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Line-of-Sight Determination from Digitized Imagery

Digital gray shade data for points within a stereo model were correlated and the existence of lines-of-sight between those points were determined.

Abstract: *The basic notion of regarding the photograph as the primary data base is used to develop three single-model techniques for determining whether line-of-sight exists between any two points within a stereo model. Two of the techniques use digital imagery. Only one of the methods is analyzed numerically. Matching processes using correlation methods are applied to a pair of digital images to determine the line-of-sight of two points 1,200 meters apart. A microdensitometer with comparator capabilities created the digital gray shade data. The third technique, a visual one, requires that the model be set up in a stereoscopic device.*

Introduction

Whether a clear line-of-sight (LOS) exists between two points *A* and *B* often can be determined accurately enough from a contoured representation of the topography taken from a map or viewed instantaneously by optical methods. If more accuracy is required, the question of intervisibility can be resolved by a numerical determination using regularly spaced terrain elevation data. In the latter case, the elevations may be represented by a mathematical function or an elevation data bank subset that includes both points and the region between them.

If the terrain function is required to represent large areas of the earth's surface, then a lack of precision will be introduced into the LOS determination because of large excursions of the estimated surface between known data points. If the terrain model is one in which the elevation data is segmented into overlapping regions and simple functions are chosen to insure at least first order continuity (see, for example, reference 1) at region boundaries, then the excursions can be reduced significantly. In fact, the procedure given in reference 1 can be used to compact data and determine intervisibility as well as for the computation of contours. In any event, the LOS can be evaluated by comparing the profile between points *A* and *B* to the imaginary line between the points. In the case where a subset of elevation data between the points is given, the profile between them can be obtained by numerical interpolation in the elevation data. Continuity in the estimated profile can be maintained by utilizing low-order spline functions.

In either method, the extraction of the profile and subsequent comparison to the imaginary line between points *A* and *B* can be done quite easily in the computer. If the type of terrain that caused the loss of intervisibility is required as output, then a terrain information data bank referenced to the horizontal coordinates must be provided. These methods require that a large and in some instances sophisticated data bank be provided. The purpose of this paper is to describe

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three methods of LOS determination that can be applied to two or more points contained in single stereo model. In all three methods the primary data bank is the photograph itself and in two of the methods digital image matching techniques are used to produce a semi-automatic LOS determination. The three methods are classified as: (1) Absolute; (2) Relative; and (3) Visual.

Single Model Techniques

The three LOS solutions given below have been considered by Engineer Topographic Laboratory ETL personnel. Only the absolute method is being evaluated numerically. It was chosen for numerical analysis because of the flexibility offered by digital image processing and because of its superior accuracy. The method is accurate because all known distortions can be corrected. This means that the output can be used directly in the field. For example, heights of towers at points *A* or *B* can be calculated so that the LOS does exist in cases where a natural LOS does not. A brief description of the method and of the numerical results to date are given in this paper. A more thorough analysis is given in reference 2. Since a complete description of the relative method is given in an appendix of reference 2, only a brief description will be given here. The visual method is presented as a quick and possibly inaccurate technique for near real-time LOS determination.

Absolute Technique

The absolute technique utilizes a digital approach to the LOS problem. The image points corresponding to *A* and *B* are identified in the overlap region of a stereo pair of photographs. Their intervisibility or lack of it in object space is determined by using digital image matching methods. The technique calculates the profile between *A* and *B* and then determines if the LOS between the two points is obscured by an intervening land mass.

Points *A* and *B* are intersected in object space and the local frame is defined where the origin is at the nadir of *A* and the Z_LX_L-plane includes point *B* (see Figure 1). The matching process begins at *A* and proceeds along the profile trace where the X_L-coordinate is increased incrementally from $X_L(A) = 0$ to $X_L(B)$. Y_L is constrained to be zero. $Z'_L(P)$ of a general point *P* along the profile is estimated from previous Z_L-values. An iterative procedure is used to improve the estimate $Z'_L(P)$. The process is iterated until the image coordinates associated with $[X_L(P), 0, Z'_L(P)]$ produces a correlation function that is maximal at those coordinates.

