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3D accident reconstruction using low-cost imaging technique

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ABSTRACT

This research is about the implementation of close range photogrammetry (CRP) technique to investigate the traffic accident scene. CRP technique representing and measuring the 3D objects using data stored in 2D photographs. It is non-contact measurement requiring multiple pictures capture to measure objects of interest. Currently, a police officer uses a conventional technique to collect data on traffic accident scene using tape measurement in order to reconstruct the accident scene. The development of camera technology increases the efficiency, stability of consumer grade digital cameras for photogrammetric applications. This development can help police officer to apply a CRP technique for data collection on traffic accident scene. CRP technique offers fast data acquisition, and only need one officer during data capture. This research is to investigate traffic accident scene using the imaging technique. The methodology of this research used a measuring tape and total station for data acquisition on traffic accident scene. This research also evaluates the accuracy of data based on mathematical model standard deviation and root mean square error (RMSE). Based on this research, the implementation of CRP in accident reconstruction is very effective because can achieve a cm-level accuracy in range 40 m traffic accident scene.

1. Introduction

Close Range Photogrammetry (CRP) is a technique representing and measuring 3D objects using data stored on 2D photographs. It also a non-contact measurement requiring multiple pictures captured at the scene for measuring feature points of interest. The technology is best applied by using a good quality digital camera for fast, accurate and permanent 3D data recording. This technique has been used for many applications such as in deformation survey, modeling buildings, medical, reverse engineering purposes, accident reconstruction and crime investigation. CRP cost, reduce time on-site and processing data and effective for small or large projects. The CRP technique has been developed rapidly based on the current technology [1,4].

A separation of instrument components for data recording and data processing are location, time and personnel between on-site recording of the object and data evaluation in laboratory. For conclude that, this technique acquired a very time consuming from recording until processing and many stages of processing cannot completed on site [6]. In the development of technology in imaging has been developed a CRP to a new-era. Using a new technique that called digital photogrammetric systems, that their capability can solved a problems on analogue photogrammetric systems. A fully automatic analysis on targeted points has been replaced the manual procedures for measurement and orientations. The digital processing has been limited in stage of processing from recording until processing a data on computer [2,15]. This technique also acquired a minimum one person to do a photogrammtery work from recording until processing. The new technology has been developed using software to processing, without need others adds-on software to process the data. After data through a phase that called CRP data processing. A final product will be in a graphical form either 2-dimensional or 3-dimensional and in others words an object modeling in software or computer. An analysis in CRP is do based on their applications, user requirements, and what product to produce and others. A general analysis that common used is a derived a dimensions, for example areas, lines, distances and surface definitions. This analysis can be done using a specific CRP software which able to complete the task until the end [9,22]. Before make an analysis the photogrammetric processing will produce a product to do some analysis. After photogrammetric processing, the

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product is divided into two sections. Firstly coordinate, from processing a images, the photogrammetry technique can transform image coordinate to a real coordinate from this data, a user can make analysis on distance, area, surface data, a processing to acquire control data on certain area or object and images and lastly, user can make a comparison with a design that reconstruct on object model. Secondly, orthophoto image represent the graphical information which produced from the processed aerial photo. The CAD format can be used by several users for example the architecture user can used to reconstruct an old buidling, redesign the model, do a measurement and sell it to the public [20,21].

Today, a using of consumer grade camera in photogrammetry has been using widely around the world by photogrammetric or not-photogrammetric in photogrammetric applications. These cameras are ubiquitous, have ever higher resolution and are quite suitable for medium accuracy measurement at, say 1:5000 to 1:20,000 level required in architectural and archaeological recording, forensic measurement, engineering documentation and in numerous other applications domains [3,5]. The improvement of photogrammetry data processing includes computational models, orientation in the software system and automated image measurement that has been designed for use with low-cost digital cameras. This led to an easily to process a data because most of the software nowadays, has been fully automated image processing in CRP [7]. An innovation of imaging technology from 2-Dimensional to 3-Dimensional has brought a CRP to a new level as a tool of imaging analysis [11]. Besides, this photogrammetric can represent a 3D mapping of traffic accident scenes, which commonly termed as an Accident Reconstruction. 3D mapping can make a technical investigation such as analysis of vehicle collision event dynamics, provision of evidence in court hearings and vehicle speed determination [31].

