# Highway Dimensions from Photolog

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Abstract: Photolog pictures are taken from a vehicle as it moves along a highway with the camera directed straight ahead. A method for determining the highway station, and the offset and elevation of objects visible on two photos, is developed. Also, bridge clearance, degree of curve, and skew distances are determined. A digitizer and computer aid in rapidly gathering these data. Accuracies are on the order of ±0.5 feet in elevation and offset and ±3 percent in station distance.

## DESCRIPTION OF PHOTOLOG

Photolog pictures are taken with a 35-mm camera through the windshield of a van type vehicle as it moves along the highway at about 50 mph. The interval between exposures is 52.8 feet as determined by a counter on the vehicle's wheel. The camera is mounted 5.61-feet above the pavement and directed nearly straight ahead. Figure 1 is an example printed in black and white. The actual photos are in color.

The top portion of each photo contains data from an inertial device which is similar to aircraft navigation systems. The most important items of inertial data, for the purpose of this study, are the transverse slope and the grade.

Most highway departments are now using photolog as a pictorial record of highway performance. Photos are typically taken at intervals of about two years in order to monitor pavement performance, signing, maintenance effectiveness, encroachments, etc. The photos are kept on reels as diapositive transparencies. They are viewed using a backscreen projector at about 10:1 enlargement.

## APPLICABILITY OF ESTABLISHED METHODS

Most of the methods of photogrammetry are based on stereo pairs of photographs. However, photolog pictures do not come in stereo pairs because there is no significant distance between photos in a direction perpendicular to the camera axis. A study by Pryor and Miller (1973) demonstrated that the position of an object on photolog can be determined under limited conditions. The study is useful for the development of three-dimensional equations which provide the basis for further study.

Several analytical solutions have been developed (Merchant, 1983; Miller, 1984) in which the orientation parameters are determined from photo coordinates of points identified in consecutive photos. The approach has usually been to adapt theory and computer software developed for aerial photogrammetry to the special conditions of photolog. The non-photogrammetric camera and the distortion caused by the windshield of the vehicle present problems which require special processing. However, the biggest drawback to analytical solutions is the practical difficulty of identifying the required five points in two photos.

The author has developed an analytical solution, using cylindrical coordinates, which reduces the required number of points to four, but even this is usually impractical to implement. The problem is solved in aerial photogrammetry by viewing stereo pairs in a point transfer device and marking identical points on both photos. This method was tried with photolog film with fair results. Although stereo vision is not possible, common viewing can be accommodated for a portion of the pair at a time by changing the magnifications. The difficulty is that the film must be cut to accommodate the point transfer device and then spliced to accommodate the projector.

Until a device is developed to alleviate the practical limitations of an analytical solution, we will concentrate on other methods. The remainder of this report describes a method which we developed and have found practical in highway applications.

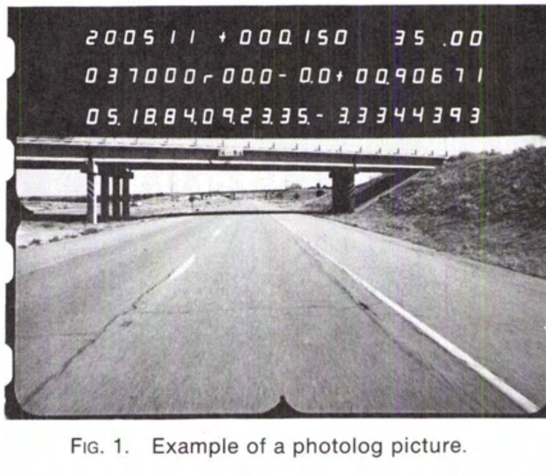


Fig. 1. Example of a photolog picture.



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## PRINCIPALS OF PHOTOLOG GEOMETRY

For geometric purposes, a photolog picture is a perspective view along the highway. Objects decrease in size in direct proportion to their distances from the camera. The problem is to convert these vanishing dimensions into true dimensions, or more accurately stated, to convert a perspective view into an isometric view.

We can start with an ideal case where the camera moves along a straight highway without any side or vertical movement. The plan view in Figure 2 shows a line connecting two camera positions and extending to infinity. An object to the side or this line is shown on the two photos at positions 1 and 2.

