Michael Jackson
Clifford Greve
George Hoffman*
Automeric Incorporated
Falls Church, VA 22041
David Ackerman
U.S. Geological Survey
Reston, VA 22092

A Parameterization of the Itek KA-80A Panoramic Camera†

A rigorous mathematical model describing the Itek KA-80A optical bar panoramic camera is presented and preliminary test results are discussed.

Abstract: *Because of the panoramic camera's ability to provide a vast amount of photographic information cheaply, more and more people are investigating the potential of this alternative method of data collection. With today's analytical stereoplotter, the use of this alternate source of information is widening. This paper presents a dynamic mathematical model or parameterization describing the perspective geometry of the Itek KA-80A panoramic camera. This mathematical model presents the panoramic image as a series of constantly changing small framelettes. The mathematical model is tested and the results are presented.*

Introduction

Panoramic cameras in general are fast becoming one of the most cost effective photographic information collection systems available. This high cost effectiveness is due to the ability of the panoramic camera to combine the superior resolving power of long focal length lenses with the ability to provide wide swaths of quality coverage from a single vehicle pass. The wide use of panoramic photography for reconnaissance has been well documented (Case, 1966; Peterson, 1973). More recently, studies have compared the cost effectiveness of gathering information with the panoramic camera to gathering information by conventional methods (Eva *et al.*, 1979).

The treatment of panoramic cameras as dynamic systems is not a new idea. Several papers address the dynamic nature of panoramic cameras (Case, 1966; Gyer and Haag, 1971). However, some previous papers indicated that the panoramic photograph should be reduced to its equivalent frame photograph before photogrammetric techniques such as space resections, relative orientations, space intersections, and aerial triangulation are employed. This is not a theoretically exact approach. The imaging event is dynamic and should be treated as such. The parameterization development herein is significant in that it treats the imaging event and related photogrammetric processing dynamically.

The Panoramic Concept

Aerial cameras may be categorized into two basic groups: static cameras which expose an entire frame at the same time, and dynamic cameras which expose only a small portion of a frame at any one time. A frame of imagery from a dynamic camera system is composed of many of these small portions or framelettes exposed sequentially over a small finite period of time as the system moves

* Now with DBA Systems, Inc., P.O. Drawer 550, Melbourne, FL 32901.

† Revised version of paper presented at the ASP-ACSM Fall Technical Meeting, San Francisco, California, 9-11 September 1981.

0099-1112/82/4805-0761$02.25/0

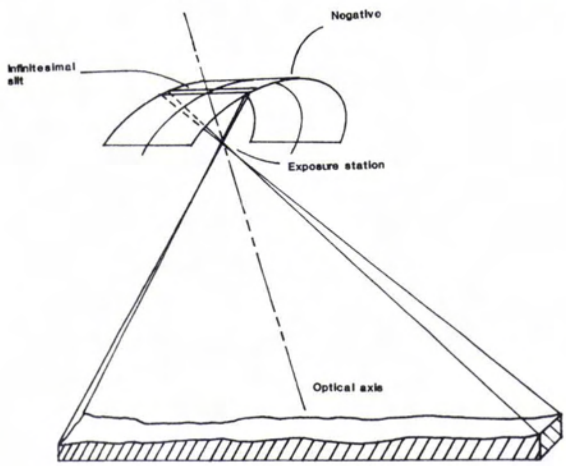

FIG. 1. Panoramic concept.

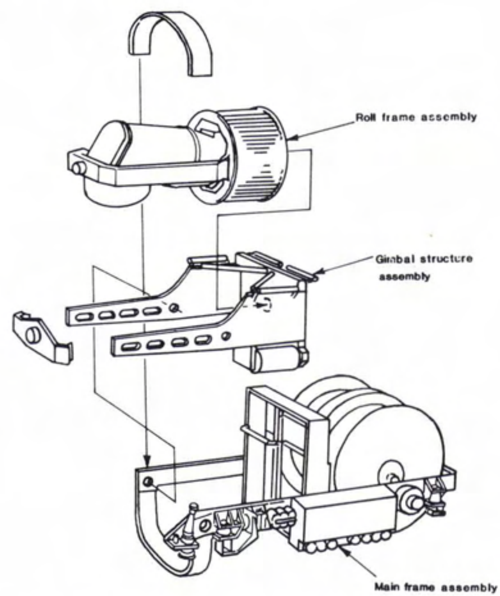

FIG. 2. Major camera assemblies (Itek, 1970).

forward through space. Frame cameras represent the majority of static cameras, while strip and panoramic cameras fall into the realm of dynamic systems.

The static or frame camera is typically composed of a lens, a focal surface, and a shutter which, for all practical purposes, instantaneously exposes a frame of imagery over its entire format. Similarly, a panoramic camera typically consists of a lens and a focal surface. However, the panoramic camera system does not contain a shutter in the same sense that a frame camera does (the Itek KA-80A does contain a capping shutter). Instead, the focal plane frame is limited to a slit, oriented parallel to the direction of flight. This slit is theoretically of infinitely small width and therefore only a small portion of the film, parallel to the direction of flight, is exposed at any instant. One method of sequentially exposing these small strips of film for vertical panoramic photography is to continuously rotate the optical system of the camera about an axis parallel to the vehicle's direction of flight. For tilted (fore and aft) photography, the rotation axis lies in the vertical plane containing the direction of flight but is tilted with respect to the flight vector. Continually rotating the optical system causes the camera to scan the terrain from horizon to horizon (or less depending on the panoramic field of coverage) normal to the direction of flight as the vehicle moves forward. The image of the terrain is exposed through the scanning slit onto the film, which is constrained to lie on a cylinder whose axis is again parallel to the direction of flight and whose radius is equal to the focal length of the lens. Figure 1 represents the panoramic concept.