Creating of 3D mapping traffic accident scene required only one officer to do this work from collecting a data on accident scenes using the low-cost camera and later on, processing the data on the computer and the final product is a 3D mapping of accident reconstruction. An innovation of software technology in CRP also has made that this software not limits to photogrammetric only [12]. It can also use by none-photogrammetric, this is because mostly software outside there has been fully automated not same in earlier of CRP introduced that mostly using a manual technique with limitations of hardware and software that very expensive and limit to the photogrammetric only. Another advantage of this latest software, it user-friendly and can integrate with third-party software for other uses [13,14].

CRP has been widely used in mapping field, however the accuracy of the product is still a big issue. After, some people has been done their research about this, It can be concluded that CRP applies to objects ranging from 1 m to 200 m in size, with accuracies under 0.1 mm at the smaller end (manufacturing industry) and 1 cm accuracy for the larger end (architecture and construction industry) [17,18]. According to previous research a Hybrid Measurement approach for CRP discuss a hybrid measurement approach which involves fully automatic network orientation with targets while at the same time supporting follow-up semi-automatic and manual operations such as feature point and line extraction and surface measurement via image matching. The term “Hybrid Measurement” is referring to a CRP measurement approach that incorporates automatic 3D measurement of targeted points. To achieve this automated network orientation it is used retro-reflective targets and highly controlled illuminations conditions [23,27]. This technique can measure the precision in image space of 0.03–0.05 pixels. This technique is developed for a new software example Photomodeler and iWitness that focus on maximum ease of use with a minimal prerequisite for knowledge of photogrammetry (Fig. 1).

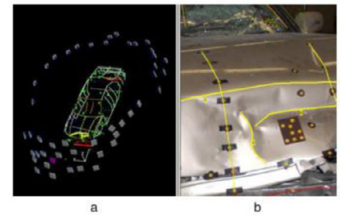

Fig. 1. The hybrid network (a) automatic network orientation and (b) manual digitizing of 3D line feature labelled 2, 3 and 4.

Digital CRP is a technique to acquire 3D spatial information with doing a measurement on the image without non-contact to object. This technique has been popular to use widely over the worlds because fulfilling of requirements in the survey in aspects accuracy, cost, time, user-friendly and manpower. Digital CRP is appropriate to a variety of applications such as monitoring of slope displacement, industrial measurement, forensic analysis, deformation survey, and etc [19,28,29]. From the previous research a CRP for accident reconstruction is the important issues to deal with. It's including near-planar network geometry in the image, high automated processing and fully automatic camera calibration. Two innovative developments are undertaken to enhance the applicability of CRP and consumer grade camera to accident reconstruction. The aim of accident reconstruction is to reconstruct motor vehicle collision scene either 2-dimensional or 3-dimensional. Traditionally method use to collect a data on traffic accident scene such as using a total station that led to a higher cost and takes a long time at an accident scene to capture a data [8]. iWitness system that a new software use in close range photogrammetry that their capability is automatic on-line computations that occurred automatically in the background with every image point referencing. This software generated attributed point clouds which are preserved to export object coordinate data in DXF format. Using this system, a camera station is not needed on the accident scene because it can support photogrammetric orientation process use of evidence markers. The evidence markers should be placed evenly at the specific object in order to get accurate results during processing. The markers are used to be a reference during image matching process. The size of marker depends on the object size and distance of camera from the object. The markers should be placed at the position that can be viewed by the camera station during image acquisition.

