A Three-Dimensional Visualization Approach to Traffic Accident Mapping

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ABSTRACT: This paper describes the design and development of PMCAD II—a system born out of an attempt to produce a low cost, simple to use, photogrammetric-based, three-dimensional (3D) computer graphics visualization system for traffic accident mapping. The traffic scene is restituted through the use of non-metric (or amateur) cameras, digitizing pad, and the direct linear transformation (DLT) algorithm. Object space coordinates derived are channeled to a microcomputer-based 3D drafting package to produce the shaded 3D traffic accident scene.

INTRODUCTION

TRAFFIC ACCIDENTS are a fact of life on our highways. In spite of safer and better highways, the accident rates of all developed countries have increased. Accidents invariably cause traffic jams. The efficient disposal of traffic accident debris is, therefore, an important aspect of traffic management. In most countries, however, the law requires that major traffic accident sites, those involving serious bodily injury and deaths, cannot be cleared until the traffic police have arrived and meticulous measurements of the site have been made. From these measurements, a traffic accident plan like Figure 1 is prepared as part of a report to be used as evidence in court for possible settlement cases.

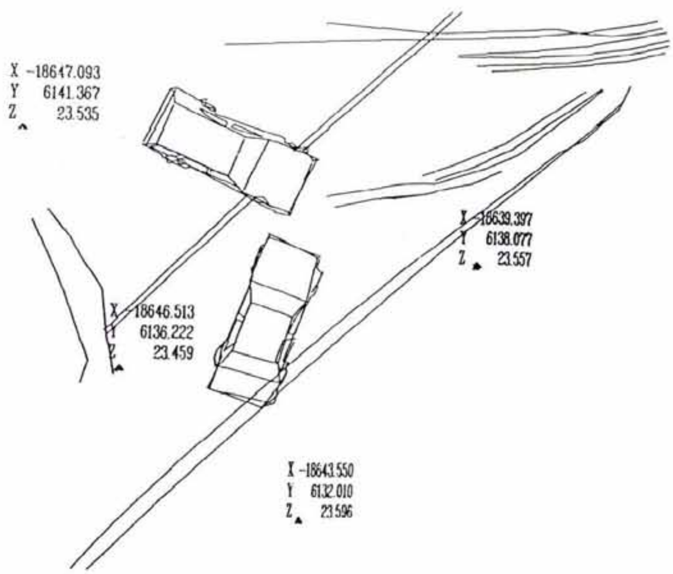

FIG. 1. A typical traffic accident plan prepared from close-range photogrammetry (original scale 1:100).

This procedure of gathering information to compile the accident plan is rather tedious, time consuming, and error prone. Not surprisingly, therefore, many countries have resorted to using photogrammetric techniques to compile the plan. This method of employing close-range photogrammetry for traffic accident mapping was first adopted by Switzerland in 1933. Subsequently, in 1935 Germany followed suit. Today, photogrammetric traffic accident mapping is an accepted practice in many parts of Europe. However, few countries have embraced this technique with as much enthusiasm as Japan (Ghosh, 1980). Of course, Japan is a non-litigious society, but still it is impressive to know from Ghosh (1980) that "there is no road accident related court case pending anywhere in Japan beyond one week after the accident." Economically, thousands of hours which would otherwise be lost in traffic jams are saved. These saved hours also translate into a better quality of life for all road users.

Elsewhere in the world, however, there is much less enthusiasm for using photogrammetry to produce traffic accident plans. There are a few reasons, but two of the most commonly cited reasons are (1) resistance by the legal profession to accept photogrammetrically produced drawings as admissible evidence in courts, and (2) the high initial cost of training manpower and acquiring specialized equipment to produce what is generally perceived to be simple drawings. The first reason, if true, is insurmountable unless the court rules otherwise. The second reason can be overcome technologically. This paper describes one successful attempt at breaching the technological cost barrier.

PHOTOGRAMMETRY AND TRAFFIC ENGINEERING

Traffic engineers are no strangers to photogrammetry. The application of photogrammetry to traffic studies go as far back as 1947 when Greenshields (1947) made an early attempt to use aerial photography for traffic analysis. Since then various researchers, e.g., Treiterer and Taylor (1966), Baker and Owens (1974), and Makigami *et al.* (1985), have extended the technique to different areas. Most of these works are confined to aerial photography. Traffic accident mapping, however, involves mostly close range photogrammetry.