The distance $f_w$ (working focal length) is a function of the camera focal length, the projection enlargement, and various distortions. It is best determined by measuring a known dimension of known distance from the camera on a projected photo. Using similar triangles,

$$f_w = \frac{Zd}{D} \tag{1}$$

where Z is the distance of an object of known dimension, D, from the camera lens and d is the measured image of the object on the projected photo. By making a number of such measurements at various distances from the camera, an average $f_w$ was determined for this particular camera and projector as 11.78 in. A finite element camera calibration is being done which should improve accuracy.

Having determined $f_w$ and having identified an object on two photos, a three-dimensional coordinate system is established to locate the position of the object. Figure 2 is a plan view showing the X coordinate as the horizontal distance from line 0-0. The Z coordinate is the distance along line 0-0 from the front camera position. The Y coordinate is the vertical distance from line 0-0 and is not seen in plan view. We will use small $x$ and $y$ to denote coordinates measured on photos and capital X and Y to denote real world coordinates about the vanishing point. Using similar triangles in the front photo,

$$\frac{x_f}{X} = \frac{f_w}{Z} .$$

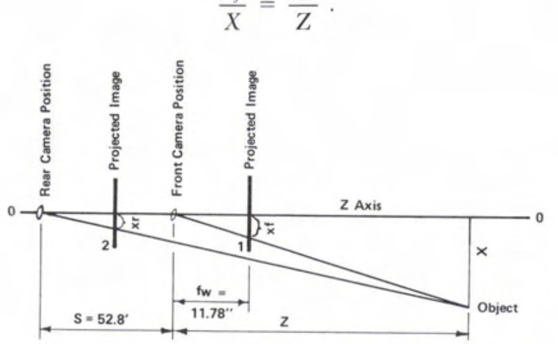


FIG. 2. Plan view of two camera positions—ideal case.

By similar triangles in the rear photo,

$$\frac{x_r}{X} = \frac{f_w}{Z + S} .$$

The only unknowns are X and Z, which are determinable as follows:

$$Z = \frac{x_r S}{x_f - x_r} \tag{2}$$

$$X = \frac{x_f Z}{f_w} \tag{3}$$

Similarly, Y can be found as follows:

$$Y = \frac{y_f Z}{f_w} \tag{4}$$

These formulas are similar to those developed by Pryor and Miller (1973) for the case where distances such as $x_f$ and $x_r$ can actually be measured on the photos. However, if only a single point is identifiable, then it is necessary to establish the location of line 0-0 on both photos. Under the ideal conditions assumed thus far, this could be done by establishing the geometric center of both photos and measuring $x_f$, $x_r$, $y_f$, and $y_r$ from it. However, in practice the camera is not directed straight ahead and the vehicle moves from side to side as well as up and down. A method of compensating for these movements is needed.

If the Z axis is parallel to the road, then the point on the photo which is the Z axis will be the vanishing point of a straight highway. This is because all parallel lines vanish at the same point. The vanishing point on the rear photo is not as important as the location of the vanishing point on the front photo transferred to the rear photo. The situation is shown in Figure 3.

The vanishing point on the front photo is located by projecting the edges of the pavement as seen in the foreground of the photo to their point of intersection. The centerline stripe and one edge of pavement could also be used. If the road is straight for 200 feet or more in the foreground, then the vanishing point for the straight portion is established by intersecting the edge lines. If the road is curved in the foreground, then another method is used which is explained later.

Transferring the vanishing point so established to

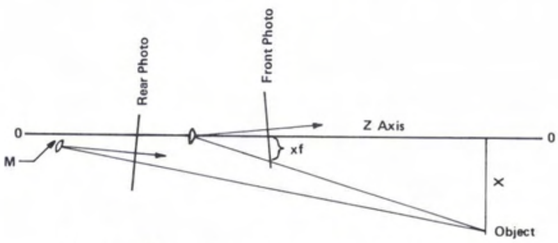


FIG. 3. Plan view of exaggerated real case.

the rear photo involves an intermediate step. Because the vanishing point is not identifiable, it is necessary to select a point on the front photo which is in the far distance and which can be identified on the rear photo. The horizontal and vertical distances from the distant point to the vanishing point are measured on the front photo. Then the transferred vanishing point is set on the rear photo by measuring the same horizontal and vertical distances from the distant point. This method is only accurate if the distant point is far enough away to be unaffected in its image position by the distance between the two photos.

Once the Z axis is established on both photos, it is a simple matter to measure $x_f$, $x_r$, $y_f$, and $y_r$ for as many points as are desired. Because accuracy increases with the size of the measured distances from the vanishing point, both $x$ and $y$ are used to find the diagonal distance. Equation 2 is then used to find Z which is the relative station distance. The distance ($M$) which the vehicle moves in the $X$ direction between photos will be considered later.