CRP software is used to measure photographs taken at the scene and to prove whether bus driver or woman that guilty. This article also discuss a chronology of police officer that take a data on traffic accident scene with interviewed some witnesses at an accident scene to determine the accuracy assessment that gets from doing an analysis [25]. Before doing an analysis five images has been selected from traffic accident scenes that have been captured by a police officer. The camera used for CRP must be calibrated to achieve a good accuracy. To determine their errors using a CRP software either accept the tolerance limits or not. To proves the facts that whether bus had moved over the curb and encroached sidewalk area the four points photogrammetric was measured on the top surface of curbing close to the impact occurred. This point was created for define the curb horizontal plane and provides a 3-dimensional vertically extended plane directly over the sidewalk or curbing & perpendicular to the street space [26,30]. As a result, the accuracy of several check distances that already measured on site accident using a steel tape and Nikon D70 photogrammetry survey revealed that measurement accuracy was better than ¼ (RMS 1-sigma level).

Dechant [10] investigates of an actual accident were a metro bus hit a woman that standing on the side walk. CRP software is used to measure photographs taken at scene and to prove whether bus driver or woman that guilty. In determines the accuracy assessment that get from doing an analysis. Before doing an analysis five images has been selected from traffic accident scenes that has been captured by police officer. The camera used for CRP must be calibrated to achieve a good accuracy. To determine their errors using a CRP software either accept the tolerance limits or not. To proves the facts that whether bus had moved over the curb and encroached sidewalk area the four points photogrammetric was measured on the top surface of curbing close to the impact occurred. This point was created for define the curb horizontal plane and provides a 3-dimensional vertically extended plane directly over sidewalk or curbing & perpendicular to the street space. As a result, the accuracy of several check distances that already measured on site accident using a steel tape and Nikon D70 photogrammetry survey revealed that measurement accuracy was better than ¼ (RMS 1-sigma level) [10]. From the photogrammetry measurement proves that the woman leaning her body over the curb into the street space and also revealed that the woman face has over three inches into street space this reason she was struck by bus. Therefore, a further study on the accuracy assessment need to done especially on point coordinates and length measurements aspects.

The measurement done by police officer is usually used measuring tape and made croquis drawing which is standard procedure where drawing and measurement is all done on site. The accuracy of measurement depends on the terrain configuration and road infrastructure. This method has led many gap between the recorded situation and actual accident scene. At the police station, a qualified draughtsman will redraw the croquis drawing as a hand drawn precise drawing according to the technical drawing rules [24]. This technique intend to gradual error and less accurate. The hand drawing has meter level of accuracy.

Nowadays, law enforcement agencies have traditionally employed a range of dimensional measurement techniques for traffic crash reconstruction. These include the roll wheel, steel tape and using the total station for electronic distance measurement. Even in quick response, the time from accident happens to completion of both techniques traditional baseline tape method or total station can often be over two hours and some cases even more. This led a law enforcement agencies to improved officer safety in a crash investigation by reducing the amount of time the roadway is closed, to reduce traffic delays, including concerns of secondary crashes that will happen and to collect more comprehensive and accurate data in a shorter period of one scene time. Therefore, the solution is using CRP technique [16].

2. Material and methods

This research methodology is divided into five phases. The first phase focuses on the preliminary research on accident reconstruction. Second phases focus on study area to simulate a traffic accident scene at the specific area. The third phase focuses on an image and data collection at road accident scene using a measuring tape and total station as an instrument to collect data. Fourth phases are about data processing using software iWitness, in this phases a basic concept photogrammetry to processing a data from interior orientation until bundle adjustment will be done. The last phase focuses on a result and data analysis. In this phase, a product of this research is a 3D simulation of traffic accident scene and for analysis is using mathematical model where standard deviation for dispersion of the data and RMSE for indicates the accuracy of data.

2.1. Preliminary research

Based on this research, the first phase includes a preliminary research about accident reconstruction. Based on previous studies, the instruments used for data capture at the road accident scenes, are metric camera, laser scanner, roll wheel, and total station which are very expensive. The photogrammetrist has been tested the camera as a tool for measurement and their result is impressive and it is suitable for work which requires a medium-accuracy. This has been led widely used of the camera in an accident reconstruction. Moreover, the camera price is reasonable compared to other instruments. The CRP technique is used in this study to capture the road accident scene on site. The image acquisition technique has been studied to obtain accurate results.