The theory of close-range photogrammetry is well established (Atkinson, 1980; Ghosh, 1988; Karara, 1989). Traditionally, traffic accident maps are produced using stereometric cameras and special analog plotters. In recent years, non-metric and semimetric cameras have been preferred, and analog plotters are slowly being replaced by analytical plotters. The use of analytical plotters for traffic accident mapping for the present may be a bit of a technological overkill. In the future, however, as the cost of analytical plotters comes down, the issue will take on a new perspective. Regretably, many of the present breed of analytical plotters, in spite of all their power and flexibility, lack three-dimensional (3D) graphics visualization facility, something which in fact is needed in most traffic accident mapping. For this reason, the restituted 3D model is often re-mapped onto two-dimensional plans for visualization purposes.

WHAT'S WRONG WITH PLANS?

Plans are fine for topographic mapping where extreme absolute accuracy matters. But there is a plethora of applications

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for which extreme accuracy of the object points is not very important. Traffic accident mapping is one such category. Instead of using expensive, high accuracy plotting systems to plot accident plans, what is really needed are low cost, photogrammetric-based systems to generate useful three-dimensional computer graphics for measurement, visualization, and interpretation. Kennie and Mclaren (1988) and Petrie and Kennie (1988) summarize some applications of visualization systems in photogrammetry.

Apart from the ease and clarity with which visualization systems convey ideas and messages to involved persons (such as judges and traffic policemen), there is one more compelling reason why it is in fact sometimes necessary to employ visualizations systems for traffic accident mapping. Because of the limitations imposed by metric photography, there is an increasing trend in traffic accident mapping to use convergent non-metric photographs for data acquisition (Waldus and Kager, 1984). Generally, convergent photographs do not make good stereoscopic models for three-dimensional viewing. Hence, reconstruction of traffic accident scenes from convergent non-metric photographs must be done analytically. A three-dimensional visualization system must, therefore, work in cooperation with analytical photogrammetry for displaying the restituted 3D traffic accident model. Computer visualization is a powerful communications medium. Users can immediately relate to the 3D model created from photogrammetry. In reality, therefore, analytical photogrammetry and computer visualization systems work in combination: the former creates the 3D model, while the latter puts the reconstructed model in full visual display.

THE PMCAD II SYSTEM

The PMCAD II system represents one successful attempt at developing a low cost photogrammetric-based visualization system for traffic accident mapping. The acronym PMCAD stands for Photogrammetric Mapping through Computer Aided Drafting. PMCAD II is a refinement on PMCAD (Koo, 1989) in that it allows shaded renderings of the traffic accident scene. This prototype system has been designed for the non-photogrammetrists. Using off-the-shelf cameras, PMCAD II is able to reconstruct traffic accident scenes in a microCAD system from "random" pictures taken of the accident scene. Although PMCAD was originally conceived for traffic accident mapping, the resultant system is eminently suitable for the re-creation of any wire-frame or pseudo-solid (shaded) model from 2D imagery.

The concept of PMCAD II is illustrated in Figure 2. Essentially, the system marries analytical photogrammetry with microCAD. Two software bridges, a pre-processor suite and a post-processor suite, work in cooperation with the Direct Linear Transformation (DLT) of Karara and Abdel-Aziz (1974) to build up the solid model piecewise from 2D images obtained from enlarged non-metric photographs. The DLT solution was preferred over that of the 11 parameter solution (Bopp and Krauss, 1978) and Metric Photo Perspective Transformation (Gruen, 1985) because the DLT algorithm is relatively easy to code, occupies little space on the microcomputer, and processing time is very fast. Also, in this problem formulation, additional control is not a problem.

