	639
	471	580
Photogrammetry	435	380

From Table 7, it showed that the average time taken for the conventional method in collecting data of vehicle 1 and vehicle 2 was 488.5 seconds and 550.75 seconds. This average time was longer than the time taken for placing and removing the reflective markers which was 435 seconds and 380 seconds, respectively. The total time taken for photogrammetry setup was 10.9% and 44.9% shorter than the conventional method.

The time required for vehicle 2 was longer because of its bigger size and higher complexity of damaged surface for vehicle 2. For photogrammetry setup, the placement of these reflective markers was conducted by participants who were inexperienced and had to heavily rely on the provided guidance diagram while placing the markers. Thus, the time required for placing the markers can be further reduced if it was applied by an experienced user familiar with the photogrammetry method. Therefore, photogrammetry method is a method that is more time efficient if compared with the conventional method that relies on measurement tape.

5. Conclusion

The purpose of this study was to determine the performance of photogrammetry method in measuring damaged vehicle. The measurement from CMM was used as a benchmark to evaluate the accuracy of photogrammetry analysis. The study findings showed that residual of 75% of the photogrammetry measurement points were within the range of 22.9 mm when 14 photos were used for the photogrammetry analysis. The mean residual was only 7.5 mm which indicated that photogrammetry analysis was a reliable and accurate method to measure damaged vehicle. The finding of this study was consistent with previous studies which reported that the tolerance of photogrammetry analysis was ± 1 cm.

In terms of time efficiency for the photogrammetry method, this study found that the time required to set up reflective markers was shorter than the average time required in a conventional method (using measurement tape and flexible ruler). The time taken to set up the photogrammetry reflective markers were 435 seconds and 380 seconds for vehicle 1 and vehicle 2, respectively. It was believed that the time taken can be further reduced if proper training was provided on placement of the reflective markers. Therefore, photogrammetry method can help to reduce the on-site time for crash investigators in gathering the physical dimensions of a damaged vehicle.

While comparing with the conventional method in measuring the basic dimensions of a damaged vehicle, it was found that the developed photogrammetry method out-performed in terms of accuracy. The standard deviation of residual with CMM measurement for photogrammetry was found to be 0.69 cm and 0.43 cm for vehicle 1 and vehicle 2, respectively. These residual values were far better than the conventional method which were 8 cm and 5.4 cm, respectively. Besides that, this study also discovered that the measurement of conventional method was inconsistent and different between groups. This problem was not only limited to basic dimension measurement but also applied to crush profile measurement. This was mainly caused by human error as stated in the problem statement. Aside from that, it could be possibly due to subjectivity of professional judgment because most of the measurement deviation between groups were on damaged components of the vehicles. These human errors can be greatly reduced by using the photogrammetry method. This is because the method could accurately determine the coordinates for each of the markers which can be used to outline the shape of the damaged vehicles in 3-D. This could allow the crash reconstructionist to analyse the data from different angles which can provide better visualisation of the damaged surface.

In terms of optimizing the performance of photogrammetry, this study has compared the performance of two (2) difference cameras (DSLR camera vs smartphone camera) and the number of photos used in the photogrammetry analysis. It was found that the performance of DSLR camera was more reliable and had additional 1 cm of accuracy as compared to the smartphone camera. However, the performance of a smartphone camera can be considered reliable because the 75% of the points were within the residual of 30 mm. To fully capture the details of a damaged vehicle, a minimum of eight (8) photos is required to be taken to perform photogrammetry analysis. Nonetheless, it was found that using only eight (8) photos may cause reliability problem and higher residual. This is because the photogrammetry analysis can only determine the coordinate of a point using only 2 – 3 reference points from the 8-photo set. Thus, increasing the number of photos for a target can increase the number of intersection between points to increase the accuracy of the analysis.

In conclusion, this study has found that the performance of photogrammetry analysis is better than the conventional method in measuring the basic dimension and crush profile of a damaged vehicle. Besides that, the photogrammetry method is also found to be more time efficient. Therefore, the photogrammetry method is recommended to replace the conventional method to increase reliability and accuracy of the measurement of damaged vehicles.

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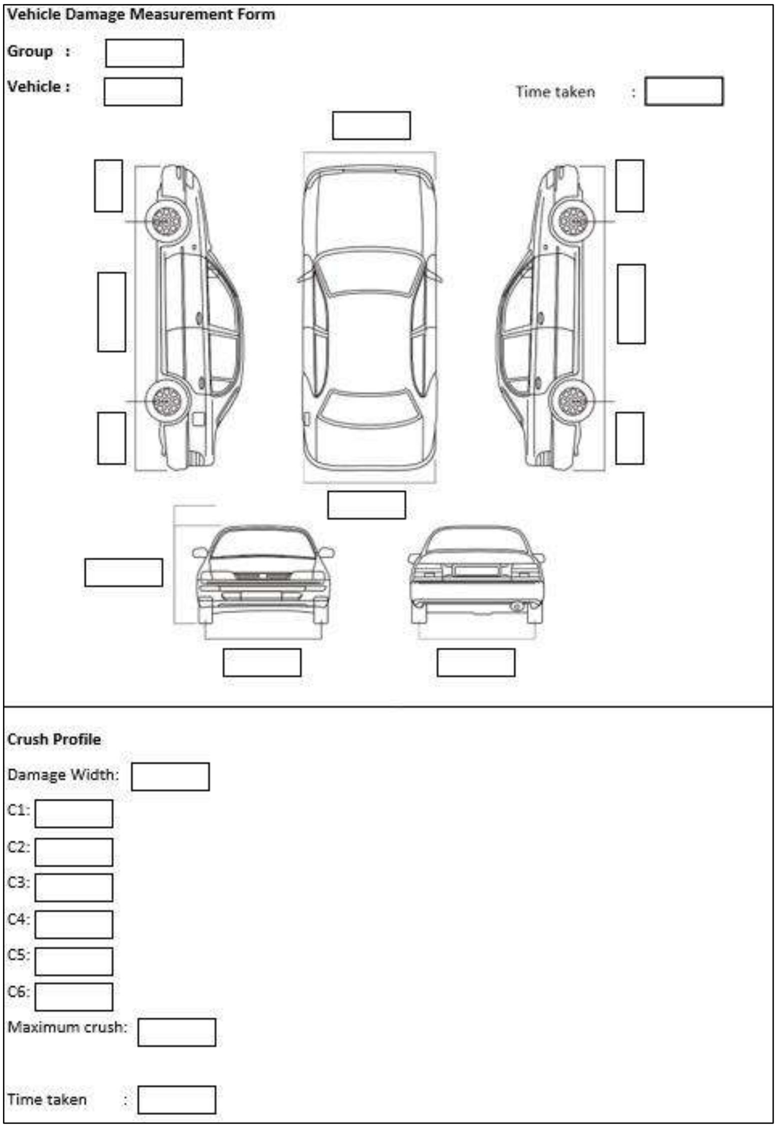
Appendix A