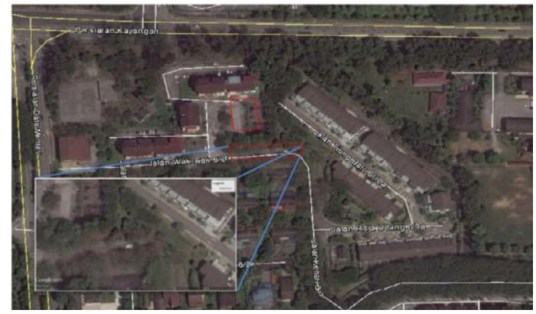

Fig. 2. The study area of road accident scene at Seksyen 6, Shah Alam with a coordinate (N 3°05"16.91″ E 101°30"22.74″).

2.2. Study area

The second phase is about the selection of study area. The study area is focused on a simulation of road accident scene at the open space parking lot in Section 6, Shah Alam. Based on planning, the road accident scene consists of an accident between one motorcycle and one car. This road accident simulation is carried out on this parking lot between 40 m in range. The close-range photogrammetry technique is used to collect data in the field. Fig. 2 illustrates the study area of this research

2.3. Data collection

The third phase is about, data collection which consists of techniques in data collection for road accident scene using Digital Single Lens Reflex (DSLR) camera. This phase also includes the camera calibration, where camera calibration is to determine an internal parameter of the camera because it can affect a data that already been collect and to ensure the error is within a tolerance that can acceptable. The Nikon D3100 DSLR camera is used as an instrument for data collection at the road accident scene. This camera must be calibrated, to achieve an accurate result and determine the camera internal geometry that can be used in interior orientation. In this research, it will focus on using a self-calibration technique. In iwitness software, the self-calibration technique requires four or more images, orthogonal roll angles present (one image rotated 90°), convergence angles of greater than 30° and 12 or more object points. The self-calibration technique is been done during data acquisition on traffic accident scene. A fixed focal length 18 mm has been choosen during data acquisition. Others criteria have to take care when to make a calibration is a camera in manual focus mode and make a focus to infinity. The user skills when setting a camera such as ISO, shutter speed and aperture also important to get clear and sharp images that can help when processing a data.

Before the image acquisition, the focal length of the camera must be set same as focal length during camera calibration. It is important to control the accuracy of work. First place an evidence markers at the evidence of accident for example, skid marks, vehicles, side line on the road, accident vehicle and others evidence that can be model and important. Fig. 3 illustrates the evidence markers on traffic incident scene. Then take numerous distances

Fig. 3. Evidence markers on traffic accident scene.

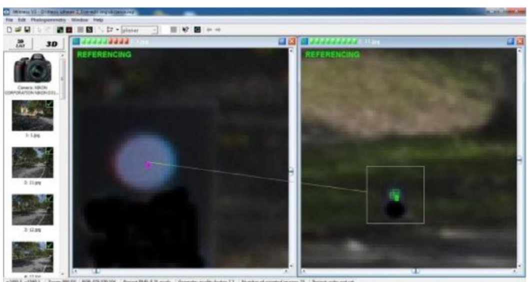

Fig. 4. Centroid determination function.

using a steel tape as a check distance to scale the digital imagery. Then establish ground control points around traffic incident scene to acquire a data using total station, start capture images and ensure the images have 15%–30% overlap and lastly process the acquired image using software iWitness.

2.4. Data processing

Interior orientation is carrying out to determine the internal geometry of the camera. The internal geometry of the camera defined by camera calibration before capturing images of the object or it can be calibrated using an actual object. This orientation is important to determine the error of the camera and determine the camera is in good condition to use as a tool to collect a data on road accident scene. To perform this calibration, the user must do their referencing process between images with achieving a minimum multi-image network with certain characteristics. After the result of calibration is acceptable, the value internal geometry that already defines it will be used for processing a data. The feature point of interest in accident reconstruction becomes a most challenging part because a road accident scene can be 50–100 m or more. This led to a network geometry problem in close range photogrammetry. To solve this problem, evidence marker is used to support a photogrammetric orientation process. Evidence markers is used to assist the user to match the same points at two different images (Fig. 4).