FIELD WORK AND PHOTOGRAPHY

The DLT formulation of Karara and Adbel-Aziz, Equations 1 and 2, represents the relationship between the image coordinates and object space coordinates with the parameters of interior and exterior orientation embedded in L_1 to L_{11}. That is,

$$x + v_x = \frac{L_1X + L_2Y + L_3Z + L_4}{L_9X + L_{10}Y + L_{11}Z + 1} \tag{1}$$

$$y + v_y = \frac{L_5X + L_6Y + L_7Z + L_8}{L_9X + L_{10}Y + L_{11}Z + 1} \tag{2}$$

where

x,y are image coordinates;
X, Y, Z are the object-space co-ordinates of (x,y);
L_1 to L_{11} are the transformation parameters; and
v_x, v_y are residual image coordinates.

To solve for the DLT parameters, the values of the photo and object space coordinates of at least six well distributed homologous points must be known. To satisfy this minimum requirement, PMCAD recommends that at least four control points be marked out on site to surround the circumference of the accident area (Figure 3). The four points, distributed 90° apart, will fall on the circumference of a prescribed ring outside the accident site. Calibrated vertical range poles are erected on each of the marked control stations. Hence, four ground control points can in fact provide an "array" (i.e., more than the minimum of six) control points needed to solve the DLT equations. Because the purpose of any traffic accident mapping system is the expeditious removal of debris in order to allow normal traffic flow to resume, the (X, Y, Z) coordinates of the ground control points need only be measured sometime after the accident site has

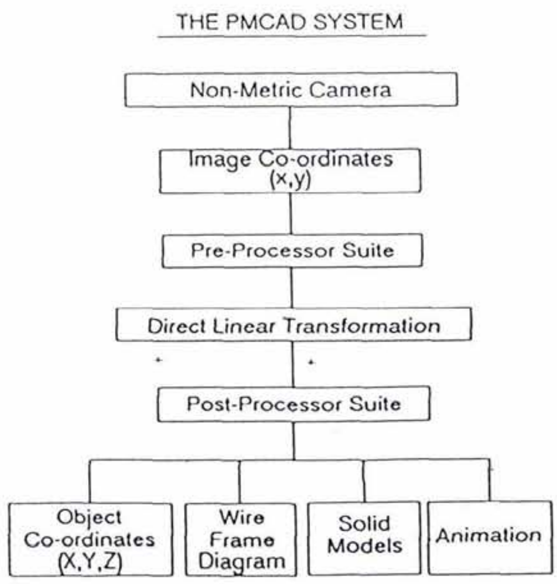

FIG. 2. The concept of the PMCAD II system.

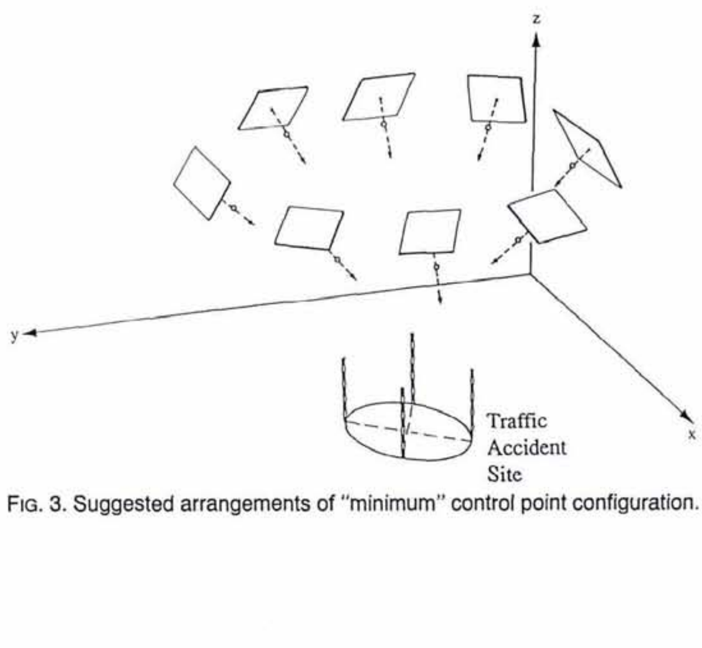

FIG. 3. Suggested arrangements of "minimum" control point configuration.

been cleared. Keeping in mind that the pictures are to be taken by non-photogrammetrists, only two simple rules are prescribed for the amateur photographer.

