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Photogrammetric Application of a Video System in Three-Dimensional Recording

The system, used for surveying and recording structures and architectural objects, proved to be simple, effective, and inexpensive.

ABSTRACT: *The use of a portable video system in three-dimensional metric recording is investigated. The presented technique proved to be very efficient in the surveying and recording of structures and architectural objects. Recording is carried out completely automatically, and the coordinates of the chosen objects are computed using a programmable hand calculator while the recording tape is viewed on a* TV *set or a monitoring screen. The accuracy is equivalent to that obtained by tacheometric surveying.*

INTRODUCTION

MODERN ADVANCES in technology have opened new avenues for photogrammetric engineers to meet their objectives. The selection, matching, and adaptation of the appropriate technology which will fulfill the needs of the various users of the survey output have become inevitable.

In architectural and archeological applications, a major problem arises when the users are not specialists in photogrammetry. The persons who may find it necessary to utilize the infinite amount of information the stereopairs contain may not be civil engineers or photogrammetrists. They cannot deal with sophisticated photogrammetric methods, nor are they trained to be photogrammetric operators. On the other hand, the conventional methods of data extraction from photograms are very expensive and time consuming, and they require a well trained photogrammetric specialist.

Accordingly, new simple photogrammetric techniques that provide those users with the required reasonably accurate dimensions should be developed to minimize manpower, expense, and time.

The presented technique incorporates an inexpensive continuous recording possibility supplied by a color portable video cassette recorder with its video camera. A video deck and a color television monitor (or receiver) together with a programmable hand calculator are utilized for data extraction.

MATHEMATICAL MODEL

Figure 1 shows the principals of determination of the location of point i in the ground coordinate system X, Y, Z. Angular measurements carried out at two stations, A and C are the two horizontal angles, α and β, at A and C, respectively, and the vertical angle γ at A. Linear measurements are the two components, B_X and B_Y, of the base B. B_Z is not required. If the origin of the coordinate system is chosen at A and the X-axis is the horizontal to C, B_Y vanishes and B will be defined as the horizontal distance between A and C. The Y-axis is the horizontal towards the object, perpendicular to the X-axis, and the Z-axis is directed upwards perpendicular to the XY plane. Therefore, the coordinates of point i are calculated from

$$X_i = B/(\tan\alpha\cot\beta + 1) \quad (1)$$

$$Y_i = B/(\cot\alpha + \cot\beta) \quad (2)$$

$$Z_i = Y_i\tan\gamma/\sin\alpha \quad (3)$$

The above equations are very simple, hence their solution can be easily automated by the use of any programmable hand calculator.

TECHNICAL MODEL

The recording unit consists of a small portable color video camera connected to a mechanism which

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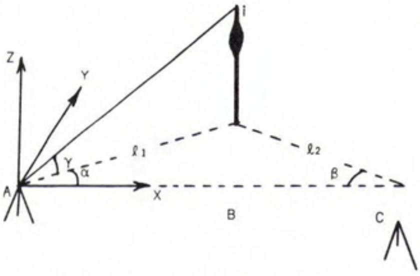

FIG. 1. Coordinate system for video recording.

allows the camera to scan the features either horizontally or vertically by turning about two orthogonal axes (Figure 2). The vertical scanning axis is adjusted vertical by the use of a 10 arc second spirit level. This mechanism is connected to a tribranch and a tripod. The rotational motion is controlled by a stabilized electrical motor that can operate at two different speeds, 2 rph (revolution per hour) or 1 rph.

The instrument is leveled on stations A and C, respectively. At each station the camera is made to scan horizontally the required objects, starting from the other station as an initial direction. The time lapse is recorded simultaneously from a chronometer (1/30 sec) on the same recording tape. Therefore, the image of the timer is superimposed on the photographed features when the film is viewed. Vertical scanning is done in the same manner at station A, starting from the horizontal until the required objects are covered.

The coordinates are computed in the office when the films are played back on a video deck. The two films taken at stations A and C can be observed successively or simultaneously on two TV monitors or TV sets. Two reference-lines, one horizontal and the other vertical, are drawn on the TV screen so that their point of intersection lies at the center of the screen. The horizontal and vertical lines act as reference lines for observations of vertical and horizontal angles, respectively.

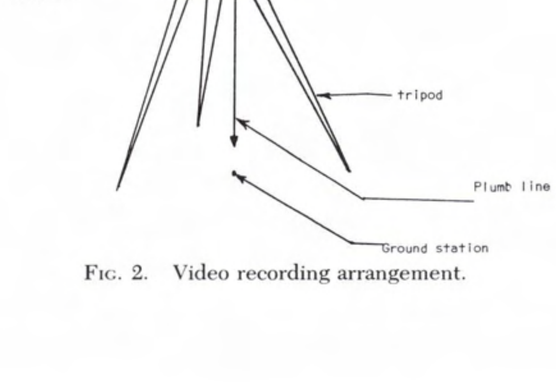

FIG. 2. Video recording arrangement.