During a referencing process, a minimum of 5–7 well distributed referenced points is needed between two images before using the same point to reference the third and subsequent images. The higher number of referencing between images, the higher the accuracy of network geometry between images. To the accuracy of referencing, the user can check at the top bottom of this software that stated on “Total Project RMS: (value in pixels unit)”. Moreover, the quality of network geometry shows on “Geometry Quality Factor: (value in factor)”. RMS value shows the residual mean square of the image processing in order to determine the quality of control points during image processing.

This orientation focuses on a two technique to introduce true scale to the XYZ coordinates it is necessary to specify one or more point-to-point distances or assign a true coordinate at several control points. Scaling via point-to-point distance method, the user needs to choose a set scale from the menu and specifies the projects unit that refers only to object XYZ coordinate. Then, select two points on images that known their actual distance and then apply the register scaled distances. Additional scaling distances can be added at any time. For a final scale will be a weighted average of the nominated scaled distances (Fig. 5).

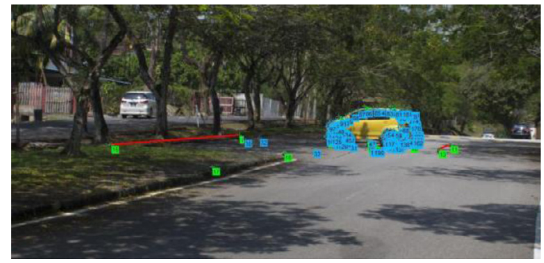

Fig. 5. Scaling distance.

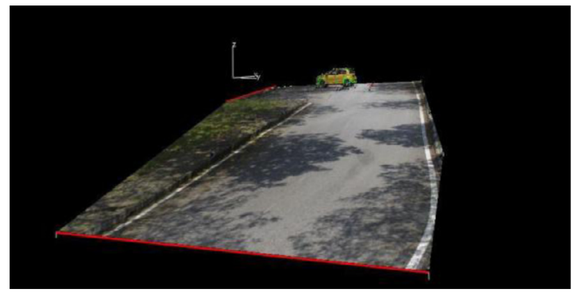

Fig. 6. 3D modeling traffic accident scene.

Table 1
Control points.

Pt	X(m)	Y(m)	Z(m)
1	986.276	993.730	10.628
2	954.192	999.818	12.302
3	965.185	1000.289	11.801

Coordinate transformation to control point’s method, the user required to select transformation to control from menu and key-in a true coordinate of control points. Then, link the true coordinate to control points in the software. After the linking process of every control point has been done. The transformation computation every point automatically process and it can show the 3D point list. The RMS values of accuracy control points indicate the quality of shape correspondence between the measured and the control point networks (Fig. 6).

The control points used in this study illustrates in Table 1. There are three control points used to transform the model into local coordinates system.

3. Results and analysis

The accuracy assessment of this research is based on a comparison between actual measurement during traffic accident scene and measurement from software. These assessments are divided into two namely comparison between software and total station coordinates and comparison between measuring tape and distances from software measurement. In this research, the analysis on software coordinate that already been computed is based on the control that already key-in on features in software which was known as “transformation to control points”. This transformation to control points is needed to transform software coordinates into another reference coordinate system.

Table 2
Comparison of coordinates-X between actual and software.

Marker No	Software (m)	Actual (m)	Residual (m)
1	976.474	976.476	0.002
2	986.179	986.174	−0.005
3	994.850	994.835	−0.015
4	993.412	993.402	−0.010
5	976.751	976.759	0.008
6	970.402	970.405	0.003
7	970.784	970.791	0.007
8	957.078	957.080	0.002
9	955.929	955.942	0.013
10	955.867	955.860	−0.007
11	955.992	955.994	0.002
12	956.194	956.201	0.007
13	958.015	958.017	0.002
14	958.833	958.836	0.003
15	959.355	959.361	0.006
16	959.668	959.669	0.001
17	960.029	960.031	0.002
18	955.416	955.429	0.013
19	957.491	957.495	0.004
20	961.074	961.088	0.014
21	955.799	955.806	0.007

Table 3
Comparison of coordinate-Y between actual and software.