Rule 1.
The estimated base-distance ratio should be about 1/5. On restricted sites, this condition might be difficult to fulfill.
Rule 2.
Every picture must be taken such that the range poles appear in the preferred positions shown in Figure 4 (the "preferred positions" refer to the four end points of any two perpendicular diameters of an "imaginary circle" whose center is chosen to be the center of the accident scene, and whose diameter represents the extent of the accident scene that needs to be mapped).

An example of a picture taken with a zoom 35-mm to 75-mm variable focal length lens on a 35-mm format Minolta XGM camera is shown in Figure 4. This picture has been framed to comply with rules one and two. Using a zoom camera, and the suggested control point layout, it is seldom difficult to frame a picture to satisfy Rule 2. Non-linear points on the cars e.g., wheels) are pre-marked with white dots for digitizing purposes. Notwithstanding Rule 1, the photographer is encouraged to take as many pictures in as many orientations as possible. Useless pictures can always be discarded and, if enough are taken around the accident scene, at least four pictures will approximate Rule 1 and conform to Rule 2. The resultant pictures are usually enlarged to either 3R-sized (3 inches by 5 inches) or 5R-sized (5 inches by 7 inches) positives for on-line data acquisition by the pre-processor suite.

PRE-PROCESSOR SUITE

The PMCAD pre-processor suite serves to extract, analyze, and format image coordinates (x,y) on-line from the non-metric photographs for the DLT solution. A low cost, commercially available A3-sized (420 mm by 300 mm) digitizer was used in our studies for this purpose. Published studies by Carson (1985) and Ali (1988) on these off-the-shelf digitizers suggest that their use for photgrammetry for projects where extreme accuracy is not required is justified. Most A3-sized digitizers have a resolution of 25 micrometres and an accuracy of about 140 micrometres. Studies conducted by the author confirm that the pointing precision in x and y co-ordinates of digitizer tablets is about 6 micrometres and 7 micrometres, respectively.

An A3-sized digitizer allows four 3R-sized (3 inches x 5 inches) pictures or two 5R-sized (5 inches by 7 inches) to be digitized in one instance. Figure 5 shows how the enlarged 3R-sized (3 inches by 5 inches) photos are arranged for on-line data acquisition. Studies suggest that this is a very good arrangement. Four 3R-sized (3 inches by 5 inches) pictures should provide enough coverage to provide a full three-dimensional model. At the same time, a 3R-sized (3 inches by 5 inches) picture is large enough for visual pointing without the aid of a magnifying glass other than the one provided on the digitizer's cursor.

THE DLT SUITE

The formatted image coordinates are sent into the DLT suite for processing. Marzan and Karara's DLT FORTRAN program (1975) was modified and coded in Ryan-McFarland FORTRAN to enable it to run in the IBM Personal Computer.

ACCURACY DISCUSSION

Although the DLT solution is rigorous, it is clear that the limiting accuracy of the PMCAD II system lies in the relatively low accuracy of the digitizer. An experimental comparative study was conducted to determine the accuracy of the control points of a simulated traffic accident site using image coordinates derived from the digitizer and the accuracy obtained from the Wild Aviolyt BC2 used in a monocomparator mode. The digitizer derived coordinates were obtained from four 3R positives, and the BC-2 derived coordinates were obtained from the 35-mm format (focal length = 50 mm) negatives of the same pictures. The results are shown in Table 1. It can be seen that the standard deviation of the control stations derived from the A3-sized digitizer is only about two times worse than that obtained from the BC-2, in spite of the fact that the quoted accuracy of the Wild Aviolyt BC-2 system is 2 micrometres.

POST-PROCESSOR SUITE

After processing the modified DLT program, an output file of the digitized object space coordinates become available. This X,Y,Z file now forms the basis for re-creating the three-dimensional computer model. In the PMCAD II solution, the 3D computer model is re-created inside a microCAD system. This approach of marrying microCAD assisted analytical photogrammetry has the important advantage of eliminating the tedium of writing graphic entities—lines, text, symbols, points, splines, 3D faces, 3D lines, 3D splines—which together make up the three-dimensional model.

