CASE STUDY IN ACCIDENT SCENE RECONSTRUCTION

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abstract: The accuracy of obtaining a single-image/ photo is frequently constrained by the photographing process at an accident scene. These constrains include the different positions and angles taken from a camera, impending processing time and insufficient equipment, high processing cost of the photos, etc., so that it is hard to take sufficient overlapped-photos to cover the entire scene. Thus, it is absolutely necessary to reproduce important accident data by using single-image photogrammetry methods. The focus of this case study is to show the comparative results of three single-image photogrammetry methods which include the plane-to-plane transformation method, marker setting method, and pseudo-marker setting method. The items for comparison contain it's basic constraints, the degree of restitution, the way the accident is handled, the procedure of building up the accident scene, etc. The results will provide useful references for practical application.

1. INTRODUCTION

Photos taken from an accident scene can record the entire accident data and so compensate the insufficient data collected with measurements at the scene by police/investigators. Since images in a photo are formed by a non-linear mapping transformation, the actual sizes and positions of the objects in the photo are not easy to be determined by the human experiences. Therefore, using the photogrammetry method to reproduce the actual sizes and positions of the objects in the photo is an effective way for collecting the correct and entire data at the accident scene.

Since the tasks of photographing the accident scene were usually constrained by the photographing angles and positions, limited processing time and equipment, the safety consideration of the policeman in processing, the cost of the photos, the lack of photographing criteria for the policemen/investigators, etc., the important accident data were frequently shown in a single-photo. Therefore, it is absolutely necessary to develop a single-image photogrammetry method to reproduce the data in the photo.

This study employed three kinds of reproduction methods: the plan-to-plane transformation, marker setting and pseudo-marker setting-to restitute the actual length of a skidmark on the roadway at the accident scene. Their results were analyzed and compared. In this article, the theoretical basis of the accident scene reconstruction and the practical operational procedure of scene processing and restitution were described. Firstly, the analysis of the reproduction results obtained from the above methods in some items such as accuracy, operating cost and time, were undertaken. Lastly, we simply proposed the conclusions and recommendations .

2. THEORETICAL BASIS

The Theoretical bases of the plane-to-plane transformation method, marker setting method and pseudo-marker setting method, are described respectively as follows.

2.1 Plane-to-plane Transformation Method

The projection behavior from the roadway surface (two-dimensional plane) to photo plane (two-dimensional plan) was formulated by the Hallert [1] in the early days, as shown in Formula (1) and (2). The geometric relationship between the photo coordinates and the scene coordinates is shown in Figure 1. Later, Bleyel applied this formula to solve the issues of the accident scene reconstruction [3]. Basically ,this method uses four control points measured at the scene and their corresponding points on the photo to estimate the projection parameters in the eight joint equations, assuming that the roadway surface at the scene and the photo plane are nearly flat.

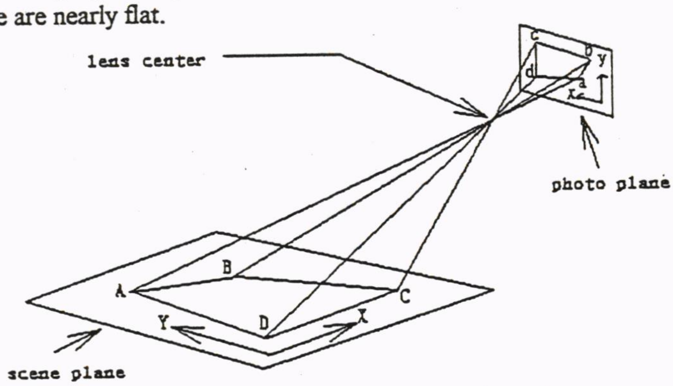

Figure 1 Plane-to-plane transformation.

Thus, the coordinates (x, y) of the points on the photo can be used to determine the coordinates (X, Y) at the scene, i.e. , knowing the coordinates of the points on the photo the scene coordinates can be estimated by using the formula (1) & (2). Basically, this method assumes that the roadway surface and picture plane are flat and the relationship of their transformations is linear, not considering the errors introduced by the distortion of camera lane, the unevenness & deformation of the film, non-flat terrain of an accident scene, etc.(this error was smaller than the calibration errors of the transformation parameters).

$$x = \frac{L_1X + L_2Y + L_3}{L_7X + L_8Y + 1} \tag{1}$$

$$y = \frac{L_4X + L_5Y + L_6}{L_7X + L_8Y + 1} \tag{2}$$

where

x, y : the photo coordinates .

