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Analysis and Documentation of Roadway Incident Using Software and Photogrammetric Techniques

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Authors

Su, Ray J.
Chan, Ching-Yao

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Analysis and Documentation of Roadway Incident Using Software and Photogrammetric Techniques

Ray J. Su
Ching-Yao Chan

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Executive Summary

This report is a deliverable of a project, TR0002, sponsored by the California Office of Traffic Safety, contracted through California Department of Transportation, and conducted by California PATH.

Roadway incidents, besides their direct impacts of property damage, injuries and fatalities, can quickly lead to further congestion or even secondary incidents of nearby traffic. Due to the direct and indirect effects of incidents and congestion afterwards, it is important that post-incident handling proceed as quickly as they can. One primary factor in the delays of incident handling is the necessary and proper documentation of incident information for legal and technical reasons.

The prevailing method of scene measurement is often conducted by physically walking the scenes with wheel measures or similar tools. The common method and its conventional approach present several issues: time consumption, road hazard, limitations at site, and needs of photographic evidence. The objectives of this application are to resolve some, if not all, of the aforementioned issues encountered typically at accident scenes.

In this project, we investigated and developed a computer software application using photogrammetric techniques to facilitate the measurement of the aforementioned incident scenes. This software will allow the user to simply take one or a few photographs and extract all needed measurements in the convenience of the office, solving the shortcomings of the conventional method. Jointly used with other field tools deployed by CHP or Caltrans, this application aims at alleviating the burdens of on-site measurements and expediting the process of evidence gathering. Ultimately, the goal is to reduce the impacts of incidents on roadways thus leading to reduced congestion, smooth traffic flows, and enhanced public safety.

From this exploratory project, we have developed a software application that improves upon a current method of roadway incident documentation. This improved method is advantageous since it is a non-contact method, allowing the incident scene to be undisturbed and also allowing difficult or almost impossible-to-measure scenes to be measured effortlessly. Also, the photographs serve as a permanent record allowing future measurements to be made. Finally, the amount time this method saves during each incident is important to quickly restore roadway conditions and thus help resume traffic flow.

1.0 Introduction

In roadway incidents, the law enforcement and operation agencies, such as California Highway Patrol and Caltrans, have needs to obtain all the necessary measurements so that dimensions and parameters of the scene can be properly documented. The prevailing method of measurement is often conducted by physically walking the scenes with wheel measures or similar tools. The common method and its conventional approach present several issues:

- (1) It is very time consuming to gather all measurements, thus leading to delays in post-incident handling and likely traffic congestion.

- (2) It can be potentially hazardous for personnel to carry out their duties around the scenes with traffic maneuvering around the sites and wreckage.
- (3) Poor weather or lighting conditions, and/or accessibility of certain portions of the scene at the time of documentation can further impede the completeness or accuracy of measurements.
- (4) Once vehicles are removed and scenes are cleaned, there are rare opportunities to confirm or re-measure missing measurements. Therefore accident scene documentation are often supplemented by photographs.

The goal of this project is to investigate and deploy a suitable application for facilitating the measurements at the sites of roadway incidents. The objectives are to resolve some, if not all, of the aforementioned issues encountered typically at accident scenes.

A method of measurement can be approached by Photogrammetry. Photogrammetry as defined by the American Society for Photogrammetry and Remote Sensing (ASPRS), in the Mapping Sciences, *“is the art, science, and technology of obtaining reliable information about physical objects and the environment through the processes of recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant energy and other phenomena”*. Or more simply put, photogrammetry is the technique of measure 2-dimensional and 3-dimensional objects from photographs using physics, geometry and mathematics.

During this project, we investigated and developed a computer software application using photogrammetric techniques to facilitate the measurement of the aforementioned incident scenes. This software will allow the user to simply take one or a few photographs and extract all needed measurements in the convenience of the office, solving the shortcomings of the conventional method. Jointly used with other field tools deployed by CHP or Caltrans, this application aims at alleviating the burdens of on-site measurements and expediting the process of evidence gathering. Ultimately, the goal is to reduce the impacts of incidents on roadways thus leading to reduced congestion, smooth traffic flows, and enhanced public safety.

2.0 Basics of the Photogrammetry Application

A quick overview of the application will be given this section to show generally how the software can help extract information from photographs.

This software application was developed on the Java programming language platform. [1] The particular advantage of this platform is its motto of “write once, run anywhere”. It can be run on any operating system without future changes and maintenance. Furthermore, not only can it be deployed as a desktop application on any platform, but if necessary, it can be deployed onto any web page as a Java Applet or as a Java Webstart Application.

To use this application, a photograph taken from the incident scene must be loaded as a digital format. Such digital formats can be obtained directly from a digital camera itself, or scanned from a physical photograph into any of the supported digital formats. Currently, the digital formats supported include:

JPEG: (Joint Photographic Experts Group) www.jpeg.org

GIF: Compuserve GIF

PNG: Portable Network Graphics

The jpeg and gif formats are the most widely used in terms of storing highly compressed lossy (jpeg) and lossless (gif) photographs. Should other formats be used, they can be easily converted to these formats with any convenient graphics program such as Windows Paint, Photoshop, or ACDSee.

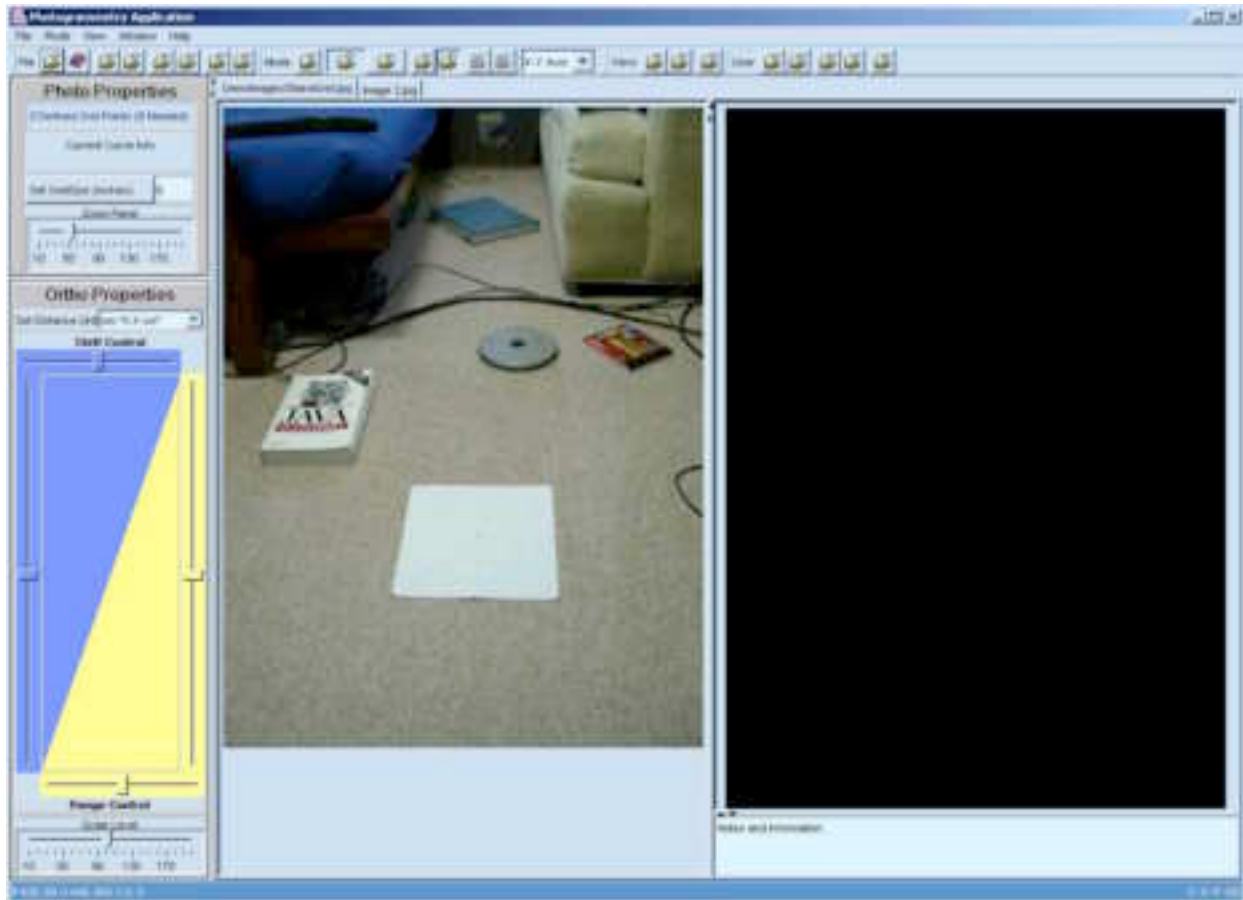


Figure 1: Basic Screenshot of application

Figure 1 shows the main display or interface for the developed application. The application itself has an intuitive and easy to use Graphical User Interface (GUI). There are two main views of the loaded image:

- Photo View: Shows the original loaded digital image. Located in the center of the GUI.
- Orthographic View: Shows the result of the photogrammetric techniques; where all the measurements are shown. Located on the right of the GUI.