The choice of a suitable microCAD is important because it is within this environment that the solid model resides. In this project AutoCAD was chosen because it was available and because it fulfils the basic requirements for shading and solid

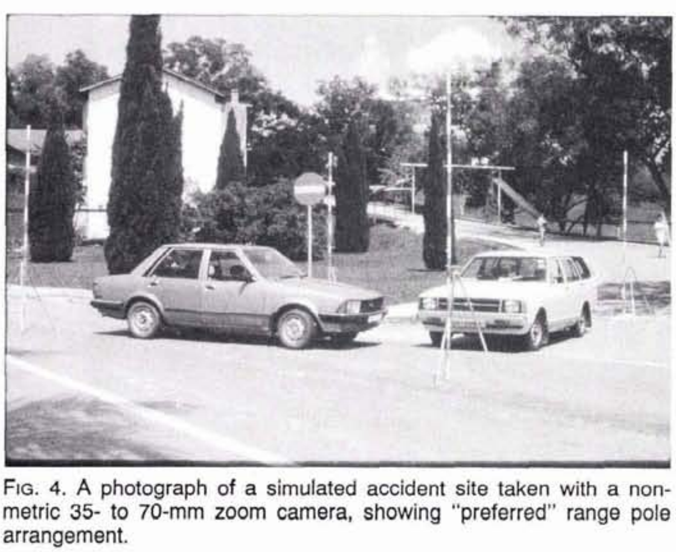

FIG. 4. A photograph of a simulated accident site taken with a non-metric 35- to 70-mm zoom camera, showing "preferred" range pole arrangement.

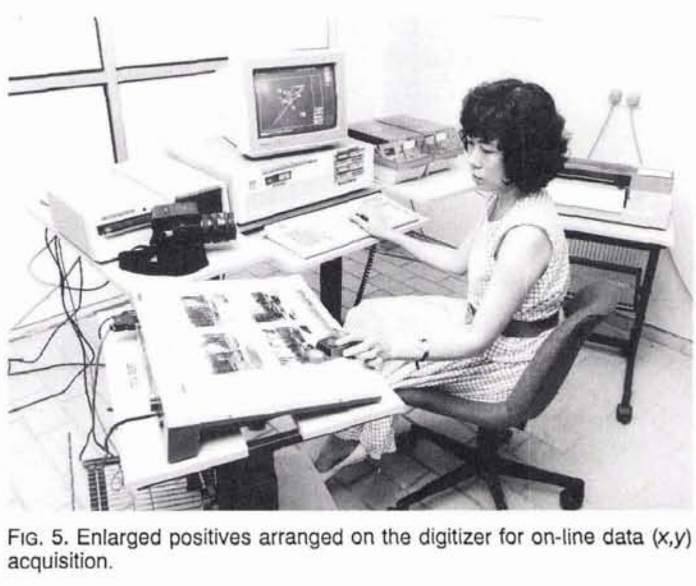

FIG. 5. Enlarged positives arranged on the digitizer for on-line data (x,y) acquisition.

TABLE 1. RESULTS OF CONTROL POINT COORDINATES USING (A) 35-MM NEGATIVES WITH WILD AVIOLYT BC-1 ANALYTICAL PLOTTER, AND (B) 3 INCH BY 5 INCH ENLARGED POSITIVES WITH DIGITIZER PAD.