Marker No	Software (m)	Actual (m)	Residual (m)
1	1000.822	1000.821	−0.001
2	1001.282	1001.285	0.003
3	1000.910	1000.912	0.002
4	993.526	993.526	0.000
5	993.341	993.346	0.005
6	993.033	993.037	0.004
7	987.626	987.629	0.003
8	986.749	986.749	0.000
9	990.422	990.423	0.001
10	991.951	991.943	−0.008
11	993.118	993.113	−0.005
12	992.217	992.210	−0.007
13	993.417	993.412	−0.005
14	993.915	993.923	0.008
15	993.063	993.075	0.012
16	993.311	993.315	0.004
17	993.110	993.107	−0.003
18	995.600	995.605	0.005
19	994.275	994.277	0.002
20	995.984	995.991	0.007
21	990.837	990.838	0.001

Table 4
Comparison of coordinate-Z between actual and software.

Marker No	Software (m)	Actual (m)	Residual (m)
1	11.276	11.279	0.003
2	10.713	10.718	0.005
3	10.290	10.293	0.003
4	10.241	10.245	0.004
5	11.291	11.290	−0.001
6	11.685	11.682	−0.003
7	11.650	11.645	−0.005
8	12.302	12.290	−0.012
9	12.329	12.318	−0.011
10	13.806	13.803	−0.003
11	13.814	13.804	−0.010
12	12.318	12.309	−0.009
13	12.618	12.613	−0.005
14	12.182	12.174	−0.008
15	12.146	12.140	−0.006
16	12.130	12.123	−0.007
17	12.116	12.109	−0.007
18	12.338	12.328	−0.010
19	12.249	12.236	−0.013
20	12.061	12.045	−0.016
21	13.328	13.317	−0.011

This transformation needed at least three control points to create a 3D transformation between control points. This transformation occurs automatically, as soon as enough control points are referenced to their corresponding measured points. The transformation residual can be displayed in the columns headed DX, DY, and DZ in the control points box. This coordinate discrepancy values can be used to indicate the quality of shape correspondence between the measured and the control point networks. The columns of Z-offset are used when the referenced point is measured using photogrammetry, but the desired control point is measured at road level using a total station. In this cases, Z-offset is used, with a positive Z-coordinate offset value must be applied to the control point at the road surface to bring it into positional correspondence with the referenced point. An overall quality value for this transformation is indicated by the Quality RMS is about +0.001 that shows the error in this control points. The analysis of coordinates is based on 3D coordinates (x, y and z) in software.

Table 2 shows the residuals values between actual coordinates-X from the total station and that measured from software. This table illustrates accuracy of this data on software using Root Mean Square Error (RMSE), indicates that the overall accuracy of coordinates. RMSE value for x-coordinates is ± 0.008 m indicates the accuracy of the data.

Table 3 shows that the residuals values of Y-coordinate from actual values and software values. RMSE values it indicates that the accuracy and amount of dispersion of the data are same. RMSE value for y-coordinates is ± 0.005 m indicates the accuracy of the data.

Table 4 shows that the residuals values of Z-coordinate from actual values and software values. RMSE value for z-coordinates is ± 0.008 m indicates the accuracy of the data.

The analysis of distance has been done using point-to-point scaling distance in software. The user needs to enter a minimum of three scaling distance to enhance scaling accuracy and reliability. This scaling is used to transform a software distance to a true distance on the ground. The scaling information requires the user to key-in a three control points of true distance, then the automatically software can transform the measured unit in software to a true unit same as a ground measurement. Also, a difference between measured distance and true distance can be shown in this scale information. In the analysis, 21 sample of actual distance has been taken using measuring tape between evidence markers to compare between actual and measured distance in the software. The RMSE for the x, y and z coordinates illustrates in Fig. 7.

This comparison is shown in the Table 5 comparison between the measured distance and actual distance. Table 5 shows that the residuals values between the actual distance that measured using measuring tape and distance from software. The accuracy of this data on software by using Root Mean Square Error (RMSE), indicates that the overall accuracy of this measured data is in range ± 8 mm.