The offset (distance from centerline) is found from Equation 3. However, it must be corrected for the horizontal distance from the camera to the road centerline at the front camera position (see Figure 4).

The point on the $x$ axis which is directly below the vanishing point (Point A) represents the camera position in the photo. The offset distance $x_{10}$ is the difference between the $x$ intercept at centerline and $x_i$. The ratio of $x_9$ and $x_{10}$ to their true ground distances is constant; i.e.,

$$\frac{x_9}{D} = \frac{x_{10}}{OS} \qquad (5)$$

where $D$ is the pavement width and $OS$ is the offset from centerline to camera. $OS$ can be found from this equation if $D$ is known. The pavement width as measured on the photo is to the vertical distance measured to the vanishing point as the real pavement width ($D$) is to the real height of the camera ($H$). Because the measurements can be made anywhere along the pavement, we will do it at the $x$ intercept; i.e.,

$$\frac{x_9}{y_i} = \frac{D}{H} \, . \qquad (6)$$

$H$ can be measured and is 5.61 feet in our case. Knowing $D$, $OS$ can be found from Equation 5. The offset of any point from centerline can be found by: Offset $= X + OS$, where $X$ is from Equation 3.

Up to this point we have not considered movements of the vehicle other than Z movement. Figure 3 shows two kinds of movements—angular and positional. Angular movements of the camera between the two photos are compensated by the vanishing point transposition method already presented. However, positional movements in either $X$ or $Y$ are sources of error. Movements in $X$ can be detected by observing the change in slope of the right edge of pavement. If the vehicle moves to the right, the slope becomes more negative. From Equation 5,

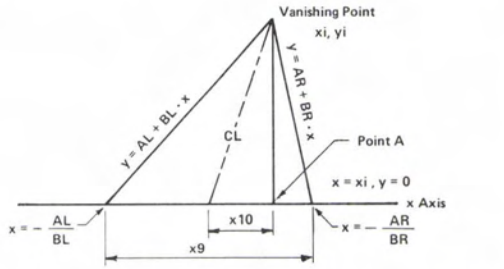


FIG. 4. Offset distance of camera and pavement width.

$$OS = \frac{D\,x_{10}}{x_9} \qquad M = \frac{D \cdot \Delta x}{x_9}$$

$$\Delta OS = M \qquad \Delta x = \frac{y_i}{\Delta B}$$

$$\Delta x_{10} = \Delta x \qquad M = \frac{D\,y_i}{x_9}\left(\frac{1}{B} - \frac{1}{BR}\right) \qquad (7)$$

$M$ = vehicle movement in $x$,
$D$ = pavement width,
$B$ = rear photo, slope of right edge, and
$BR$ = front photo, slope of right edge.

The correction to $x_r$ for $M$ is found by reference to Figure 5. The derivation is similar to that for Equations 2 and 3; i.e.,

$$Z = \frac{S\,x_r + M\,f_w}{x_f - x_r} \qquad X = \frac{x_f\,Z}{f_w}$$

By similar triangles in the corrected rear photo,

$$\frac{X}{Z + S} = \frac{x_{rc}}{f_w} \quad \text{and} \quad x_{rc} = \frac{x_f\,Z}{Z + S} \, .$$

$x_f$ and $x_r$ are used to find Z. $x_{rc}$ is computed so that the same computer subroutine can be used for straight and curved roads.

Movement of the vehicle in the $Y$ direction is not easily detected. Its effect upon the results is caused by errors in $y_r$. If $Y$ movement is 0.10 feet, $y_r$ will

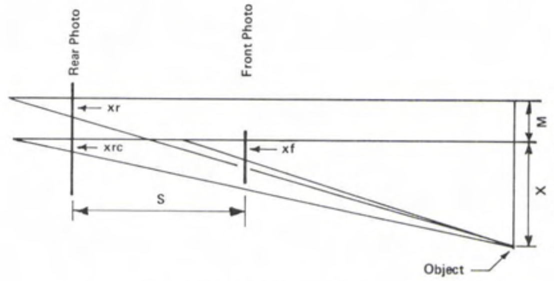


FIG. 5. Correction for vehicle movement.