In addition to the Photo View and the Orthographic View windows, the application also contains various tool bars, drop-down menus on the left side and top side of the displays. For example,

the two-color rectangular window on the left of the GUI is used for scaling and zooming adjustments of the Photo View and the Orthographic View.

In using the application, any of the interested point in the photograph can be selected or defined by directly clicking onto the photograph in the Photo View, resulting in a numbered point. The result of defining a point will produce a corresponding point in the Orthographic View. Multiple points can be defined to outline more complex objects. See Figure 2.

The projection from the Photo View to the Orthographic View yields the real-world distances between any two of the defined points, which is shown in the right-side window of GUI. To extract measurements from photographs of accident scenes, the simple technique of defining the distances between two points and the length of any straight edged object does not suffice. Usually the projection and measurement of curves are also needed. The developed application supports this required functionality.

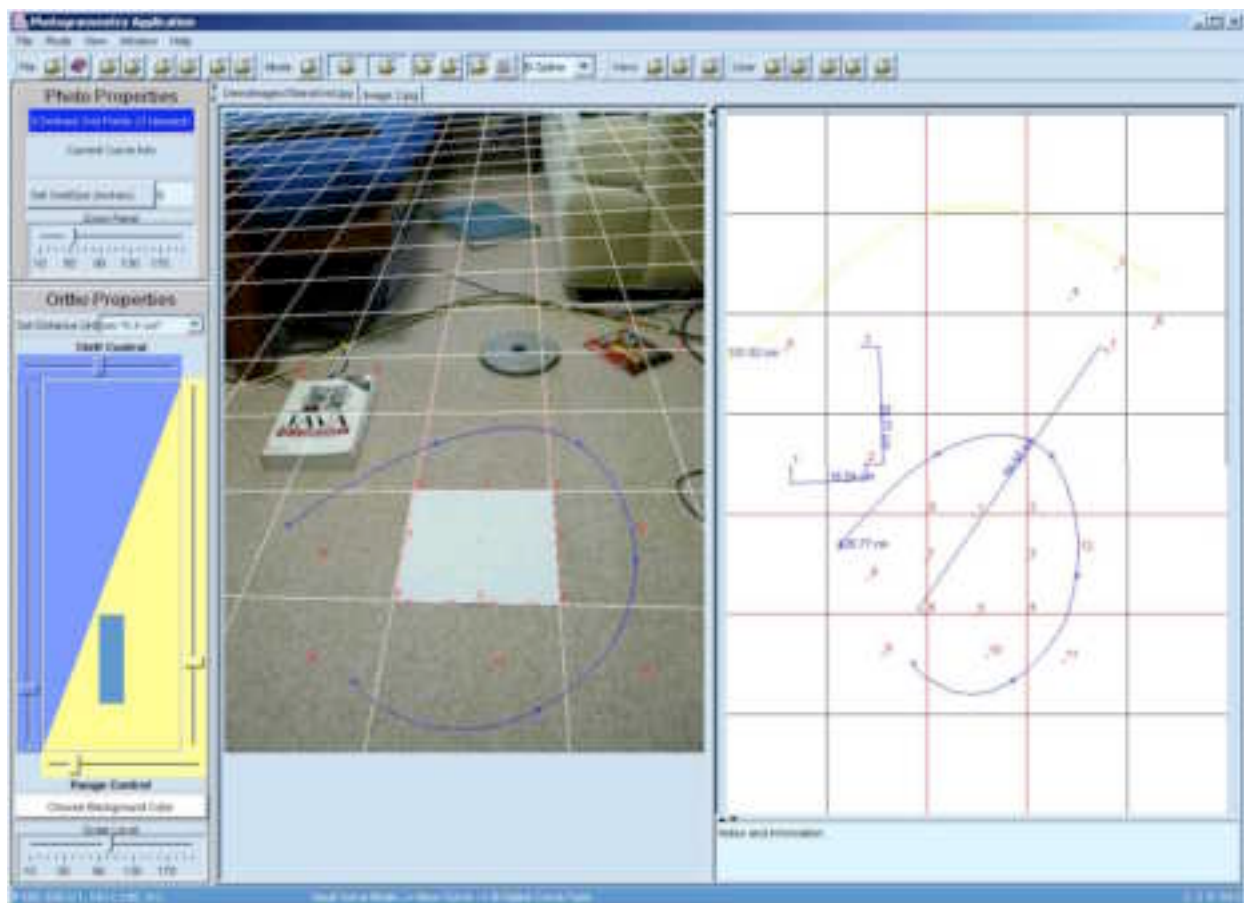


Figure 2: Screenshot with multiple defined points on the Photo View and corresponding points in the Orthographic View.

Note for Figure 2: Real World distances between any two points in the Orthographic View. Distances can be converted between Metric Units (cm) to US/English Units (ft./in.). The length of a curve in Orthographic View. Curve Types can be that of a B-Spline or two versions of a Lagrangian Polynomial Curve.

3.0 Photogrammetry Technique Explained

In the previous section we showed the basic features of an application and how they can be used to convert points on a photograph to the desired dimensions on a planar diagram. This section will provide more details on the photogrammetry techniques and the associated requirements.

The photogrammetry technique requires certain control points to be defined in the photograph. These control points are known as reference points or real-world locations. For our application we require 8 standardized control points, which can be easily provided by a “square grid” as shown in Figure 3 below.



Figure 3: Sample square grid w/ 4 corner points and 4 midpoints. Simply a piece of paper cut square with the points drawn in black.

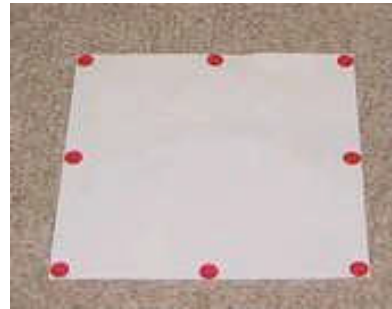


Figure 4: A variation of the square grid with larger colored control points highlighted.

A “square grid” like the above picture can easily be folded and carried in the trunk of CHP patrol officers or other users. The only requirement is that the grid be completely planar, placed in complete view in the photograph, and have all 8 of the control points unobstructed. The grid can be of any size. In a revised feature of the software application, an option was provided to mark colored dots on the grid to enhance the usability and accuracy of calculation. An exemplar marked grid is shown in Figure 4. If this additional feature of the software application is used, the color of the control points can be of any color but should be identical to each other.



Figure 5: Example of Photo View with the 8 Points defined and the infinite grid overlaid.

From these 8 defined control points, the photogrammetry software can interpolate and extend, using rules of geometry and mathematics, an infinite grid that spans the plane that the “square grid” resides on. See Figure 5. This infinite grid outlines squares that are all identical in size and dimension to the original square grid if they were tiled across the entire real-world plane. With known dimensions of the original grid as well as each grid in the infinite grid, any point located on this planar grid can be correctly located.

An alternative method of the photogrammetry technique using only 4 control points was initially explored. [2] However, this method was found to be too restricting. It required that the “square grid” be placed in the scene such that it is orthogonal to the view of the photograph – a requirement that can be difficult to follow, considering all probable limitations at accident scenes.

4.0 Accuracy of the Photogrammetry Technique

A major concern of the photogrammetry technique employed in the software is the precision of definition of the 8 control points. These 8 control points need to be entered manually by way of user mouse clicks. Incorrect placement of these 8 control points can lead to an incorrectly generated infinite grid. An example of an incorrect infinite grid resulting from incorrect placement of the control points is depicted in Figure 6.



Figure 6: Example of an incorrectly placed control point and its skewed infinite grid.

It should be noted that slight deviations from the true control points and the user defined control points will result in an infinite grid with magnified errors farther away from the original “square grid”. Thus, it is evident that the correct placement of the control points is imperative to the accuracy of the photogrammetry software.

Two features were added to the software to ensure this accuracy.

4.1 Feature #1: Zoom Window.

The user is able to box out a sub-region of the photograph that contains the “square grid” and zoom-in/enlarge that sub-image. This enlarged image allows the user to select the control points with greater ease and accuracy. See Figure 7. Once the 8 control points are defined in the Zoom Window, they are automatically defined in the Photo View as well.



Figure 7: The Zoom Window containing the enlarged "square grid". The last figure shows the Zoom Window with the 8 control points.

4.2 Feature #2: Dot Detection Window

This feature eliminates almost all user interaction needed to define the 8 control points. Using the same windows as the Zoom Windows described above, the user is only required to right click on one of the 8 control points. From that one sample point, the software takes the color information of that specific pixel and tries to find the 8 control points that match that color. This feature therefore requires that the 8 control points be of one uniform color and ideally the same shade of that color. See Figure 4 for an illustration of the grid with marked color dots. Specific technical explanations of this implementation follow.