X,Y: the scene coordinates (two-dimensional coordinates).

$L_1 \ldots L_8$: transformation parameters .

This method has been practically used in accident scene reconstruction for many years. There are some algorithms developed for finding the optimal transformation parameters. The parameters can be calibrated by the scene coordinates of the multi-points measured in the field as well as their corresponding photo coordinates. As a result, the best four control points, which result in the minimum deviation between the actual scene coordinates and the estimated plane coordinates, will be found and the corresponding scene plane be reconstructed. In later days, some researchers used the coordinates of the multi -points measured at the scene and the picture plane to calibrate the transformation parameters by the least -square method. Because the formulas (1) and (2) can be transformed into AL= b, the parameters L(a vector) is equal to $L = \left(A^T A\right)^{-1} A^T b$.

Then, by considering the differences of the measuring accuracies of the points at the scene and subsequently introducing the weight matrix to find the L, a more accurate transformation plane (roadway surface) will be obtained .

2.2 Marker Setting Method

Yo-Chung Kuo [2] proposed a marker setting method to estimate the real lengths of the skidmarks on the roadway surface at the accident scene by setting poles with fixed length along the skidmarks, as shown in Figure 2. The basic idea of this method is that the image length of the objects in a photo is a function of the length of the corresponding objects in the field .

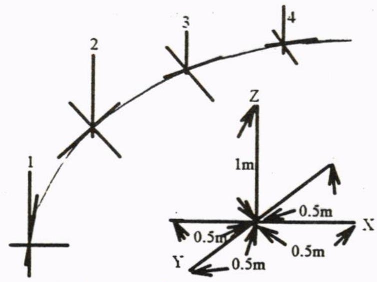

Figure 2 Four poles setting along a curve.

There is a mathematical relationship between the curve formed by the poles on a photo and the ratio of the pole's actual length to image length . The mathematical relationship can be represented by a polynomial function as show in Formula (3). Thus, the actual distance of the skidmark can be directly estimated by the Formula (3) with the known length of the poles in a photo.

$$\text{Length} = b_0 + b_1 \times s_i + s_i^2 \qquad (3)$$

where

length :the actual distance in the field which is measured along the curve from the starting point to the specified s_i position in an image .

s_i: the image distance from the starting position of the curve to the particular point in the curve.

b_0, b_1, b_2 = constants

2.3 Pseudo-marker Setting Method

This method is based on the camera model and digital terrain model as well as combined with the theory and skill of the computer graphics to correctly estimate the actual plane coordinates and elevation of any point on a photo [9],as shown in Figure 3.

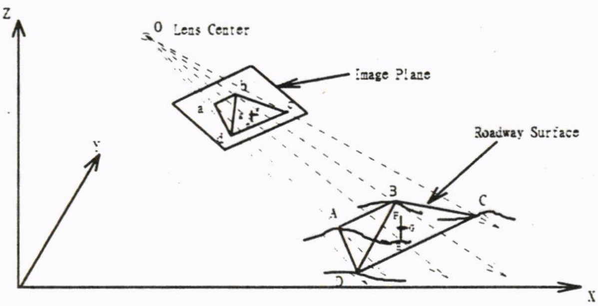

Figure 3 Reverse projection lines intersect the roadway surface.