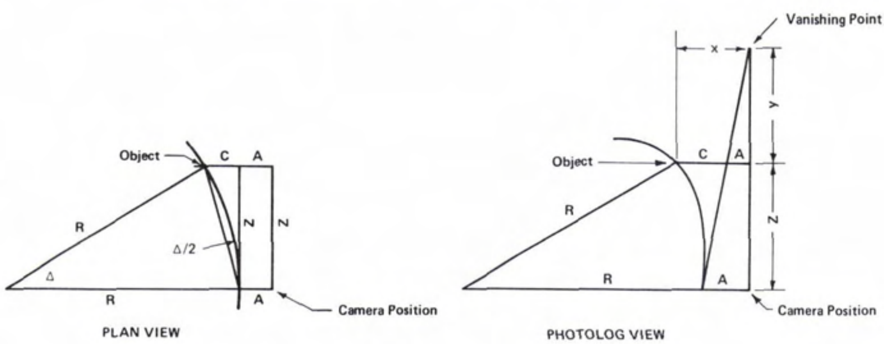


FIG. 6. Curved road.

be off by 0.01 inches, Z will be off by 0.6 feet, and $X$ by 0.2 feet. These errors are at the typical conditions of $Z = 100$ feet and $x_f = 2$ inches. We expect these to be maximum probable errors because $d_r$ is affected also by $x_r$ which has been corrected. Very bumpy roads could cause $Y$ movements of perhaps 0.5 feet which would affect Z by 3.0 feet and $X$ by 1.0 feet if $x_r$ is insignificant. No method of compensating for this error has been developed.

Having the station and offset, it remains to find the elevation which would be a direct function of $Y$ from Equation 4 if the $X$ axis were truly horizontal and the grade of the Z axis were known. The photolog inertial device described earlier computes the road grade and the transverse slope of the road and displays this data above each photo. When we multiply the grade by Z and rotate the $X$ axis by the transverse slope and by the tilt of the projected photo, then $Y$ becomes the relative elevation.

## AUTOMATION

It is necessary to use a digitizer which does not degrade the photo image as displayed on a backlighted screen. We used a sonic digitizer which determines $x$ and $y$ coordinates as functions of the time in which sound travels to linear microphones at the edges of the screen. A mouse with cross hairs is placed over the desired point. When the mouse button is pressed, a piezo-electric signal is sent to the linear microphones. There is nothing on the screen to degrade the image. Resolution is about 0.01 inch.

## CURVED ROADS

When the road is curved, the vanishing point cannot be established by intersecting the road edges as was done for straight roads. Because the camera is rigidly mounted in the vehicle, the position of the vanishing point with respect to the geometric center of each photo remains fixed. The precise vanishing point is not critical as long as the point is accurately transferred to the rear photo.

Several points along both edges of pavement are digitized. An iterative solution is programmed to find the best fit and to determine $R$ and $A$ for both edges as shown in Figure 6. Then the position of any point relative to centerline is determined.

## BRIDGE DATA

Using the methods developed so far, it is possible to determine bridge clearances, skew, width, and grade. Clearances are desired at four points under the bridge where the edges of pavement are directly below the edges of the bridge. These points are not determinable by inspection of the photos and must be found analytically.

The equations of the two edges of the bridge are determined by least-squares solutions of several points digitized along each line in both the front and rear photo. It is assumed that these are straight lines and, therefore, arched bridges are not included in this procedure. However, minimal arching can be accommodated by digitizing prints close to the clearance points and omitting points near centerline and abutments. The equations of the edges of the bridge are

$y = AN_1 + BN_1 \cdot x$ front photo, near side
$y = AF_1 + BF_1 \cdot x$ front photo, far side
$y = AN_2 + BN_2 \cdot x$ rear photo, near side
$y = AF_2 + BF_2 \cdot x$ rear photo, far side

Because many bridges are not perpendicular to the roadway underneath, it is necessary to consider the skew. It is assumed that the bridge has no curvature, reducing the Z function to

$$Z = C + FX$$

where $C$ and $F$ are constants. If $x = 0$ in the two equations for the near side of the bridge, then

$$Z = \frac{AN_2 \cdot S}{AN_1 - AN_2} = C \quad \text{(from Equation 2 using } y\text{)}.$$

If $y = 0$ in the same two equations, then

$$Z = \frac{BN_1 \cdot AN_2 \cdot S}{AN_1 \cdot BN_2 - BN_1 \cdot AN_2} \quad \text{(from Equation 2)},$$

$$X = -\frac{AN_1 \cdot Z}{BN_1 \cdot f_w} \quad \text{(from Equation 3 with } Y = 0\text{)},$$

$$F = \frac{Z - C}{X}, \text{ and}$$

$$x = \frac{X \cdot f_w}{Z} \quad \text{by rearranging Equation 3.}$$

The $X$ distances, as previously determined, are

$$X = \frac{D}{2} - OS \text{ Right } X = -\left(\frac{D}{2} + OS\right) \text{ Left}$$

where $D$ is the pavement width, and $OS$ is the camera offset from centerline. Because $Y$ is measured from the vanishing point which is 5.61 feet above the pavement, the clearance is $Y + 5.61$.