This feature is implemented by use of image processing and a color matching technique involving the HSB Color Model. The sub-image is processed by scanning row by row, pixel by pixel. Each pixel contains RGB (Red, Green, Blue Color Model) color information that is inherent in the digital image format. The RGB information can be converted into HSB (Hue, Saturation, Brightness Color Model) color information. We are particularly interested in this color model since we can match the color directly by the Hue value. The Hue values will vary slightly, so we search for pixel values that are within plus/minus some small threshold (Hthresh). Since the "square grid" will be taken in outdoor environments, we can expect that sunlight, shadows and other factors can alter the Saturation and Brightness color variables. Therefore, these thresholds (Sthresh, Bthresh) will be larger than that of Hthresh. Through trial and error experimentation, the following thresholds were found to be effective in finding the 8 control points in various environmental conditions.

Hue	(Range:0-360)	Hthresh: 5
Saturation	(Range:0-100)	Sthresh: 10
Brightness	(Range:0-100)	Bthresh: 100

These threshold values are not optimal, and further experimentation may reveal better values for certain environmental settings.

It is worth noting that while boxing out the sub-image for use by the Dot Detector Window, colors that are very similar to the colors of the control points should be avoided so that the software does not process the incorrect dots.

This solution is for experimentation purposes only and is not intended to be robust enough to handle ALL situations. In the odd chance that the auto detection does not work, human intervention will be needed in the form of the Zoom Window feature.

4.3 Dot Detection by means of Edge Detection

An attempt was made at automatic detection of the 8 control points by means of edge detection algorithm. This method was found to be an inappropriate solution since it required too much image processing. Initial edge detection on the image reveals the edges of the square and thus the four corners of the square, but it does not reveal the other 4 control points needed, as shown in Figure 8.

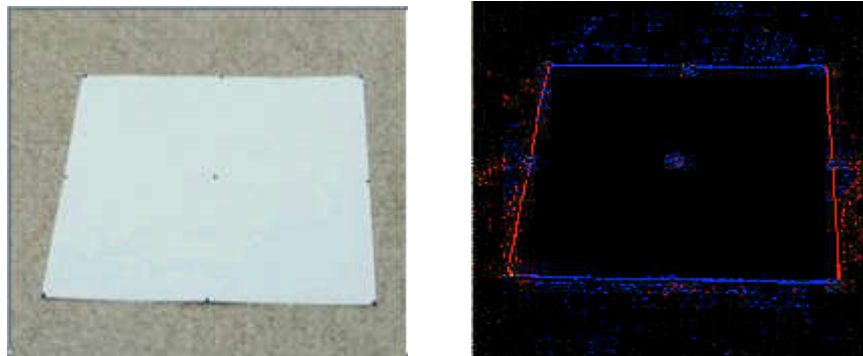


Figure 8: Edge detection reveals four edges of the "square grid". The 4 corner control points can be found after some image processing, but the 4 midpoint control points are not.

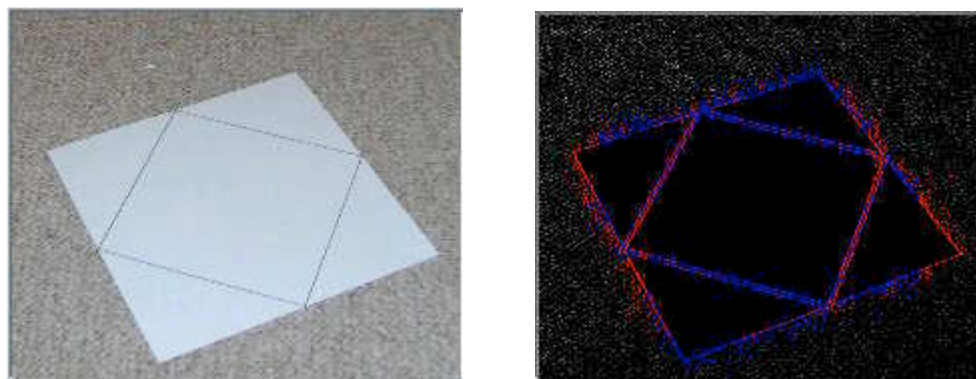


Figure 9: A modified "square grid" revealing all 8 control points. Note the noise of extraneous edge points throughout the edge-detected image. Such noise would have to be filtered out.

A modified “square grid” could be used with edge detection that would reveal all 8 required control points, but processing of those edges would be difficult. Furthermore, results of edge detection showed too much noise and thus would require substantial filtering to have successful processing of the 8 control points. See Figure 9.

This solution of automatic control point detection was opted out for the Dot Detection Method. Further study of this method could be pursued and potentially might reveal an automatic control point detector that could be more robust than the Dot Detection method.

5.0 Curve Drawing Algorithms

In implementing the curve feature of the software, different curve fitting algorithms were explored. The implementation should allow the user to define a curve on the Photo View by clicking a series of points (>2) and also dynamically modifying the curve by adding more points.

The first algorithm explored was an exact fitting polynomial equation: the Lagrangian Interpolating polynomial algorithm. [3] This algorithm will attempt to fit the curve through every point in the curve definition. It successfully handled most simple curves. However, it failed in modeling curves whose definition requires too many definition points or requires definition points that are too close together. This is because this curve is modeled by a polynomial equation that grows in order proportional to the number of defining points. Two examples of a successfully modeled and an unsuccessfully modeled curve are given in Figure 10 and Figure 11.



Figure 10: A simple curve modeled successfully by the Lagrangian Curve.

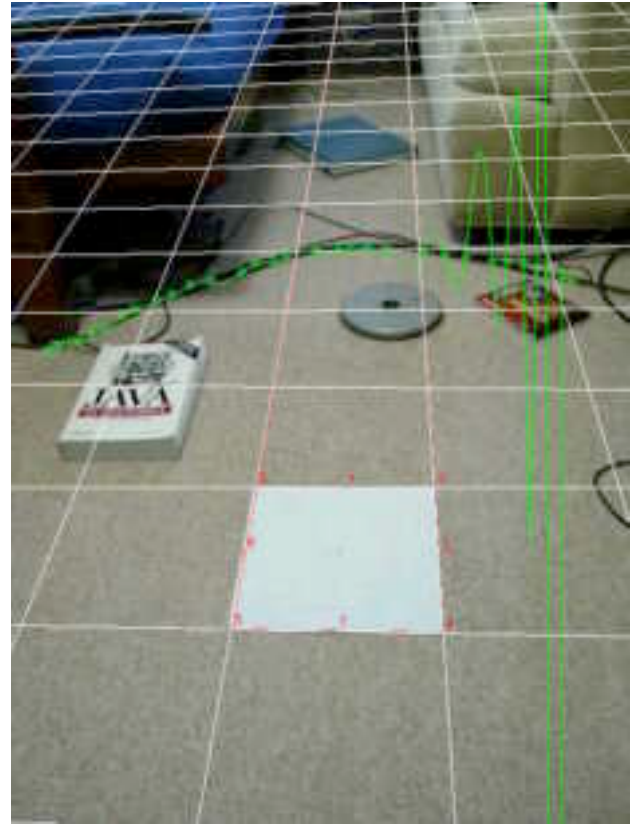


Figure 11: The same curve modeled incorrectly when too many defining points are used.

A limitation of this algorithm is that it cannot correctly model a curve similar to one that is vertically sinusoidal. To overcome this shortcoming, we implemented a variation of the Lagrangian Curve algorithm with the X and Y axis swapped.

Another limitation of this algorithm is that it can only model a curve where for every 'x' value one and only one 'y' value can be mapped. Because of this limitation, more complex curves that loop back cannot be drawn. Even a simple curve shaped like the letter 'C' cannot be modeled. Thus another solution is needed.

We found this solution in a B-Spline algorithm. [4, 5] As taken from the SDSC: A National Laboratory for Computational Science and Engineering, *"the RATIONAL B-SPLINE is an equation that permits the modeling of free-form curves between two endpoints as a function of a set of intermediate points whose values influence the shape of the curve."* This curve-drawing algorithm offers a solution that can handle all of the limitations of the Lagrangian curve algorithm. It is so robust, that it can handle most any curve imaginable for our application. Show in Figure 12 are several examples of B-Spline curves generated by the photogrammetry software.