	Control Points			Transformed Coordinates (BC2)			Transformed Coordinates (MYPAD)		
Point No	X	Y	Z	X	Y	Z	X	Y	Z
101	−18643.55	6132.01	23.596	−18643.54	6132.02	23.581	−18643.52	6132.52	23.58
102	−18643.55	6132.01	24.596	−18643.56	6132.00	24.609	−18643.54	6132.012	24.61
103	−18643.55	6132.01	25.596	−18643.55	6132.01	25.589	−18643.56	6132.001	25.60
104	−18643.55	6132.01	26.596	−18643.58	6131.99	26.595	−18643.61	6131.959	26.59
201	−18639.40	6138.08	24.557	−18639.40	6138.08	24.561	−18639.39	6138.087	24.58
202	−18639.40	6138.08	25.557	−18639.39	6138.08	25.559	−18639.40	6138.067	25.56
203	−18639.40	6138.08	26.557	−18639.39	6138.07	26.554	−18639.37	6138.082	26.54
301	−18647.09	6141.37	23.535	−18647.09	6141.36	23.525	−18647.15	6141.346	23.51
302	−18647.09	6141.37	24.535	−18647.08	6141.37	24.546	−18647.05	6141.372	24.55
303	−18647.09	6141.37	25.535	−18647.10	6141.37	25.531	−18647.13	6141.362	25.53
304	−18647.09	6141.37	26.535	−18647.11	6141.37	26.527	−18647.08	6141.377	26.53
401	−18646.51	6136.22	24.459	−18646.52	6136.22	24.467	−18646.50	6136.233	24.48
402	−18646.51	6136.22	25.459	−18646.50	6136.23	25.462	−18646.49	6136.234	25.46
403	−18646.51	6136.22	26.459	−18646.47	6136.24	26.462	−18646.48	6136.237	26.46
				V_x	V_y	V_z	V_x	V_y	V_z
				−0.010	−0.009	0.015	−0.030	−0.026	0.012
				0.010	0.008	−0.013	−0.010	−0.002	−0.012
				0.000	−0.001	0.007	0.010	0.009	−0.001
				0.030	0.024	0.001	0.060	0.051	0.004
				0.003	−0.005	−0.004	−0.007	−0.010	−0.023
				−0.007	−0.002	−0.002	0-.003	0.010	−0.001
				−0.007	0.003	0.003	−0.027	−0.005	0.013
				−0.003	0.007	0.010	0.057	0.021	0.027
				−0.013	−0.001	−0.011	−0.043	−0.005	−0.016
				0.007	−0.001	0.004	0.037	0.005	0.002
				0.017	−0.002	0.008	−0.013	−0.010	0.005
				0.007	0.004	−0.008	−0.013	−0.011	−0.019
				−0.013	−0.007	−0.003	−0.023	−0.012	−0.005
				−0.043	−0.018	−0.003	−0.033	−0.015	0.004
				σx	σy	σz	σx	σy	σz
				0.017	0.010	0.008	0.033	0.019	0.014

modeling. However, its adoption is in no way an endorsement of the product. Other equally powerful microCAD systems would do the same job. In this context, a similar development to PMCAD II can be found in the DAT/EM system which marries analog photogrammetry with AutoCAD (Rogers and Bennett, 1988).

The post-processor suite is PMCAD's visualization tool. It is here that the component entities of the solid model are put together. The post-processor suite guides the user into building up the solid model through a series of simple and unambiguous instructions. Because the feature coding post-processor suite is done interactively outside AutoCAD, there is no need for the user to have prior knowledge of AutoCAD.

VISUALIZATION

At the end of the dialog session, the post-processor file formats an ASCII coded file for the generation of a three-dimensional visualization model for AutoCAD and AutoShade, and add-on module of AutoCAD that performs shading. This specially formatted file is then imported into AutoCAD for automatic drafting and display. Figure 6 shows an example of a wire frame diagram of the simulated traffic accident scene created from PMCAD within AutoCAD. Figure 7 shows a shaded rendering of the same accident scene using AutoShade. Using the known site conditions generated from the DLT suite, the post-processor suite will select suitable "camera" positions and "lighting" conditions to render a realistic shading of the traffic accident scene (Appendix).

A series of such scenes can be joined together to create a "motion picture" using AutoFlix, and add-on module for animation. Unlike a true motion picture which does not maintain true geometric perspectives, a photogrammetrically generated CAD motion picture maintains geometric fidelity in that the user is always able to query the dimensions of the projected object. The user can view and query the three-dimensional models in various positions. All coordinates (X,Y,Z) are displayed in real world object space coordinates.