The trial coordinates $[X_L(P), 0, Z'_L(P)]$ are converted into ideal image coordinates on both exposures by using the collinearity relationship. The ideal image coordinates are distorted in turn by air refraction, lens distortion and film distortion. Finally, the approximate plate coordinates are transformed to scanner coordinates. One set of scanner coordinates (say those on the first image) are regarded as independent and the corresponding pair on the second image are determined by image matching using density data. If the scanner coordinates on the second exposure determined by matching are identical to those determined by the collinearity relation, then $Z'_L(P)$ need not be refined further. If not, a $\Delta Z_L(P)$ is computed from the scanner coordinate discrepancy and the process is repeated with $Z''_L(P) = Z'_L(P) + \Delta Z_L(P)$.

Numerical Evaluation of Absolute Technique

The test area is near Guadalupe, Arizona, 12 miles south of Phoenix, Arizona. The scale of the photography is about 1:50,000. The length of the line is approximately 1,200 meters. The exterior orientation of the model comes from a MUSAT (Multiple Station Analytical Triangulation) adjustment. The imagery was scanned and digitized on the PDS 1050A microdensitometer at ETL. The pixel spacing is 10 μm. The pixel diameter is 21 μm. The comparator capability of the PDS 1050A was used to measure image coordinates of points *A* and *B* along with the necessary fiducial and reseau marks. The

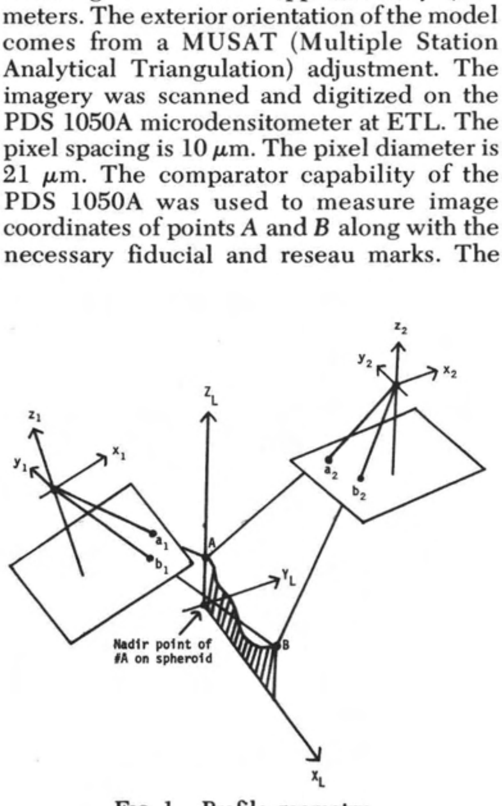

Fig. 1. Profile geometry.

density data was output onto magnetic tape. The numerical computations are performed in DIMES (Digital Image Manipulation and Enhancement System, see reference 3) to make use of the DIMES data management capabilities. Enlargements of the imagery are presented in Figure 2. Points *A* and *B* are the points whose intervisibility is in question; *C* and *D* indicate areas that are difficult to match. The imagery in Figure 2 was printed from magnetic tape by the DICOMED equipment in ETL.

The linear correlation coefficient of statistics is used as the measure of similarity. A correlation function in the form of a cross is generated around the predicted point on the second image. The shift due to parallax is determined by locating the peak of the correlation function. Normally the correlation measure is calculated from a 17 × 17 pixel window—about (9 meter)^2 on the ground. Whenever the process begins to bog down due to sparse imagery, the window size is increased to 41 × 41. Image sparseness is monitored in the program by evaluating the gray-level standard deviation. There are two areas of sparse imagery in the test model. See areas *C* and *D* in Figure 2. Area *C* is an interstate highway under construction. Area *D* is a region of sparse imagery on a steep hillside.

The previous model space Z is used to estimate the new Z-value. If matching problems due to a rapidly changing slope (indicated by an excessive number of iterations) are encountered, the horizontal increment ΔX is reduced and the Z-value is estimated by fitting a line to the previous five points. In the test area a 4-meter horizontal interval gave good results, the interval was reduced to 2 meters in steep areas.