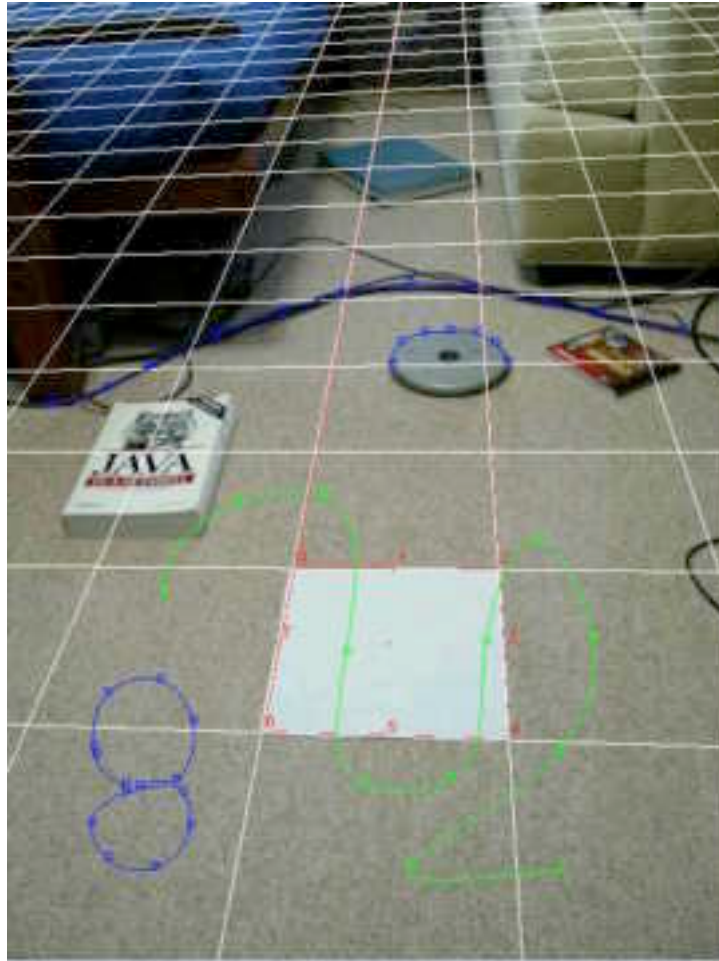


Figure 12: B-Spline curve samples.

6.0 Deployment and Testing

With the ability to map any point, line, or curve defined in the planar surface of the “square grid” into real world dimensions in the Orthographic View, this software is functional and can be deployed for testing and usage. Since this software was developed in the Java programming platform [6-12], it can be versatile enough to be packaged into any existing Java applications as a package of classes, or any other programming platform with the appropriate wrapper classes.

Currently, it can be deployed as a small, executable, desktop application file approximately 200-300 kilobytes in size. The Java Runtime Environment (Java JRE) must be installed for it to be used. Such software may already be installed in most systems and can be freely downloaded from <http://java.sun.com/downloads/>.

In addition, the software can also be deployed on the web as a Java applet or Java Webstart application. See <http://java.sun.com/products/javawebstart/> using any Java enabled browser. This web version of the software should be identical to the desktop application. One point to note, however, is the security feature of Java Applets and Webstart applications. Java web applications require that they operate in a so-called “sandbox” to prevent untrusted applications from running malicious code or reading/writing any files on the client’s computer, among other

security features. Our application will need to read digital image files from the client's computer and will have to bypass this security feature. Before any Java applet or Webstart application that will perform any actions not allowed in the "sandbox" can be run on a client's computer, a dialog box will warn of the potential dangers of the application. The user can simply choose to accept the application so then it can run outside of the Java "sandbox".

To try the Java applet version of the Photogrammetry software, go here:

<http://www.nyza.net/gromit/photogrammetry/applet/>

To try the Java Webstart version of the Photogrammetry software, go here;

<http://www.nyza.net/gromit/photogrammetry/webstart/>

A variety of tests were conducted to verify the functionality and accuracy of the photogrammetry software. Photographs were taken of scenes with objects of known dimensions and measured with the software. These objects included, books, rulers, and cords all measured at varying distances from the "square grid". The results of these simple test showed that the software was sufficiently accurate for the type of field application required by the CHP and Caltrans. Most measurements were accurate to within 90%-99% of the true dimensions. An example of such measurement by the photogrammetry software is depicted in Figure 13. More screenshots can be seen in Appendix B.

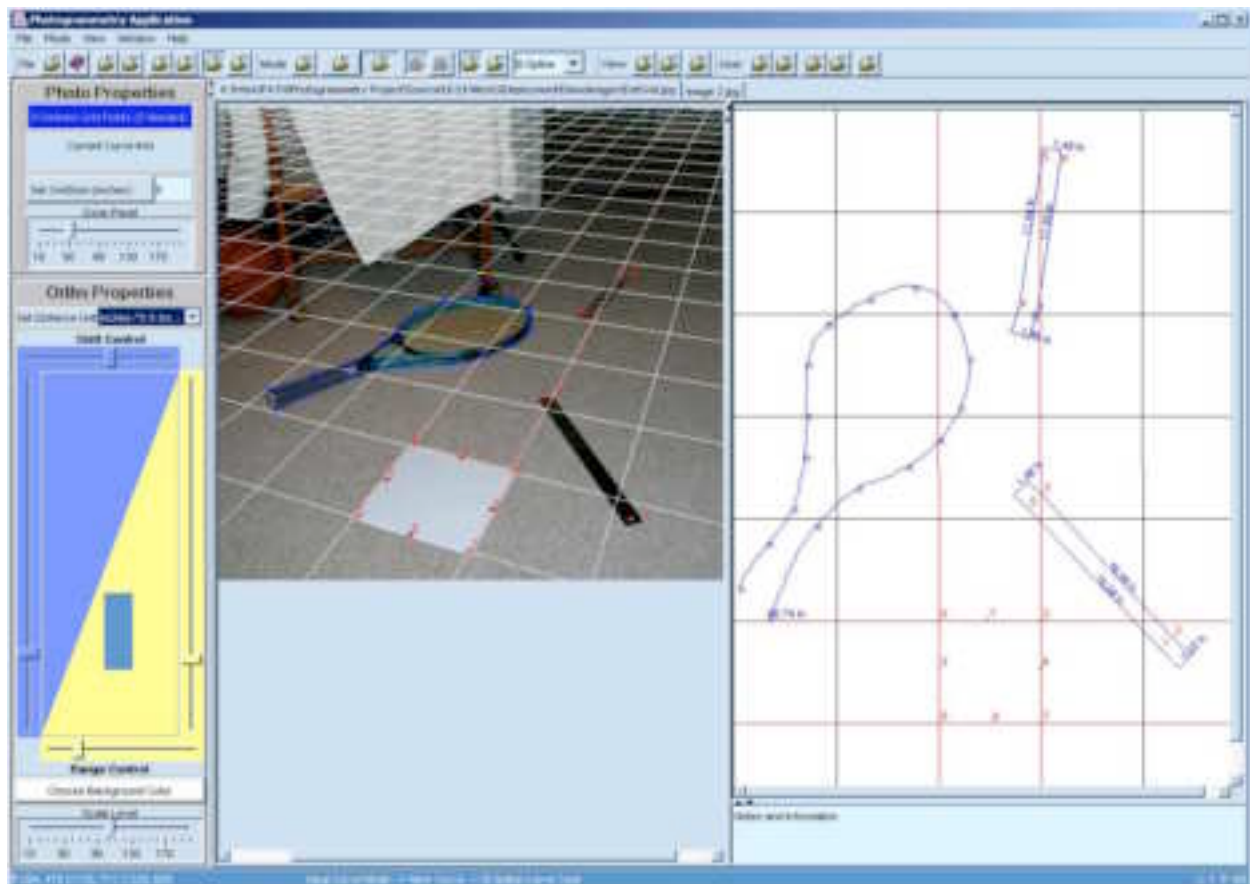


Figure 13: Testing of Photogrammetry Software with photographs of sample scenes.

In the above screenshot, two rulers with sizes of 15 inches and 12 inches were placed randomly. A tennis racquet was also placed in the scene to emulate curves that may be on the roadway. Using the software, the results of measurement are as follows:

	Real Dimensions	Measured Dimensions (averaged)
Ruler #1	12" x 1.5"	11.75" x 1.43"
Ruler #2	15" x 1.25"	15.06" x 1.34"
Racquet Perimeter	~64in	66.74"

From these results we can see that the photogrammetry software is providing decent accuracy that is required for field data retrieval.

7.0 Future Directions

In its current state, this software application is functional and can accomplish the essentials in documenting roadway incidents, but it is not complete by any means. Future developments may be pursued in these areas:

- Improved automatic detection of the “square grid”/8 control points in the area of image processing and edge detection.
- Ability to load multiple photographs, and to save work on these photographs as a project.
- An improved photogrammetry technique using predominately mathematical principles instead of geometrical principles.

From this exploratory project, we have developed a software application that improves upon a current method of roadway incident documentation. This improved method is advantageous since it is a non-contact method, allowing the incident scene to be undisturbed and also allowing difficult or almost impossible-to-measure scenes to be measured effortlessly. Also, the photographs serve as a permanent record allowing future measurements to be made. Finally, the amount time this method saves during each incident is important to quickly restore roadway conditions and thus help resume traffic flows. Together with other software, such as mobile platform of incident documentation [13], this type of application can be a powerful tool for incident handling.

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Appendices

- A. images of pages from reference
- B. powerpoint file

face. One is placed in the foreground of the picture, as a square grid would be. The other two are placed some distance, possibly 10 ft (3 m) beyond the first (Exhibit 30). No measurements are required to locate any of the disks. All three must appear in the photo, but precise camera location and aim is not necessary.