The direct linear transformation (DLT) model is used to simulate the projection behavior from the three-dimensional space to two-dimensional plane (photo plane),called the camera model as the Formula (4)and (5). Then by using the Triangular Irregular Network method, Range Research Method, to establish the digital terrain of the roadway surface, the scene coordinates of any point contacted with the ground on a photo can be estimated by the approximation method. Lastly, the actual three-dimensional coordinates in the field of any point in a photo could be estimated by the method [9].

$$x + \Delta x = \frac{L_1 X + L_2 Y + L_3 Z + L_4}{L_9 X + L_{10} Y + L_{11} Z + 1} \qquad (4)$$

$$x + \Delta x = \frac{L_5 X + L_6 Y + L_7 Z + L_8}{L_9 X + L_{10} Y + L_{11} Z + 1} \qquad (5)$$

where

x,y: the image coordinates of an image point

X,Y,Z: the scene coordinates of that point

L_i : transformation parameters, i= 1,2....,11

$$\Delta x = (x - x_{op}) K_1 \left[(x - x_{op})^2 + (y - y_{op})^2 \right]$$

$$\Delta y = (y - y_{op}) K_1 \left[(x - x_{op})^2 + (y - y_{op})^2 \right]$$

where

x_{op} , y_{op} : the coordinates of principal point

K_i : radial lens distortion parameters, i=1,2,3,...

3. THE PROCEDURE OF ACCIDENT PROCESSING AND RESTITUTION

Their operational procedures of the above reproduction methods are respectively described as follows.

3.1 Plane-to-plane Transformation Method

(1) The procedure of processing at the scene

A. Setting the marks or choosing the natural points around the important tyre marks.
B. Covering the entire marks or natural points while photographing at the scene.
C. Moving the obstacles (i.e. stopped vehicles, scattered items etc.) away from the roadway surface .

(2) The procedure of restitution

A. Measuring the two-dimensional coordinates of the control points (marks or natural points) at the scene.
B. Reproducing the actual distances of the tyre marks.

3.2 Marker Setting Method

(1)The procedure of processing

A. Setting the objects with the known sizes around the tyre marks ,such as the traffic pyramid, triangular warning sign, poles, etc.
B. Covering the entire objects while photographing at the scene.
C. Moving the obstacles away from the roadway surface

(2)The procedure of restitution

A. Directly proceeding the task of the scene reconstruction, not needing the measurement at the scene

3.3 Pseudo-marker Setting Method

(1) The procedure of processing at the scene

A. Setting marks around the important tyre marks.
B. Setting the objects with the known sizes along the roadsides, depending on the degree of simplification of neighboring environment.
C. Covering the entire objects while photographing at the scene.
D. Moving the obstacles away from the roadway surface

(2) The procedure of restitution

A. Measuring the three-dimensional coordinates of the control points (marks or natural points or objects) at the scene.
B. Reproducing the actual distances of the tyre marks.

4. CASE STUDY

A skidmark occuring on the roadway is shown in Figure 4. Based on the operational procedure of the scene processing and restitution presented in each photogrammetry method, we proceeded in doing following tasks: marking the points on the roadway, setting the objects, photographing the scene, measuring the control points, etc. After the accident data was obtained, the actual length of the skidmark can be reconstructed by using the above photogrammety methods.

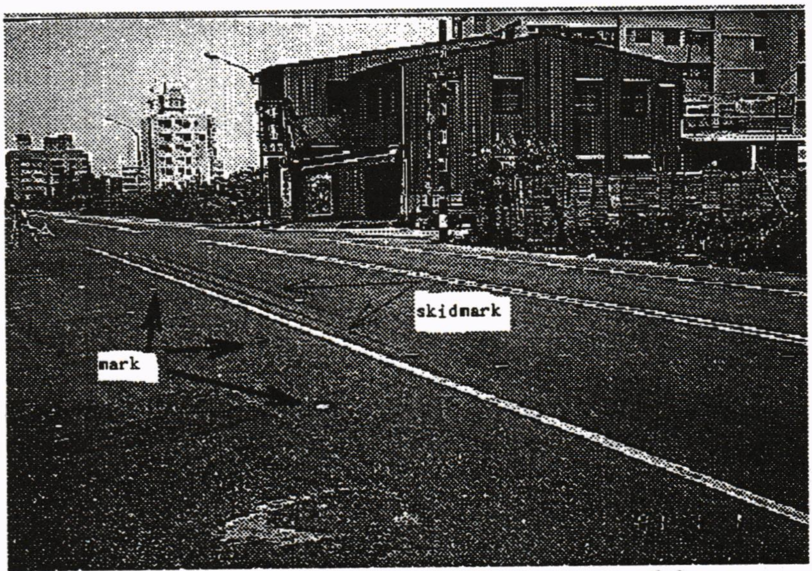

Figure 4 skidmarks on the roadway and marks set around them.