To calculate a horizontal or vertical angle, the time interval is read on the TV screen while the film is viewed. Slow motion, frame by frame, and freeze on picture are very helpful features in the video recorder for obtaining accurate results. t_o and t_i are the recorded times when the initial direction and the object i cross the reference lines on the TV screen, respectively. $\Delta t_i = t_i - t_o$ is the time lapse of scanning any required angle Θ_i. Therefore, if the motor speed is "S" rph and Δt_i is in hours, the angle Θ_i in degrees can be calculated from

$$\Theta_i = 360° \, \Delta t_i \, S_i. \tag{4}$$

Angles α_i, β_i, and γ_i are determined using the previous procedure. In the present technique the observed t_o and t_i's are fed to the hand calculator, which is programmed to give the coordinates X_i, Y_i, and Z_i as output.

ACCURACY ANALYSIS

Because the video images are used only for timing and not for image coordinate determination or model construction, the effect of image and model distortions due to the TV Technology of recording, image reconstruction, and picture tube projection is negligible. After studying this technology, it can be soundly assumed that the horizontal distortion of the projected image, on the TV screen, is symmetrical about the vertical reference line, and that vertical distortion of the projected image is symmetrical about the horizontal reference line. Because only these two lines are used for time observation, these distortions should have, theoretically, no influence on angle determination.

The accuracy of time observation in this technique is limited by the rotational angle of the motor per one frame of the recording tape. In most video systems the recording speed is half of the electrical current cycle used. If the cycle is 60 Hz (cps), the recording speed is 30 f/sec (frames per second). Therefore, if the scanning speed is 1 rph, the scanned angle per one frame is 12 arc seconds. Because the time is recorded simultaneously with the features on the same film, the error due to timing, when the object image is crossing the reference line, is cancelled and the main source of error will be the estimation of the exact crossing frame. Hence a maximum error of half a frame is expected in observing a target on the TV screen. This is equivalent to a maximum directional error of 6 arc seconds. Assuming a normal distribution of the observational errors and 95 percent level of significance, the standard error of single observation is ±2 arc seconds and of an angle it is ±2.8 arc seconds.

Another limiting factor for the accuracy of time observation is the resolution of the electronic scanning system of the video system. Because the TV image consists of 625 vertical lines, a maximum observational error of half the thickness of a line is expected. If the angular field of view of the video camera used is 4° (zoom lens), the angular coverage of the error is $4 \times 60 \times 60/(625 \times 2) = 11.5$ arc seconds. Assuming a 95 percent level of significance, the standard deviation of single observation is 3.8 arc seconds.

Two conditions should be verified in order to minimize the recording instrumental errors. First, the scanning vertical axis of the video camera assembly should be adjusted accurately in the vertical direction. This can be verified by turning the camera 180° about the vertical axis after it is leveled. If the bubble of the spirit level moves from the center of the bubble tube, the leveling screws of the tribrach should be turned so that the bubble goes back half the distance it moved. This operation should be repeated after turning the camera 90° about its scanning axis. This technique resembles the conventional method of adjusting the verticality of a theodolite's vertical axis for angle measurement.

The second condition is that the camera optical axis should intersect the vertical scanning axis. This can be verified by recording some close objects and computing the horizontal angles between these objects. The instrument is then turned through 180° about the vertical axis over the tripod's head. Then it is replumbed above the same ground point and releveled, and the recording is repeated for the same objects. Another set of angles can be calculated between these objects. Discrepancies are minimized by adjusting the camera position with respect to the motor vertical scanning axis. For the prototype used in these investigations, the discrepancies were kept below 15 arc seconds for all the observed targets. The equivalent standard deviation of an angle $m_a = \pm 5$ arc seconds. This includes the observation error, which was estimated before.

The measurement of the base can be done with very high accuracy using a subtense bar. Therefore, B is assumed to be errorless for further investigations.

Angular errors are propagated into Equations 1 through 3 to produce the position errors of any point. Also, with consideration to the correlation between point coordinates, the maximum position errors can be calculated. Hence, the estimated angular standard deviation m_a is used for the calculation of the the semi-major axis of the ellipsoid of errors, m_V. After long derivation and neglecting the lower power terms, it is found that

$$m_V = \left(\frac{2L^6}{B^2Y^2} + L^2\sec^2\gamma\right)m_a^2 \tag{5}$$

where L is the distance from the middle of the base to the target.

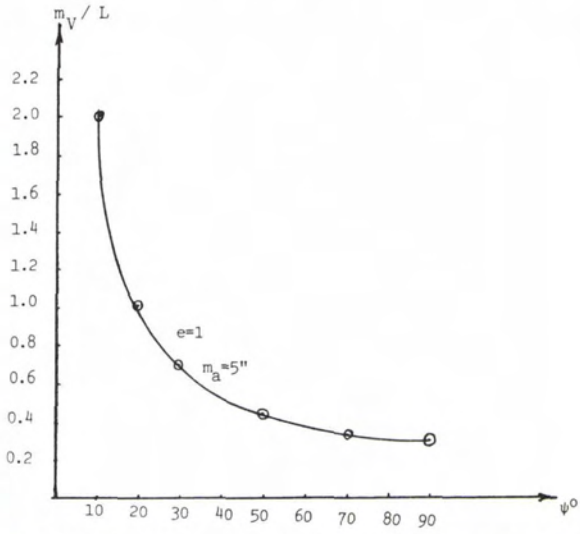

FIG. 3. The relative error for different ψ's (for unit e and at $m_a = 5$ arc sec.).