To locate other spots shown on the flat surface in the photo, proceed as follows:

1. Draw a line tangent to (touching) the left sides of the near disk and the more distant disk on the left.
2. Draw another line tangent to the right sides of the same disks. Where these two lines cross is a point on the vanishing line (Exhibit 30).
3. Draw two more lines tangent to the right and left sides of the near disk and the far disk to the right. These two lines also cross at a point on the vanishing line.
4. Draw a straight line connecting the two points that have been located on the vanishing line. This line is the vanishing line for the flat surface in the photo.
5. Draw a straight line through the center of the near disk and at right angles to the vanishing line. Where this line crosses the vanishing line is the vanishing point, P, in Exhibits 30 and 31.

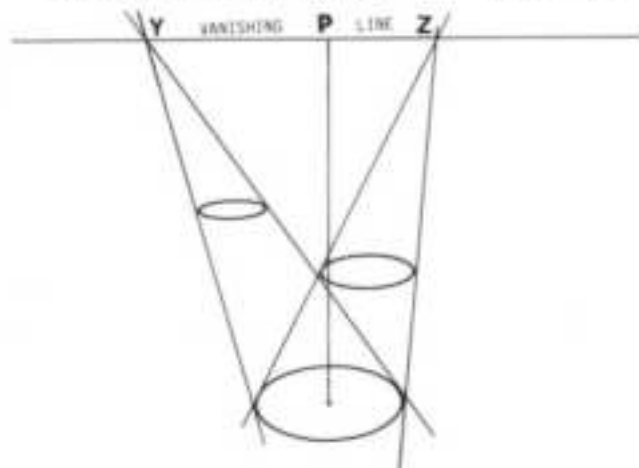


Exhibit 30. Three identical circular disks can be used instead of a square grid. Spaced some distance apart, they assist in locating the vanishing point more precisely.

This establishes the foundation and scale for a square grid which is completed as follows:

1. From the vanishing point, draw two straight lines each tangent to one side of the near (larger) disk (Exhibit 31).
2. Parallel to the vanishing line, draw two lines, one tangent to the near side and one tangent to the far side of the elliptical picture of the large disk in the photo.
3. Label the points in the photo where these four lines cross each other A, B, C, and D as in Exhibit 31.
4. Extend the nearer parallel line to the left of C and to the right of D a distance equal to CD to locate points E and F on the base line of the square grid.
5. Draw straight lines from E and F to the vanishing point.

You now have a grid system exactly like that of a portable grid with a single vanishing point in Exhibit 29. You can go on from there to locate corresponding spots on the map as already explained for the square grid.

There are a number of advantages of the circular disk scales in a perspective grid system:

1. Reduced error in locating the vanishing line. That results in greater precision in establishing grid lines.

2. Reduced error in locating the grid lines, especially those at great distances from the grid.
3. Neither measurements nor special care are needed in placing the disks.

There are disadvantages:

1. There are three devices to carry and place instead of one.
2. They require greater free road space.
3. They are more subject to interference from traffic flow because some of the disks must be placed well into the traffic lane.
4. Three disks are more trouble in strong wind and in wet weather.

7. MATHEMATICAL METHODS

For those who are handier or more comfortable with measuring scales and a computer than with technical drawing, there are numerical methods of transferring perspective locations on a photo of a flat surface to an orthogonal map. The idea is to relate the cartesian coordinates (x and y axes at right angles) of any spot on a flat surface shown in the photo to corresponding cartesian coordinates on the map. This relationship is established by equations.

With Square Grid or Circular Disk Shown in the Photo*

Coordinates in the photo may be

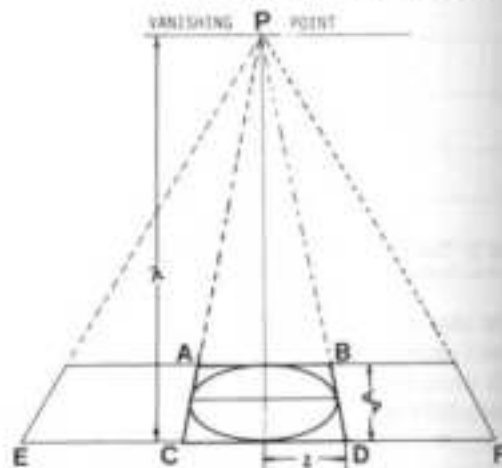


Exhibit 31. The nearer of the three disks is the basis for drawing a square perspective grid which can be treated like any square perspective grid.

designated x_p and y_p , while the map coordinates are designated as x_m and y_m .

Photo units of measurement may be any for which you have a suitable scale available. Ordinarily, this would be millimeters but it might be fiftieths of an inch on a U.S.A. engineering scale.

Map units of measurements are whatever your drawing calls for, feet or meters to scale.

The x_p axis in the photo is usually the base line of the square grid. The origin (starting place for measuring, $x_p = 0$) is the left edge of the square grid on the base line (C in Exhibit 31). Any x_p coordinate measured to the left from this line is negative. Put a minus sign, $-$, in front of it.

The y_p axis in the photo starts at the same origin (C in Exhibit 31). It is at right angles to the x_p axis and not parallel to the left margin of the grid in the photo.

To begin with, draw the x_m axis and the y_m axis for the map without attempting to locate them exactly on the map of the road layout drawn from measurements of the site. You can fit them into your map later.

The two grid equations relating photo coordinates to corresponding map coordinates are

$$x_m = \frac{d_m x_p}{l} \left[\frac{h}{h - y_p} \right]$$

and

$$y_m = c \left[\frac{h}{h - y_p} - 1 \right]$$

In these two equations,

$$c = d_m \left[\frac{h}{d_p} - 1 \right]$$

This is actually the horizontal map distance between the base line of the square grid and the position of the camera lens when the picture was taken.

d_m = diameter of the circular scale disk or edge length of the square scale grid in map units, usually feet or meters.

d_p = minor (shorter) axis of the elliptical image of the disk in the photo or the distance be-

tween parallel sides of the trapezoidal image of the square grid in the photo, d_p in Exhibit 31, measured in photo units.

h = distance in photo units between the vanishing point and the base line of the grid (x_p axis) in the photo (h in Exhibit 31).

l = half the side of the square grid measured in photo units along the base line in the photo (l in Exhibit 31).

All of these five quantities are constant for any particular combination of photo and map.

In practice, you will find it handy to have a transparent sheet with cross section lines on it in millimeters or other suitable photo units. Align this sheet with the x_p and y_p axes on the photo. With this you can easily obtain values for coordinates of spots in the photo.

Use these values in the equations to compute map coordinates for the corresponding photo spots. Repeat this for all spots, such as ends of tire marks, that you want to locate on your after-accident situation map.

Without Disk or Grid Showing in the Photo

Even if no natural or portable perspective grid is included in a photograph, it may still be possible to locate on a map some things shown in the picture.

Requirements. This photogrammetry is possible under the following conditions:

1. The spots to be located must be on a flat surface, the map plane.
2. Four or more calibrating spots which can be located on the map by measurements must clearly show in the photo.
3. No more than two calibrating spots may be in the same straight line.

The exact location of each of the four calibration spots in the photo and on the map must be systematically described. This is done by meas-

uring the two coordinates of each spot in the photo and the two coordinates of the same spot on the map.

The coordinates of a point on a flat surface (plane) are its distances, x and y , from two lines which cross at right angles. The place where the lines cross is the origin of the coordinates. The distance east, so to speak, is designated as the x coordinate; then the distance north is the y coordinate. On the photo, the coordinates of a spot are designated as x_p and y_p ; on the map the coordinates of the same spot are x_m and y_m . An example will illustrate how the coordinates are measured. Exhibit 32 is a photo of an accident scene. No measurements were made to locate the two tire marks and final positions of two vehicles, but they do show in this picture. Four calibration points are selected. These are spots that can be located at the site after all signs of the accident are gone. For instance, the point marked B in the photo is on the paving at the beginning of a curve in the curb. The other three control points are labelled A, C, and D.

The lower edge of the photo is chosen as the reference line, the x_p axis. The left edge of the photo is chosen as the y_p axis. The origin or starting point for measurements is where these two axes cross. Other pairs of axes could be used. For example, the x_p axis could be a line through C and D. Then the y_p axis, at right angles to the x_p axis, could pass through point A. That would simplify some of the calculation. From the scales along these axes, the coordinates of calibration point B in the photo are: $x_p = + 106$ and $y_p = + 107$ mm.

Coordinates of the other three calibration points, A, C, and D are measured in the same way.