4.1 Plane-to-plane Transformation Method

The results of the practical operational procedure in each method will be described and compared in the following section. In this study, "meter" is selected as the length unit and "degree" as the angle unit.

Table l The coordinates of the points at the scene and their images---four points .

scene coordinates("m")			photo coordinates("pixels")	
no.	X	Y	x	y
1	3.677	2.146	67	587
2	24.037	2.585	588	307
3	4.090	6.351	382	605
4	24.826	6.357	1452	391

Table 2 The coordinates of the points at the scene and their images---six points .

scene coordinates ("m")			photo coordinates ("pixels")	
no.	X	Y	x	y
1	3.677	2.146	67	587
2	24.037	2.585	588	307
3	4.090	6.351	382	605
4	24.826	6.357	1452	391
5	4.215	4.621	260	598
6	24.033	4.270	920	379

The transformation parameters can be calibrated by the least-square method using the coordinates of the control points in Table 1 and Table 2. With the known parameters, the joint equations formed by the formulas (1) and (2), can be solved. The actual scene coordinates of the points on the photo are then obtained. The results of the estimated length of skidmarks are shown in Table 3.

Table 3 The results obtained by using plane-to-plane transformation method

items	parameters	skidmark near outside line			Skidmark near center line		
four points	L_1: 2.88	origin point:			origin point:		
	L_2 :73.68	measured values	estimated values	errors (%)	measured values	estimated values	errors (%)
	L_3 :-107.38	X:4.82	4.34	9.9	X:6.97	5.93	14.9
	L_4 :-22.83	Y:4.08	4.12	0.9	Y:4.45	4.56	2.4
	L_5 :14.56	destination point:			destination point:		
	L_6 :590.74	measured values	estimated values	errors (%)	measured values	estimated values	errors (%)
	L_7 :-0.03	X:23.15	22.55	2.6	X:18.55	17.81	3.9
	L_8 :0.017	Y: 3.91	3.97	1.6	Y:4.35	4.42	1.6
six points	L_1 :2.92	origin point:			origin point:		
	L_2 :73.03	measured values	estimated values	errors (%)	measured values	estimated values	errors (%)
	L_3 :-106.2	X:4.82	4.45	7.6	X:6.79	6.04	11.0
	L_4 :-22.63	Y:4.08	4.12	0.9	Y:4.45	4.55	2.2
	L_5 :13.95	destination point:			destination point:		
	L_6 :590.55	measured values	estimated values	errors (%)	measured values	estimated values	errors (%)
	L_7 :-0.03	X:23.15	22.65	2.1	X:18.55	17.88	3.6
	L_8 :0.015	Y:3.91	3.97	1.5	Y:4.35	4.42	1.6

note: Unit: "m", errors: ((measured values-estimated values)/measured values) $\times$ 100

The accuracy of the estimated length of the skidmarks is low, partially because the photo is digitalized by a lower resolution(300 dpi).

4.2 Marker Setting Method

Based on the operational procedure of this method, the objects, poles with fixed three dimensional length, are set on the skidmarks as shown in Figure 5. After the photo is digitalized the coordinates of the poles are obtained. There are seven control points in each pole. The estimated length of the skidmark near the outside line is 17.47m, which is 0.87m deviated from the actual length 18.337m. Since this method can only estimate the mark length under the poles, it is also necessary to set poles on the skidmark near the central line to reproduce its length.