The relative error $m_V^r = m_V/L$ may be derived from Equation 5 which, after some approximation, may take the form

$$m_V/L = \sqrt{2\, m_a\, e/\sin\psi} \tag{6}$$

where e is the ratio L/B (scale factor) and ψ is the angle between L and B.

If m_a is taken as ± 5 arc seconds, the relation between m_V/L and ψ can be drawn for the unit scale factor (i.e., where $e = 1$).

It is obvious from this graph (Figure 3) that the error ratio increases dramatically when ψ is less than 10°. It is, therefore, recommended that video recording should cover only 320° from the horizon. The objects falling within $\psi = 10°$ on both sides of the base at its two terminals should not be computed from this set up, as shown in Figures 3 and 4.

Equation 5 gives the variance of the position of a point in space relative to the left video station as an initial point. The relative error ellipsoid can also be found between any two points in the recorded features.

PRACTICAL APPLICATIONS

Several experiments were carried out using the proposed technique. In these experiments a JVC portable video system was used. The video camera has a zooming lens with 6× magnification. The camera was used to survey the external features of

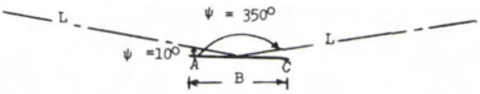

FIG. 4. Horizontal video recording coverage.

TABLE 1. TEST RESULTS

	Conventional Method			Video Method			Difference				
Point #	X m	Y m	Z m	X m	Y m	Z m	ΔX mm	ΔY mm	ΔZ mm	L m	m_V m
1	−32.126	5.423	0	−32.207	5.447	0	+81	−24	0	37.4	34
2	−31.235	15.871	0	−31.314	15.900	0	+79	−29	0	39.3	14
3	−29.970	29.574	0	−29.963	29.581	0	−7	−7	0	42.0	9
4	−16.063	28.954	0	−16.066	28.950	0	+3	+4	0	33.0	4
5	−1.172	29.890	0	−1.163	29.882	0	−9	+8	0	29.9	3
6	6.945	31.621	0	6.953	31.625	0	−8	−4	0	31.6	4
7	17.331	30.612	0	17.327	30.603	0	+4	+9	0	33.0	4
8	22.679	31.145	0	22.687	31.157	0	−8	−12	0	35.8	5
9	36.419	31.617	0	36.431	31.632	0	−12	−15	0	44.5	10
10	43.213	31.890	0	43.209	31.888	0	+4	+2	0	49.8	14
11	59.281	32.051	0	59.294	32.044	0	−13	+7	0	63.0	28
12	62.806	18.548	0	62.746	18.463	0	+60	+85	0	60.7	43
13	63.847	9.063	0	64.048	9.224	0	−201	−161	0	59.5	82
14	63.847	9.063	4.439	63.884	9.089	3.790	−37	−26	+649	59.5	82
15	63.847	9.063	9.074	63.587	8.971	8.271	+260	+92	+803	59.5	82
16	63.847	9.063	14.256	63.614	8.878	13.748	+233	+185	+508	59.5	82

Arabian-styled University of Petroleum & Minerals academic campus. The shortest and longest object distances were 32 m and 68 m, respectively. The base length was 10 m. The video recorder used had the facility of frame by frame and slow motion viewing. The calibration of the scanning motor was done every time it was used by completing the scanning through 360° until the initial target was rerecorded. The speed of scanning was chosen as 1 rph. Horizontal and vertical scanning were tested for the determination of *X, Y, and* Z coordinates and their accuracies.

The objects were then surveyed with very high accuracy using conventional techniques (1 arc sec theodolite and subtense bar). The study was based on comparing the video coordinate determination with the coordinates obtained with the conventional methods. Table 1 shows the results of the test together with the estimated semi-major axis of the error ellipsoid computed from Equation 5.

It is noted in Table 1 that the discrepancies did not exceed three times the theoretical standard deviation. High accuracy can be obtained when ψ lies between 30° and 150°. The large discrepancies obtained in vertical scanning (points 14, 15, and 16) were due to a constant error of about 653 mm which resulted from misleveling of the camera base. It was difficult to determine the elevation of points with respect to the initial station A. It was, therefore, recommended that vertical scanning be used for the determination of the relative elevations of the different object points.

CONCLUSIONS

Videometry is a new technique by which structures, architectural objects, and ruins can be recorded. The relative three dimensional coordinates can be determined using a simple mathematical model.

The proposed technique proved to save much time and the large effort required by specialists to extract the information from field data obtained using conventional methods. The color and sound film carries, in addition to metric data, useful information about the history, use, and condition of the recorded monument through video and audio recording. Additional information may be recorded in the office using audio dubbing and picture-on-picture facility. The system is simple to operate and inexpensive to own, considering that the price of all the required instruments is less than the price of a one-second theodolite.

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