Exhibit 33 is a map of the accident location to a scale of 1 in. = 10 ft. The four calibration points are shown on it. Their positions have been located at the site by careful measurements. On this map, for computation purposes, the x_m axis has been drawn 10 ft away from and par-

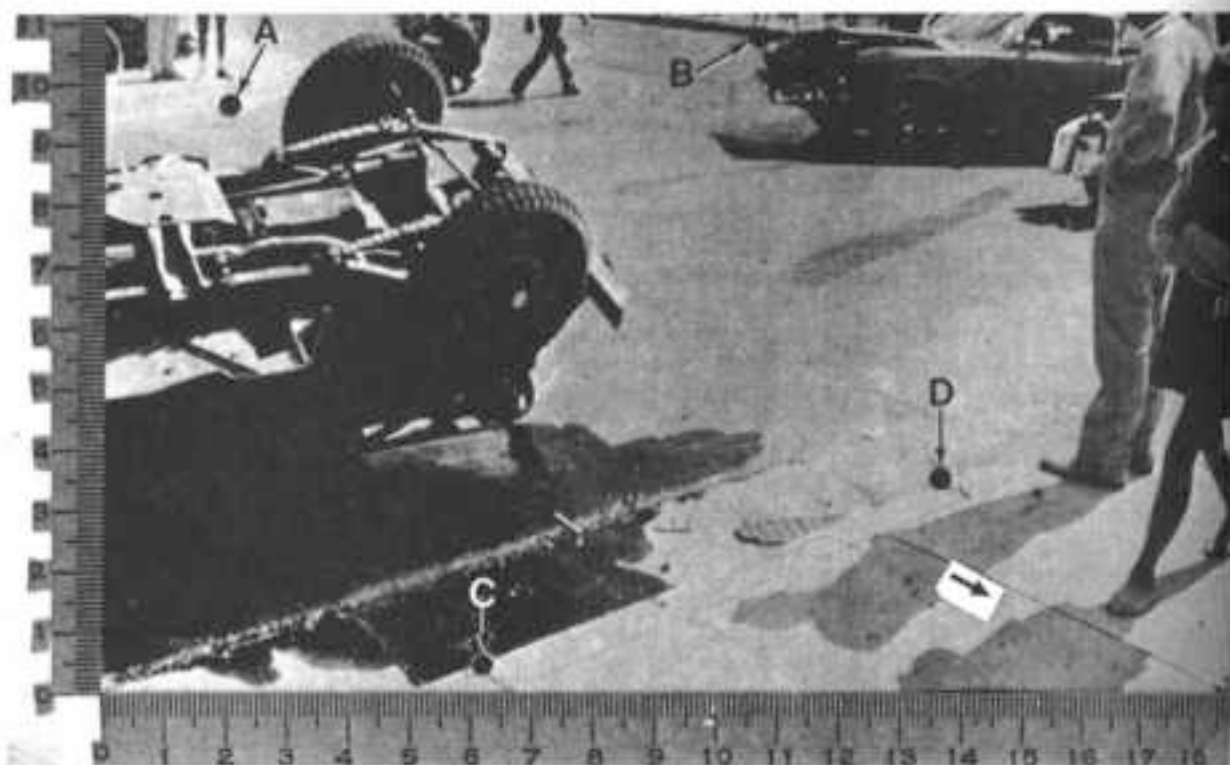


Exhibit 32. With no natural or portable grid available, positions in a photo may be transferred to a map mathematically. The spots must be on a flat surface in the photo. They are located by coordinates. The measured position of at least four spots (A, B, C, and D) on this surface must be visible in the photo and no more than two of them may be in the same straight line.

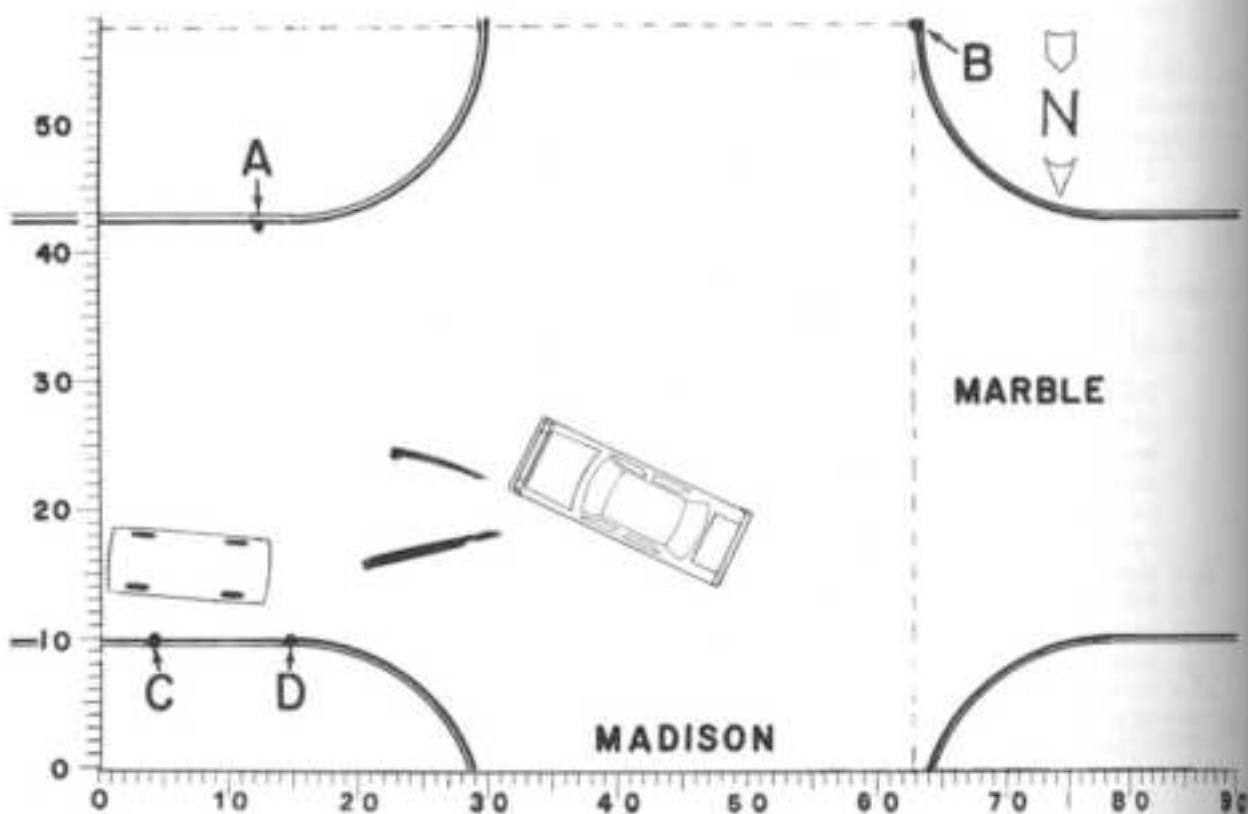


Exhibit 33. The position of the four calibrating spots (A, B, C, and D) must be located by coordinates on the map.

allel to the north edge of Marble Street. The Y_m axis, at right angles to the X_m axis, is 30 ft to scale east of the east edge of Madison Street.

Coordinates of any point on the map are described in the same way as those on the photo. For example, the coordinates of calibration point B on the map are $X_m = 63.0$ and $Y_m = 57.3$ ft to scale.

To relate calibration points on the photo to corresponding points on the map, two photo measurements and two map measurements for each point are required, four measurements per point. To describe all four points, a total of sixteen measurements are required.

Coordinates for Exhibit 32, the photo and for Exhibit 33, the map, are shown in Exhibit 34 as an illustration.

Calibration constants. Two equations, one for each map coordinate, give the map location of any point located by photo coordinates in the flat surface shown in the picture. These equations are:¹

$$X_m = \frac{C_1 + C_2 x_p + C_3 y_p}{C_4 x_p + C_5 y_p + 1}$$

and

$$Y_m = \frac{C_6 + C_7 x_p + C_8 y_p}{C_4 x_p + C_5 y_p + 1}$$

In these equations are eight calibration constants, $C_1, C_2, C_3, C_4, C_5, C_6, C_7$, and C_8 . For each particular combination of photo and map, values for each of these eight constants must be established. To do this write the two equations for each calibration point. For example, use the coordinates for point B, measured in the example

above. The map coordinates for point B are $X_m = +63.0$ and $Y_m = +57.3$. These, with the corresponding photo coordinates, x_p and y_p give two calibration equations:

$$63.0 = \frac{C_1 + 106C_2 + 107C_3}{106C_4 + 107C_5 + 1}$$

and

$$57.3 = \frac{C_6 + 106C_7 + 107C_8}{106C_4 + 107C_5 + 1}$$

Doing the same for the other three calibration points gives a total of eight equations with eight unknown constants from C_1 to C_8 . These simultaneous equations can be solved to obtain numerical values for the eight constants. How this may be done is explained in algebra textbooks. It is a tedious task beyond the scope of this topic, but there are computer programs for solving the simultaneous equations.²

Map locations. With these eight constants for a particular combination of photograph and map, any point on the surface shown in the photo can be translated into map coordinates for that point. The same basic equations are used with measured photo coordinates and the numerical value for each of the calibrating constants. In this way the map location of two or more points on each of the two tire marks visible in the photo are established. So also for the final positions of the vehicles as shown in Exhibit 32.