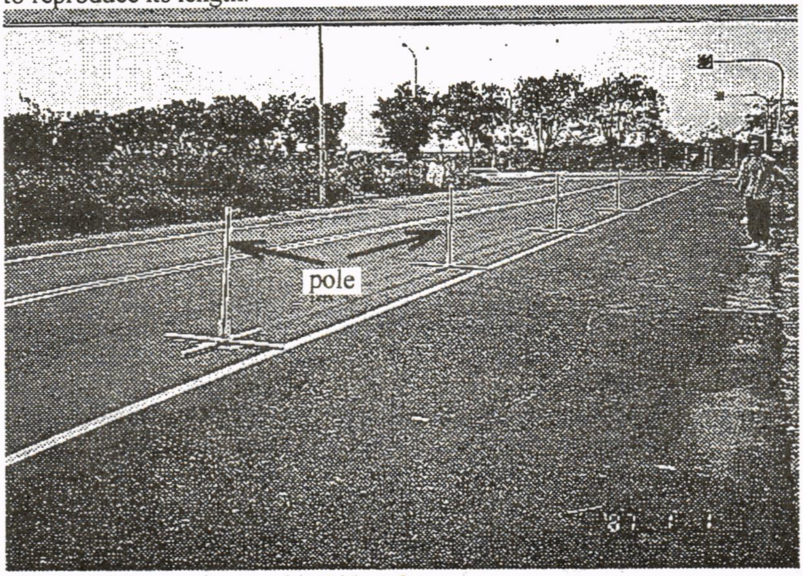

Figure 5 Poles setting on the skidmark.

4.3 Pseudo-marker Setting Method

Based on the operational procedure of this method some ground marks were set around the skidmarks . Since no other reference points could be found on the roadway, some poles were set around skidmarks, under the principle of not influencing the roadway traffic . The picture is then taken and shown in Figure 6.

After measuring the control points on the poles and the ground marks on the roadway, the author combined the three-dimensional coordinates with their image coordinates, shown in Table 4, to calibrate the camera model and establish a digital terrain model. The simulated results of the digital terrain model is shown in Figure 7. After the images were overlapped, shown in Figure 8, the length of the skidmarks can be estimated by using the above method. The results are presented in Table 5. There are two major reasons for the inaccuracies of the estimated position along the x axis. One is the control points on the poles concentrated at the corners of the scene. The other is the insufficient ground points. In addition ,the photo digitalized by a scanner with a low resolution can also result in a lower accuracy when reproducing the skidmarks .

4.4 A Comparison of Results for Reproduction

A review of the operational procedure of the scene processing and reconstruction in each method has shown that the marker setting method is the easiest one for operation, because it only requires the setting of some poles on the skidmarks, and then the actual length of the skidmarks can be estimated. In spite of its easy operation, its degree of scene restitution is the lowest one among the three methods. On the contrary, the pseudo-marker setting method can reproduce the actual positions and elevations of all points on a photo with the highest degree of accuracy, but its operational procedure is more complicated. As for the plane-to-plane transformation method one only needs to measure the ground points around the skidmarks and subsequently combined them with image points to calibrate the model. Then, the actual plane coordinates of the image points on a photo can be obtained. The degree of accuracy in restitution by using plane-to-plane transformation method is slightly higher than by using marker setting method, but is lower than by using the pseudo-marker setting method.

Table 4 The coordinates of the control points at the scene and their image points for calibrating the camera model.

scene coordinates ("m")				photo coordinates("pixels")	
no	X	Y	Z	x	y
1	13.557	2.169	0.052	0.010329	0.038105
2	13.557	2.169	1.052	0.009821	0.045974
3	24.037	2.585	0.052	0.036237	0.060960
4	24.037	2.585	2.120	0.061468	0.044196
5	4.0974	13.146	0.046	0.061299	0.049869
6	4.0974	13.146	1.266	0.099737	0.040640
7	17.546	12.747	-0.013	0.100161	0.055203
8	17.546	12.747	1.867	0.036068	0.031919
9	24.037	2.585	0.325	0.03586	0.0353
10	24.037	2.585	0.522	0.035644	0.038354
11	24.037	2.585	0.752	0.03539	0.041656
12	24.037	2.585	0.926	0.035306	0.044788
13	24.037	2.585	1.122	0.035052	0.0480
14	24.037	2.585	1.322	0.034882	0.051136
15	24.037	2.585	1.522	0.034713	0.05461
16	24.037	2.585	1.722	0.034459	0.057685
17	24.037	2.585	1.922	0.061383	0.04614
18	4.0974	13.146	0.466	0.089408	0.03302