The final result from software is a 3D texture mapping of traffic accident scene. The process is involved image rectification where the surface entities that are textured must be planar polygons, be visible from at least one oriented image and desirably have a convex boundary. If the planar condition is not fulfilled the texture will appear distorted to some extent. If the selected polygon is not convex, the texture can be potentially be turned upside down, which would make it visible from the backside of the entity, rather than the front. If no oriented image is available, or the entity is too large to fit into one oriented image a default texture (white) appears. Fig. 8 illustrates the real image on traffic accident scene and

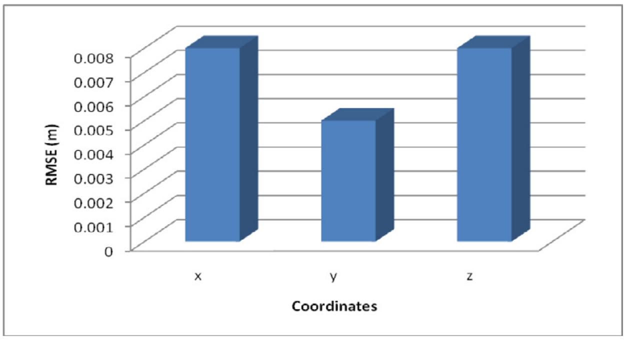

Fig. 7. RMSE for X, Y and Z Coordinates.

(a)

(b)

Fig. 8. (a) Images from traffic accident scene, (b) 3D texture mapping traffic accident scene on software.

Table 5
Comparison between actual distance and measured distance.

Samples	Distance Software (cm)	Distance Actual (cm)	Residual (cm)
1	41.300	40.100	−1.200
2	39.900	40.000	0.100
3	67.600	68.800	1.200
4	100.000	102.000	2.000
5	117.300	118.400	1.100
6	121.500	121.000	−0.500
7	181.400	181.800	0.400
8	567.800	569.000	1.200
9	439.200	439.200	0.000
10	107.100	106.800	−0.300
11	146.400	148.200	1.800
12	595.600	595.000	−0.600
13	1131.900	1131.800	−0.100
14	894.200	894.600	0.400
15	827.100	827.200	0.100
16	955.000	955.000	0.000
17	715.700	716.000	0.300
18	1119.300	1118.000	−1.300
19	1061.700	1061.200	−0.500
20	973.300	973.200	−0.100
21	748.700	748.600	−0.100
22	1332.800	1331.700	−1.100

Fig. 8 illustrates the 3D texture mapping of traffic accident scene using software.

Fig. 8 also describes the 3D texture mapping have a problem when to generated the 3D. This is because the object has complex features difficult to generate their 3D. This 3D is depending on the line of the polygon that generates based on tie point that used to referencing between images. An evidence marker is helpful to generate 3D texture mapping because from the evidence marker can help a user to join a line of polygon between images to form a good 3D texture mapping. This image can clearly see that a motorcycle cannot be formed in this texture mapping because their shapes are complex. Also, based on user manual in software, functions of 3D texture mapping is more suitable to form 3D of building or features that do not have a complex shape.

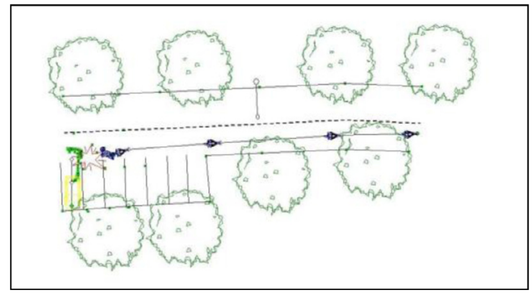

Fig. 9. 2D view of simulation traffic accident scene.