Practical considerations. Often accident locations, especially in rural areas, provide no sufficiently peculiar characteristics to serve as calibration points. Then this technique is not applicable.

A photograph is usually first examined for possible calibration points. A visit to the site may be necessary to determine whether or not the points still exist. If four photographed points can be identified and measured at the site, the projective relationship can be established and the location of any number of other points or objects shown in the photograph can then be determined.

Appropriate calibration points include any features, markings, or characteristics of the pavement surface or its edges that have not been altered or moved between the time the photograph was taken and the measurements are made. These would include manhole covers, expansion joints, pavement cracks, pavement gouges, pavement patches, drain inlets, traffic detectors, the corner of channelizing islands, pavement legends, and pavement striping.

When photos are taken at the scene to avoid making measurements, results depend on the availability of calibration points. Such points may be established when photos are made by locating four targets in the scene at measured locations. Of course this takes time and trouble which the procedure is supposed to avoid. Indeed the easiest way to be sure of quick and adequate calibration points at the scene would be to use a square perspective grid placed on the road. The corners of this grid then provide pre-measured calibration points.

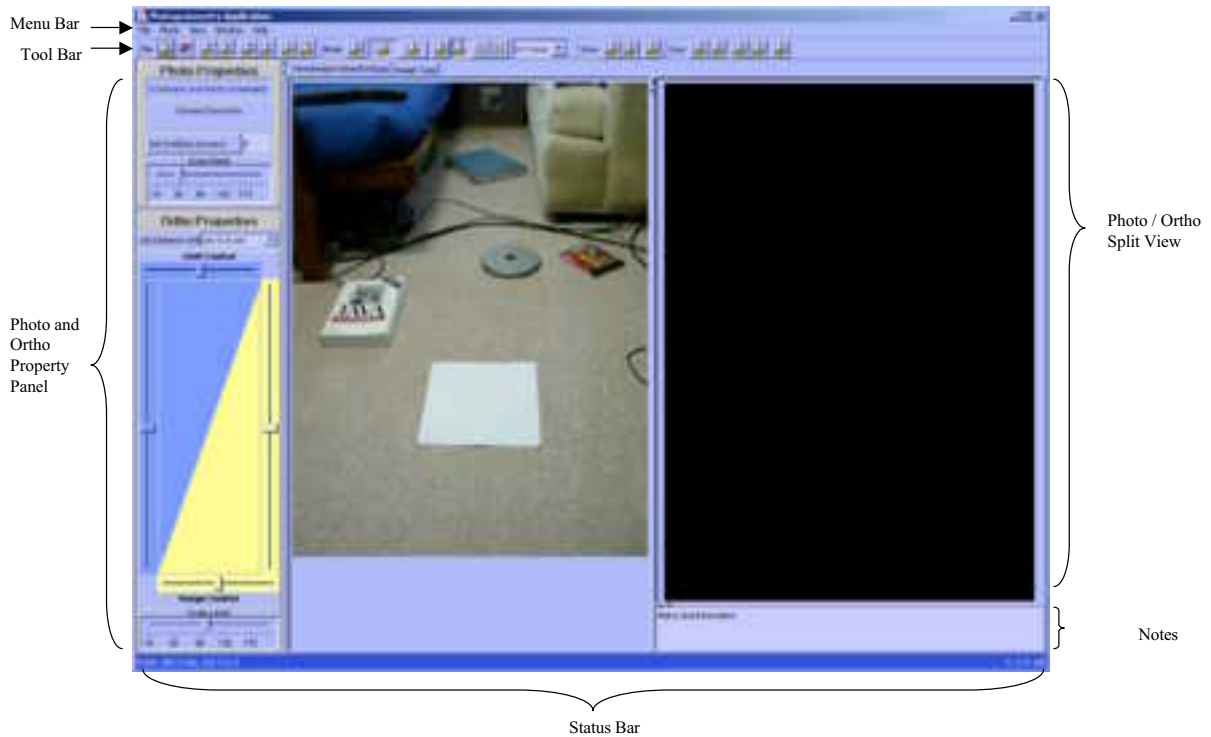
In this way, consequently, any four sided perspective grid would provide a photo which could produce map locations by the mathematical methods described here.

Mathematical methods would not be practical if the calculations had to be made by hand. Computers make a difference. Several computer programs are available for solving simultaneous equations. Computer programs have been developed to perform all of the mathematics involved, thus quickly giving map coordinates corresponding to photo coordinates for any spot.

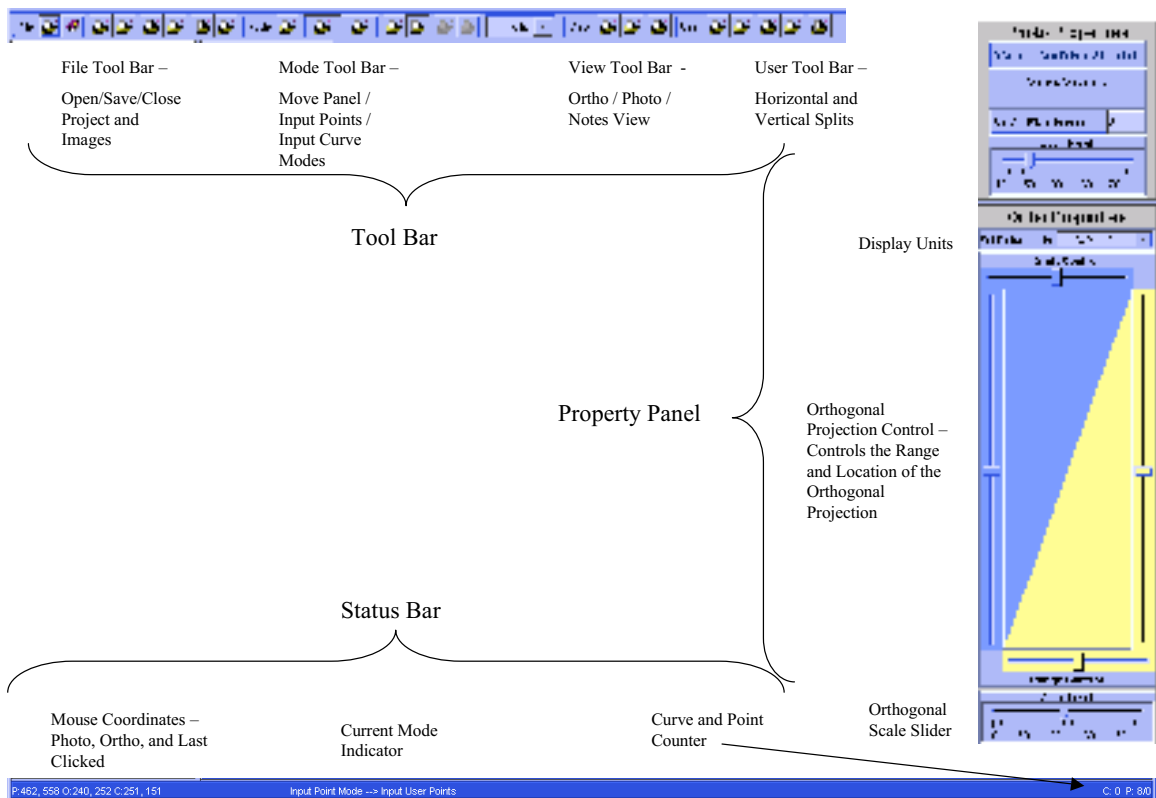
CALIBRATION SPOTS	MAP, ft		PHOTO, mm	
	X_m	Y_m	x_p	y_p
A	+12.3	+42.7	+20	+97
B	+63.0	+57.3	+106	+107
C	+4.0	+10.0	+62	+4
D	+14.6	+10.0	+136	+36

Exhibit 34. Map and photo coordinates for the four calibration spots shown as an example in Exhibits 32 and 33.