The vehicle damage measurement form used by all groups to record measured dimension using the conventional method.



Vehicle Damage Measurement Form

Group :

Vehicle :

Time taken :

Crush Profile

Damage Width:

C1:

C2:

C3:

C4:

C5:

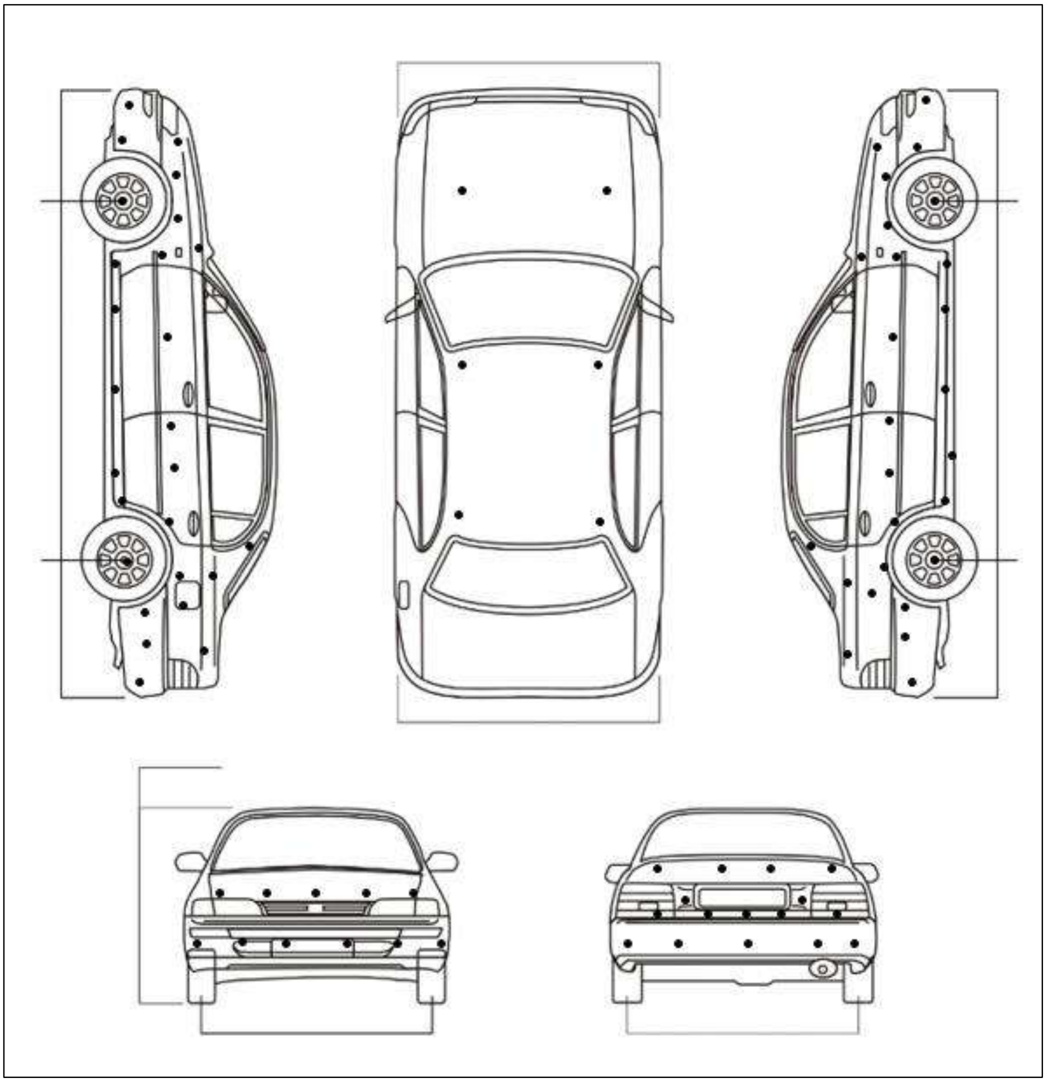
C6:

Maximum crush:

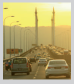
Time taken :

Appendix B

The reference sheet of marker setup on a damaged vehicle







Research Report

Development of Photogrammetry Method in Measuring Damaged Vehicle

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