The accuracy and efficiency associated with the digital determination of the LOS is sensitive to at least the following parameters:

(1) Pixel size and spacing,
(2) Number of gray levels,
(3) Window size,

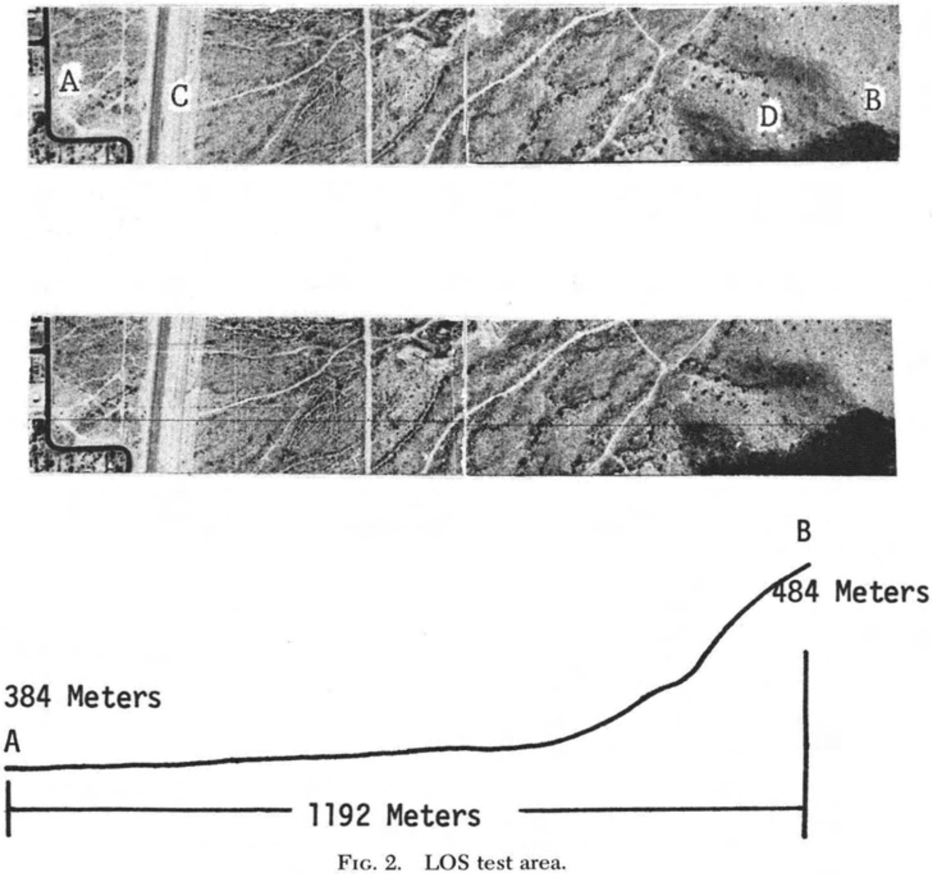

FIG. 2. LOS test area.

(4) Correlation measure,
(5) Array shaping, and
(6) Matching strategies.

Future tests will be performed at ETL to determine how best to regulate these parameters so as to produce an accurate profile in an acceptable amount of time.

RELATIVE TECHNIQUE

Suppose the relative orientation of two overlapping frame exposures is known or else computed from five or more pass points. Suppose further that the ground points A and B are imaged on both exposures. The relative method compares the relative distance (D_p) to a point P on the imaginary line connecting A and B from, say, the first lens position (C_1) to the relative distance D'_p. D'_p is the relative distance from the first lens to the point where the imaging ray $\overline{C_1P}$ intersects the ground. If $D_p < D'_p$ the point P is above the ground, if $D_p = D'_p$ the point P is on the ground and, finally, if $D_p > D'_p$ the point P is under the ground. These relationships are shown in Figure 3.

If (X_A, Y_A, Z_A) and (X_B, Y_B, Z_B) are the relative coordinates of points A and B computed by intersection, then the relative coordinates of any point on the imaginary line between A and B are—

$$X_p = X_A + \delta_X\Delta_p$$
$$Y_p = Y_A + \delta_Y\Delta_p$$
$$Z_p = Z_A + \delta_Z\Delta_p$$

where

$$\delta_X = X_B - X_A$$
$$\delta_Y = Y_B - Y_A$$
$$\delta_Z = Z_B - Z_A$$

and

$$0 \leq \Delta_p \leq 1$$

If the coordinates of P are substituted into the collinearity equations, then the ideal coordinates of the point associated with the imaging ray $\overline{C_1P}$ are produced. All points on the ray connecting the first lens and P will produce the same ideal image coordinates when substituted into the central projection equations. However, the recorded image pertains to the first optically opaque point along the ray.