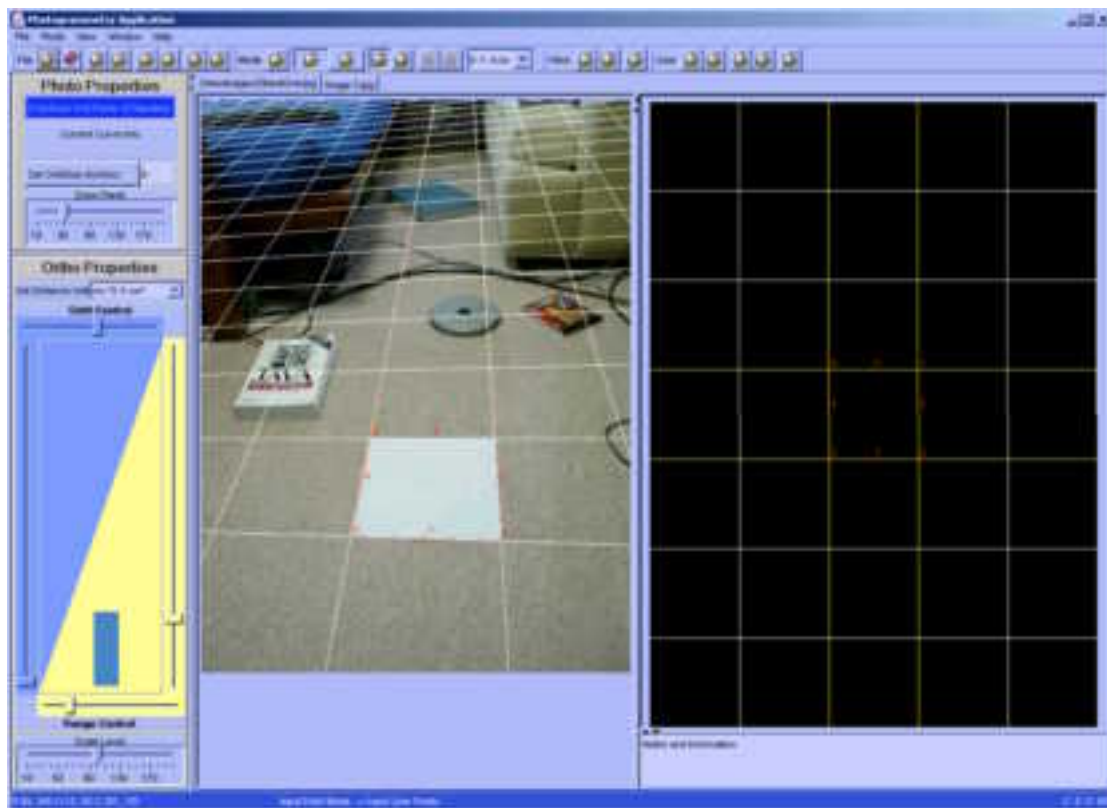
Features



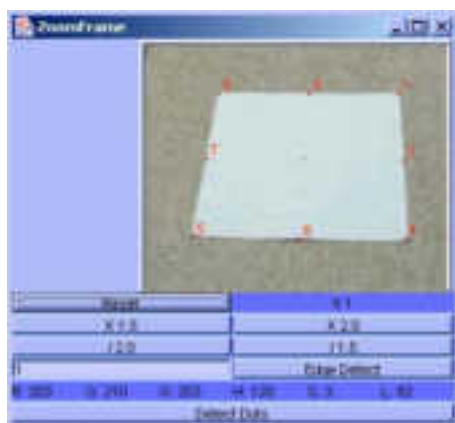
Feature Details



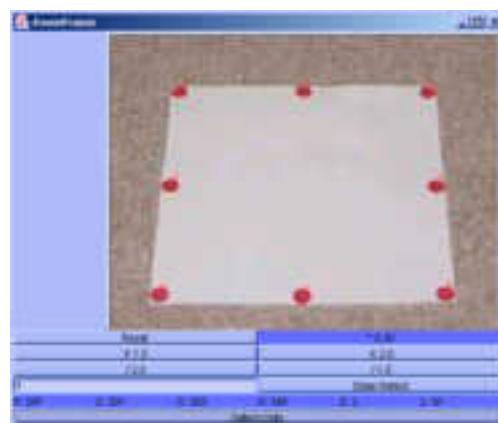
Grid Manually Inputted



Zoom Feature

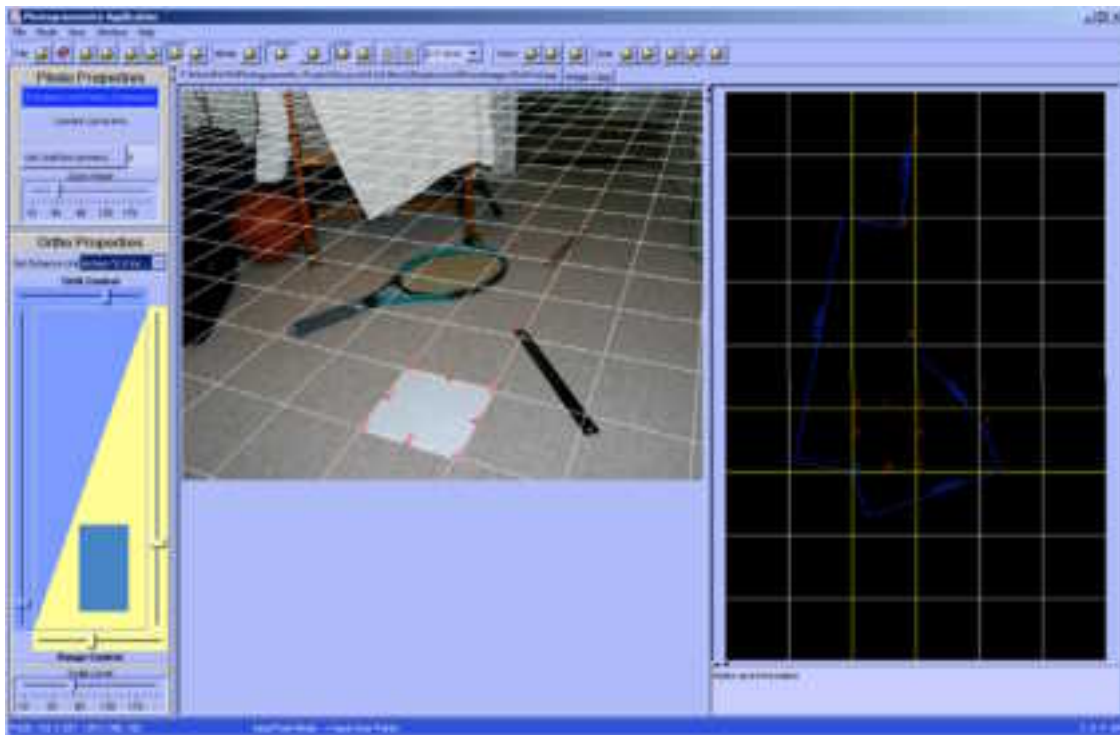


Allows for Zooming in of Square Grid and Facilitates the Selection of 8 Grid Points



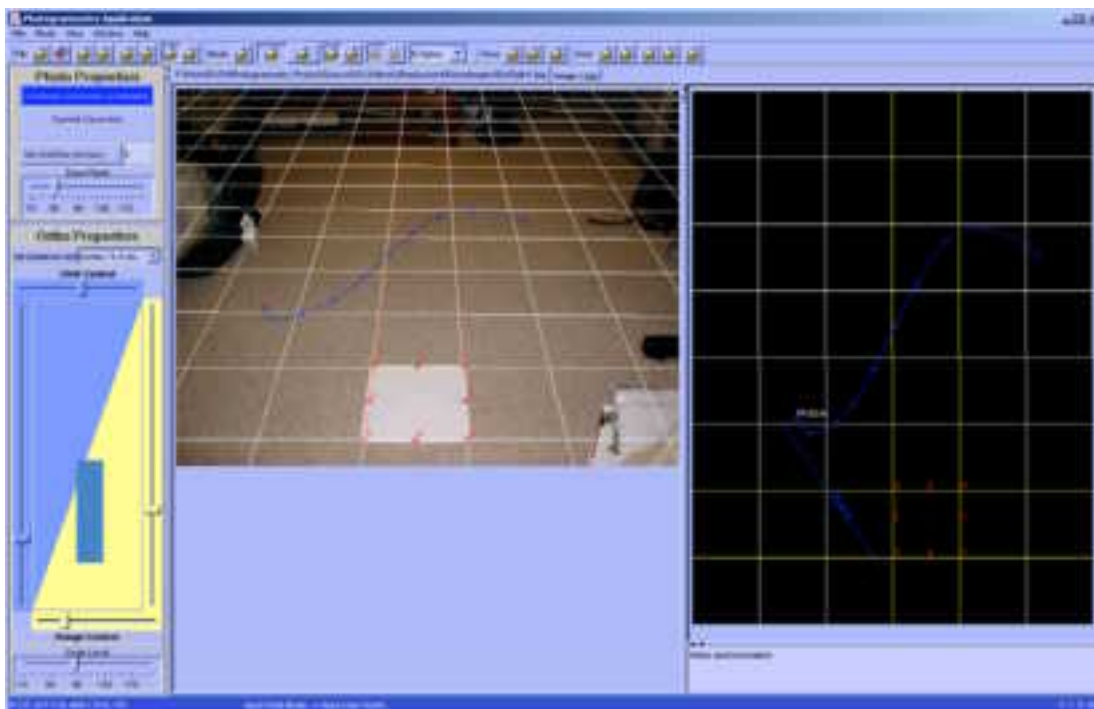
Automatic 8 Grid Point Detection –
Right Clicking on one sample Dot will locate at 8 Grid Points automatically

Application – Point Distances



A 15 inch ruler was measure to be 14.58”(0-1) A 12 inch ruler was measured to be 11.28” (2-3)
The distances between both rulers and a predefined point (5) was also found.

Application – Curve Distances



A 45 inch curve was found to be 44.92” using a B-Spline Algorithm. A Lagrangian Curve Algorithm is also implemented.

Summary