## DEGREE OF CURVE

As the vehicle moves around a curve, distant objects appear to move across consecutive photos. If an object is far into the distance, its movement is essentially a result of the curve and not of the kind of displacement discussed so far. The amount of its movement per unit of vehicle movement is proportional to the degree of curve.

$$d = \frac{100}{l}$$

where
- $d$ = degree of curve,
- $l$ = distance traveled, and
- $\Delta$ = central angle.

But $\Delta$ is a function of the movement of a distant object.

$$\text{Tan } \Delta = \frac{d}{f_w} \quad \text{If } \Delta \text{ is small}$$

$$d = 3.788 \text{ Tan}^{-1}\left(\frac{D}{23.56\, n}\right)$$

- $D$ = Amount of $x$ movement in distant objects, inches.
- $n$ = Number of photos elapsed between two $x$ readings.

The more photos which elapse between $x$ readings, the more averaging that will occur.

## ERROR ANALYSIS

The greatest difficulty in digitizing points on the photolog is the proper identification of the same point on two photos. Blur and displacement of the image as a result of distortions make proper identification difficult. It can be shown from Equations 2 and 3 that an error of 0.01 inches in digitizing $x_f$ or $x_r$ produces 0.25 feet error in $X$. This is at the typical conditions of $Z$ = 100 feet, $X$ = 26 feet, and $x_r$ = 2 inches. There are four possible sources for such an error—the vanishing point on the front photo, the transferred vanishing point on the rear photo, and the point in question on both photos. Experience shows that an accuracy of 0.01 inches in any of these points is about all that can be expected. Random errors of this magnitude will produce an expected error in $X$ of 0.5 feet. If $X$ is reduced to 10 feet and $Z$ is held at 100 feet, then $x_r$ becomes 0.77 inches. The expected error in $X$ is 1.54 feet and the error in $Z$ is 15 percent.

The error increases rapidly for points over 100 feet away from the front camera position if the measured $x$ or $y$ distance is less than about 2 inches from the vanishing point. If the diagonal distance from the vanishing point to any point is less than 2 inches and $Z$ is over 100 feet, then errors of more than one foot in $X$ and $Y$ coordinates can be expected. It is best to use photos which are as close to the objects in question as possible, especially if an object is close to the vanishing point.

Another important source of error is in the distance between photos ($S$). The counter on the vehicle's wheel which determines $S$ is in error by up to ±1.9 feet, which produces errors in $Z$ of up to ±3.6 percent. It would be a simple matter to correct this by adding more magnets to the wheel such that the vehicle moves about 0.5 feet between magnet passes.

## FIELD TESTING

In order to test the accuracy of measurements made by the procedures presented herein, a field survey was made at locations along a section of I-25 in the vicinity of Santa Fe, N.M. The tests are summarized in Table 1 by type of measurement.

TABLE 1. SUMMARY OF FIELD TESTS

| | 90% Confidence Limit | Mean Error |
|---|---|---|
| Offset from Centerline | 0.95 Feet | 0.55 Feet |
| Elevation | 0.90 Feet | 0.46 Feet |
| Bridge Clearance | 0.75 Feet | 0.54 Feet |
| Station Distance | 5% | 3.5% |
| Degree of Curve | 3% | 1.5% |

The measurements which depend on the identification of the same point or points on two photos all show similar accuracies in the field tests. Station distance accuracy is dependent on the amount of station distance. The others did not vary with any readily apparent factors. All measurements were random in their variations.

## CONCLUSION

The photolog measurement system described herein is practical for various highway design and maintenance functions. Among the practical applications are

- Preliminary design surveys to determine pavement widths, locations of various features, degree of curve, bridge clearances, etc.;
- Sign inventories to catalog locations and conditions of signs; and
- Preliminary determinations of encroachments onto rights-of-way.

If the system could be made more accurate, then it might become practical for design surveys. This could be done with a device which superimposes two photos at different magnifications for accurate point transfer. Such a device might make cross-sectioning a practicality. No such device exists, but its development should be considered. More precise camera calibration is being done, which shows promise of greater accuracy.

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