Lens distortion and film distortion are applied to the ideal coordinates to produce a set of coordinates which, except for air refraction, are equal to plate coordinates. Finally, the transformation to scanner coordinates is applied and the corresponding scanner coordinates on the second exposure are determined by digital image matching. The derived scanner coordinates on the second exposure are corrected for distortion and the corresponding ideal coordinates are intersected to produce the model point P_M corresponding to the imaging ray $\overline{C_1P}$. The relative distances $D_p = |C_1 - P|$ and $D'_p = |C_1 - P_M|$ are computed and then compared.

VISUAL TECHNIQUE

The relative and absolute techniques are performed automatically using digital image-matching methods once the image points of A and B have been identified. The visual method requires that an operator set up the model in a stereo device and that he view the process throughout the entire LOS determination. The method is described in Figure 4. The projection of the imaginary line $\overline{AB}$ on the focal plane of exposure 1 is the line $\overline{a_1b_1}$ and on the focal plane of 2 it is $\overline{a_2b_2}$. Consider exposure 1. The imagery on $\overline{a_1b_1}$ represents the first optically opaque points along rays emanating

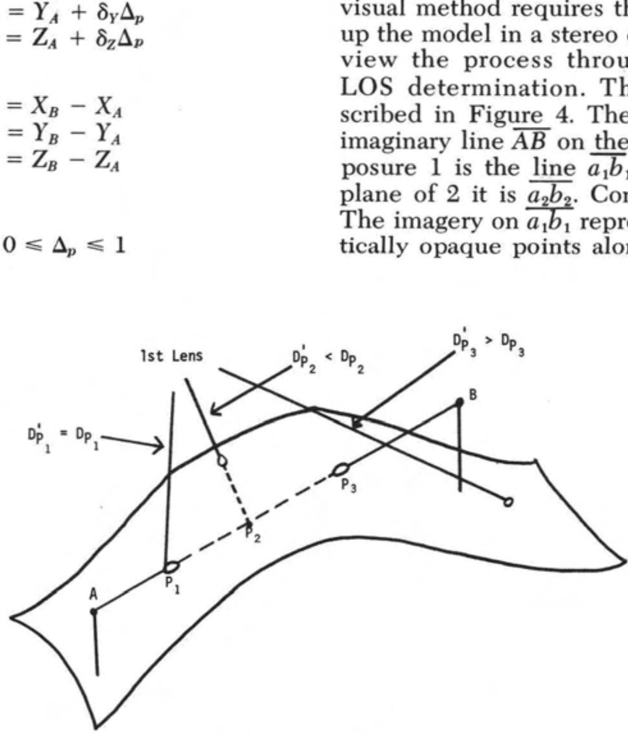

FIG. 3. Relative distance geometry.

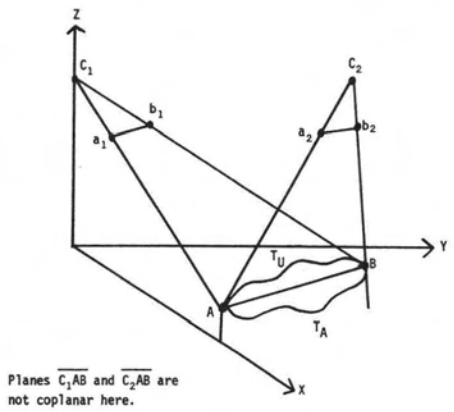

FIG. 4. Visual geometry.

from C_1 in the plane $\overline{C_1AB}$. For example, T_U represents the ground trace corresponding to $\overline{a_1b_1}$ when the LOS is completely underground. T_A represents the ground trace corresponding to $\overline{a_1b_1}$ when the LOS is completely above ground.