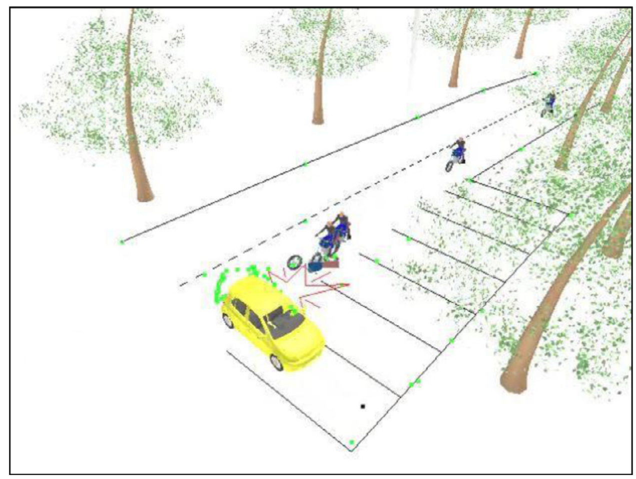

Fig. 10. 3D simulation of traffic accident scene.

To create a 3D simulation of traffic accident scene, all the data in software will be export to second software that creates especially to create a simulation of traffic. Format data were exported is in DXF. After export the data into simulation software, the user can create features based on the point coordinate that has been exporting from software. Fig. 9 illustrates the 2D view of drawing in simulation software.

Fig. 9 illustrates 2D drawing of simulation traffic accident scene. This drawing produced based on the exported point coordinates from iWitness software. A user can draw or placed a topography features on traffic accident scene using a template database in this software. For vehicles, databases in this software already have it, to help the user choose what type of vehicles to be used. With a create features based on point coordinates, the user can accurately form a 3D simulation based on data that collect on traffic accident scene. For a 3D simulation of traffic accident scene illustrates on Fig. 10.

Fig. 10 shows a final product of this research which is a 3D simulation of traffic accident scene. This research, have created traffic accident scene based on the planning. The situation of traffic accident scene, a car's driver has been a fault that makes an accident happen because he does not carefully before drive their cars out from parks. This simulation is creating based on the situation on traffic accident scene. Whereas, skid analysis based on skid marks that create on traffic accident scene. Simulation software can create a KEP point, to create a movement of vehicles and related to the time of impact between vehicles. This 3D simulation is helpful if some road accident cases can be proved in the court, this 3D simulation will be helpful to a final decision in court.

4. Conclusion and future work

As a conclusion, the close-range photogrammetry technique is suitable to use in road accident investigations, with an aid of software that specially built for a road accident investigation. This can help the user like police officers to collect an evidence or data on traffic accident scene. Based on the first objective, to construct a 3D accident reconstruction using close range photogrammetry, this objective achieved after the end of this dissertation with a 3D simulation of traffic accident scene in simulation software. The objective is to analyze 3D accident reconstruction. This objective is achieved based on the method of analysis that divided into two methods. Firstly using mathematical formula standard deviation to define the dispersion of the sample data, and RMSE is to indicate the accuracy of the data. This analysis is differences between two instruments of data acquisition, measurement tape and total station. Secondly, analysis of 3D simulation of traffic accident scene in simulation software with defines the limitations, and advantages of the software.

Using a close-range photogrammetry technique, it can reduce the cost of operations because there is only need one officer to collect all the data. Moreover, this technique offers minimum a time in data collection at accident scene from the other equipment such as laser scanner, total station and measurement tape. This led to prevent a traffic jammed when road accident happens in one location. From this research, it proves that in range 40 m road accident, with using close-range photogrammetry technique can achieve accuracy to a cm level. This more in needed on investigating the traffic accident scene, because a cm level of accuracy is suitable for road accident investigations to investigate the skid marks and others features that related to an evidence on road accident scene.

For the future work, these recommendations offer to maximize the efficiency and minimized the problem in producing and mapping 3D model of traffic accident scene using close-range photogrammetry technique. The processor needs to choose a suitable camera position when taking pictures of traffic accident scene with maximizing the number of evidence markers can see the pictures, this will lead to making a good network geometry between images. The user also needs to get a camera into a high position or suitable high, to be able to shoot down over the obstruction. Users always have an option for more marked and referenced feature points rather than less. Although in theory a minimum of 5 per image in a stereo pair is required but it encourages the user to measure at least 6 for reliability purposes. The larger the angles of intersection of images between camera positions, with two or more rays, the more accurate will be the XYZ coordinates in software.

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