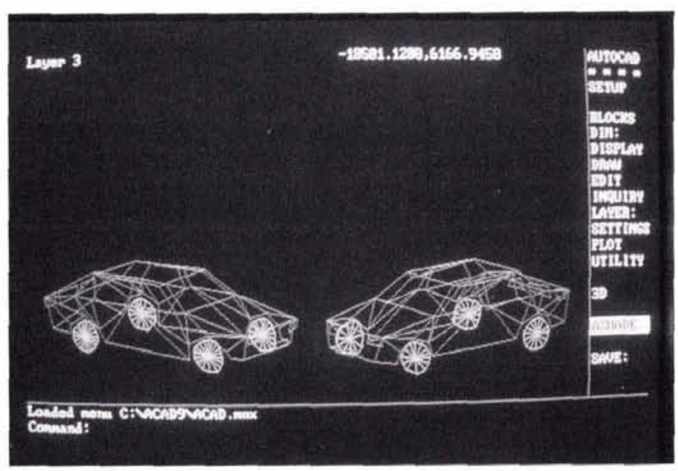

FIG. 6. Wire-framed diagram generated by PMCAD II of the simulated accident scene.

CONCLUSION

PMCAD II offers one inexpensive solution for realizing the fuller potential of photogrammetry for non-topographic, low accuracy

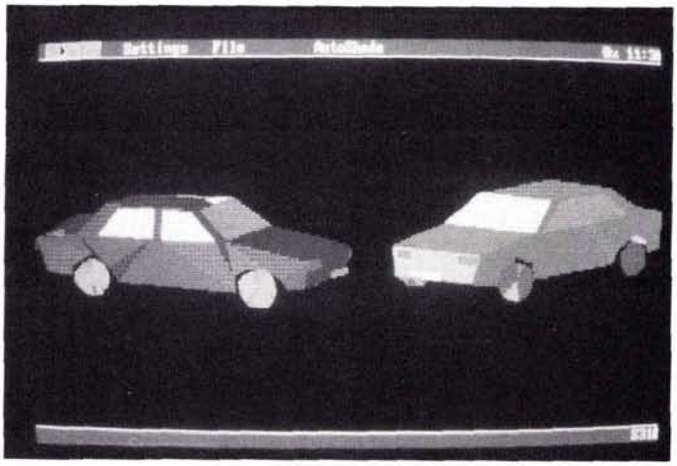

FIG. 7. Shaded rendering of Figure 6.

work of which traffic accident mapping is one. By successfully integrating desktop photogrammetry with microCAD, PMCAD II demonstrates how photogrammetry can be used as a data acquisition tool for visualization of traffic accident scenes.

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APPENDIX
CALCULATION OF CAMERA, LIGHT, AND SCENE LOCATIONS

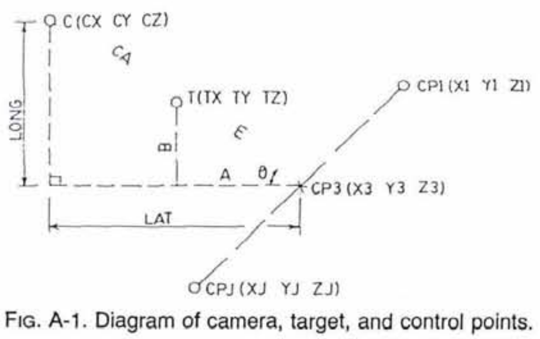

FIG. A-1. Diagram of camera, target, and control points.

Notations: CPI & CPJ = Control Points

T = Target Point

C = Camera Location

CA = Camera Distance From Target Point

CP3 = Equidistance Point Between Two Control Points

Coordinates of Equidistance Points, CP3 are

$$X3 = 0.5\ [XI + XJ]$$

$$Y3 = 0.05\ [YI + YJ]$$

$$Z3 = 0.5\ [ZI + ZJ]$$

Distance from Target Point to CP3:

$$E = SQR\ [(TX - X3)^2 + TY - Y3)^2]$$

Distance of camera to CP3:

$$R = E + CA$$

Angle THETA,

$$\theta = ATN\ [ABS\ (B/A)]$$

where

$$A = TX - X3$$
$$B = TY - Y3$$

Camera Coordinates, (CX, CY, CZ):

$$LAT = R\ COS\ \theta$$

$$LONG = R\ SIN\ \theta$$

$$CX = X3 + LAT$$

$$CY = Y3 + LONG$$

$$CZ = Z3$$

Light Coordinates, (LX, LY, LZ):

$$LX = CX + 2.5$$
$$LY = CY - 2.5$$
$$LZ = CZ + 1.0$$

Scene Clapper Coordinates (SX, SY):

$$SX = LX$$
$$SY = LY + 3$$