Now consider exposure 2. If the LOS is completely underground (above ground), then the image trace corresponding to $\overline{a_1b_1}$ remains on one side or the other of the image line $\overline{a_2b_2}$. Whenever the LOS is on the ground the image point is on $\overline{a_2b_2}$.

The LOS determination can be performed operationally in the following manner. Suppose exposures 1 and 2 are set up in a stereo viewer and that the reticle of the first eyepiece is constrained to move along $\overline{a_1b_1}$. Suppose further that as the reticle of the first image moves along $\overline{a_1b_1}$ the operator keeps the dot on the ground by adjusting the second image. If the track on the second image remains between the principal point (for the example in Figure 4) and the line $\overline{a_2b_2}$, then the LOS is below the ground. If the track remains to the side of $\overline{a_2b_2}$ away from the principal point, then the LOS is above the ground. If the track is along $\overline{a_2b_2}$, then the LOS is on the ground. Whenever the track crosses $\overline{a_2b_2}$ the LOS enters (comes out of) the ground.

This technique should work best when the model space line $\overline{AB}$ is perpendicular to the base line $\overline{C_1C_2}$. In fact, as $\overline{AB}$ approaches a model space epipolar line the technique will tend to fall apart. Whenever $\overline{AB}$ is in an epipolar plane then $\overline{a_1b_1}$ and $\overline{a_2b_2}$ are corresponding image space epipolar lines and the process completely breaks down. In this instance the ground trace corresponding to the plane $\overline{C_1AB}$ is exactly the trace corresponding to the plane $\overline{C_2AB}$ and the track in the second image corresponding to $\overline{a_1b_1}$ is $\overline{a_2b_2}$ regardless of whether the LOS is above or below the ground.

SUMMARY

The three single-model techniques discussed in this paper use the worthwhile notion of the photograph being probably the most efficient data bank in the mapping and charting inventory. The object of the LOS analysis at ETL is to determine whether LOS determination can be accomplished efficiently using this notion and whether the question of intervisibility between sets of points can be answered quickly and accurately in the field.

Only one analysis of the LOS determination has been made at ETL and that was an initial evaluation of the absolute technique using a line approximately 1,200 meters long. The study produced more questions than it did answers. For example, it is not clear what is the best pixel spacing and best pixel size to use. It is not clear to what gray level the density data should be quantized. It appears that the ΔX-spacing should vary according to the terrain. It is not clear what may be the most practical way of getting through regions wherein the process bogs down due to the lack of correlatable imagery. The process can, of course, be nursed through troublesome regions by an operator, but this will tend to slow down the overall throughput. Other methods such as processing several lines simultaneously or computing both a precise and imprecise correlation function will be considered. In the first method, matching will take place on an advancing front where, if part of the front tends to break down due to sparse imagery, it can be hopefully held together by approximations from the more successful parts of the front. In the second method, the precise method will be buttressed by a concurrent matching using either larger window sizes, low pass filtered data or both in order to maintain correlation when precise matching is difficult or impossible. The arrays were not shaped for the initial analysis. Whether or not array shaping will increase the chance of maintaining correlation and also produce more accurate matches will be determined in future studies.

The relative and visual techniques have not been evaluated nor are there any plans to do so. The relative method introduces error into the LOS because air refraction is not treated. The visual technique suffers in that the process breaks down whenever the line in question is in an epipolar plane. A corollary of Murphy's law indicates that a large percentage of trial lines will fall in or near epipolar planes. The problem can be overcome by using a sidelap exposure. Another corollary of the law tells us the sidelap exposure probably does not exist if it is needed. The visual method does, however, enable the operator to see what type of obstruction, if any, caused the lack of intervisibility in cases where the method is applicable.

As indicated in the text, the digital approach to both the absolute and relative techniques offers flexibilities which have yet to be exploited. These flexibilities include such parameters as spacing along a profile depending upon the accuracy required as output. Also, a statistical analysis is available at each step in the process so that an assessment can be made of the resulting accuracies of the elevations along profiles. Another aspect of the absolute method is that heights of towers and/or Army helicopters can be determined so that the LOS can be obtained between two points or, if the problem is one of concealment of airborne helicopters, then their flying heights above the terrain can be determined because the problem is mathematically describable.

References

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