Table 5 The results obtained by using pseudo-marker setting method

skidmark near outside line			skidmark near center line		
origin point:			origin point:		
measured values	estimated values	errors (%)	measured values	estimated values	errors (%)
X:4.82	5.01	3.9	X:6.79	7.26	6.9
Y:4.08	4.12	1.0	Y:4.45	4.39	1.3
destination point:			destination point:		
measured values	estimated values	errors (%)	measured values	estimated values	errors (%)
X:23.15	22.70	1.9	X:18.55	18.34	1.1
Y:3.91	3.92	0.2	Y:4.35	4.31	0.9

note: length unit: "m"

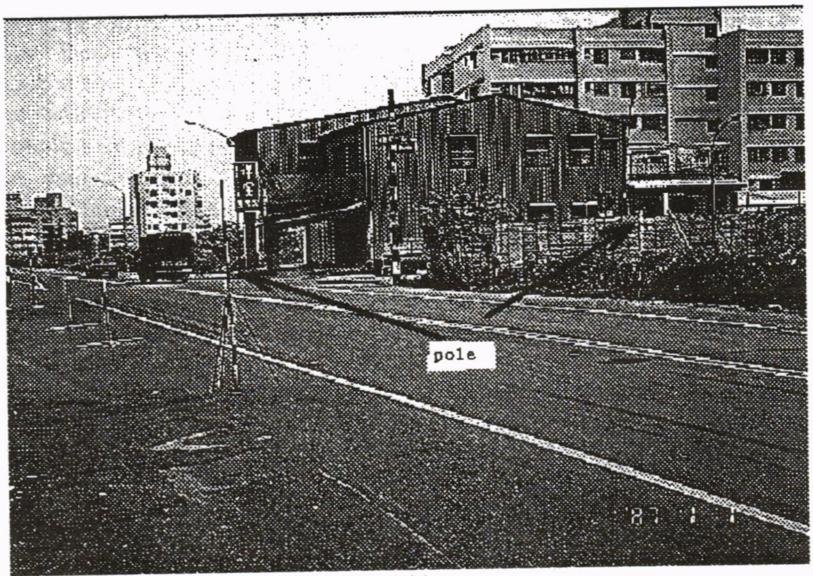

Figure 6 Poles setting along the roadside .

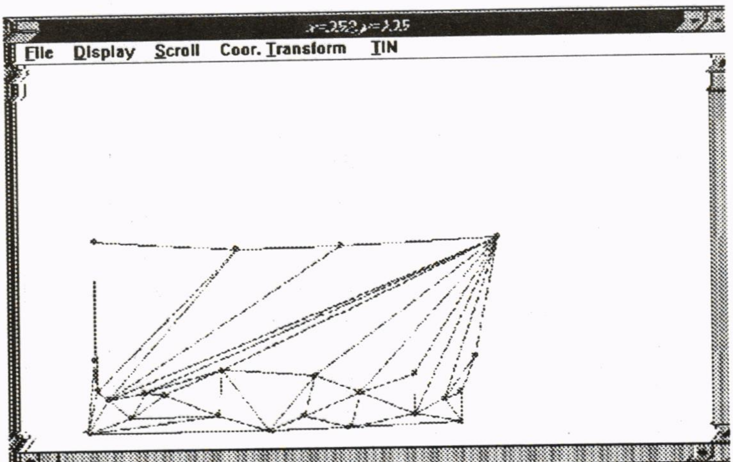

Figure7 The simulated result of the digital terrain .

Figure 8 The overlapped images.

5. CONCLUSIONS AND RECOMMENDATIONS

According to the above results, it can be concluded that the plane-to-plane transformation method and marker setting method are easier than the pseudo-marker setting method in the scene processing procedure. However, since these two methods can only repoduce ground points on the roadway, both of their degree of scene restitution and acccuracy are lower. Conversely, the pseudo-marker setting method takes a more complicated scene operational procedure, but the degree of restitution is higher. The scope of its restitution includes the three-dimensional coordinates of all points on the photo. In addition, it has a higher accuracy.

Since the degree of accuracy of scene restitution is directly influenced by the theory each method based on, it is important to find a proper method whose theoretical assumption matches the real roadway environment. From the analysis of their theoretical assumptions, the plane-to-plane transformation method is suitable for the restitution of objects on the flat roadway surface, marker setting method for the reproducing the objects on the slow changing roadway surface, and the pseudo-marker setting method for the scene reconstruction at any conditions of the terrain.

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