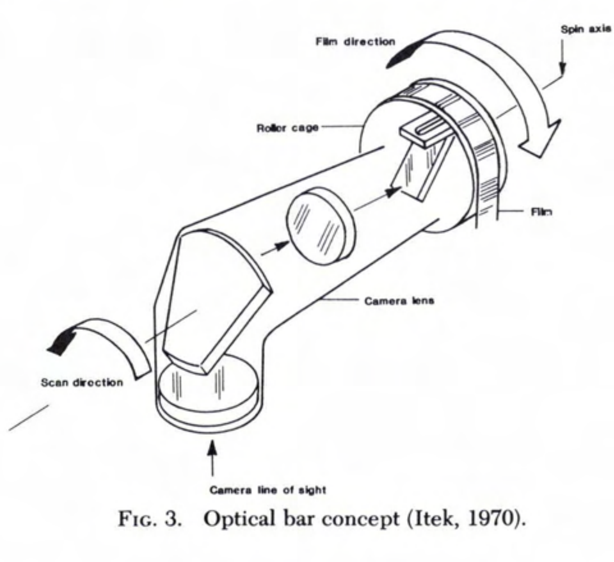

FIG. 3. Optical bar concept (Itek, 1970).

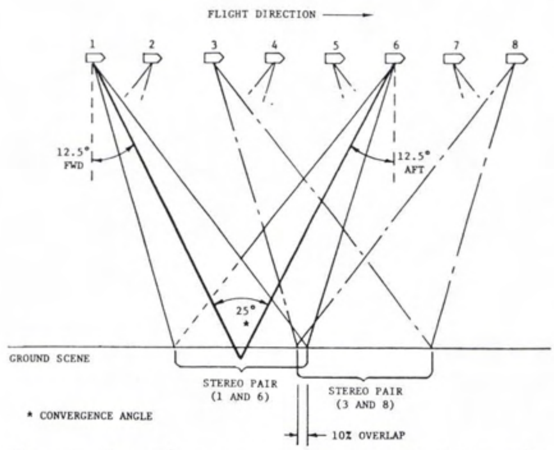

FIG. 4. Ground coverage of fore and aft photography.

KA-80A Physical Characteristics

The KA-80A panoramic camera consists of three major assemblies (Itek, 1970): the roll frame assembly, the gimbal structure assembly, and the main frame assembly, as shown in Figure 2. The roll frame assembly, sometimes referred to as the optical bar, contains the optical system of the camera and rotates continuously around the fore and aft axis during camera operation. As mentioned above, this causes the optical system to scan the terrain below the camera across the line of flight. The optical system of the KA-80A (Figure 3) is assembled and aligned as one integral structure. The optical path of the system is folded by means of mirrors to meet space requirements within this integral structure. Film is directed through the optical system about a circular path referred to as the roller cage. The axis of this circular path is the axis of continuous camera rotation. The entire optical system is mounted horizontally within the roll frame assembly.

The gimbal assembly supports the roll frame or optical bar assembly. The gimbal assembly tilts the optical bar forward or aft to provide convergent stereo coverage, and to correct for the forward motion of the camera during the exposure of the film. When the axis of continuous rotation is held horizontally, the optical system scans the terrain immediately below the camera (Itek, 1970). This vertical mode of operation provides approximately 55 percent forward overlap of successive frames. By tilting the optical bar assembly up, the optical system will scan the terrain ahead of the camera. By tilting the nose of the assembly down, the optical system will scan the terrain behind the camera. Performing these tilting operations alternately creates a series of convergent (fore and aft) photographs as shown in Figure 4. This fore and aft mode of operation provides approximately 10 percent forward overlap of successive frames and 100 percent overlap of the fifth following frame. Tilting the optical bar for convergent stereo coverage takes place during the nonphotographic portion of the camera's cycle. If convergent stereo photography is desired, the optical bar tilt alternates between the 12.5 degree forward and 12.5 degree aft positions for successive exposures. If vertical photography is desired, the gimbal assembly is held horizontal. The inclination of the optical bar for image motion compensation takes place during the photographic portion of the camera's cycle and is continuous throughout the exposure (Itek, 1970). This action modifies the inclination of the optical bar as set in accordance with the desired type of photography (fore and aft or vertical). The angular rate of change in inclination of the optical bar for image motion compensation is directly proportional to the camera's velocity and the camera's average height above the ground.

The main frame assembly is attached to the vehicle carrying the camera and supports the gimbal assembly as well as other camera components.

TABLE 1. ITEK KA-80A OPTICAL BAR CAMERA CHARACTERISTICS (ITEK, 1970)

Item	Characteristic
Lens	24-inch focal length, *f*/3.5 relative aperture
Stereo Convergence Angle	16 degrees
Scan Angle	120 degrees total, 60 degrees either side of track
Overlap	Stereoscopic: Between successive forward and successive aft frames-10 percent along ground track. Monoscopic: 55 percent
Shutter	Capping
Frame Rate	One every 17.5 seconds to one every 5.8 seconds (based on 10 percent overlap)
V/H Rate	5 to 15 ± 0.2 milliradians/sec. (auto) 7 to 15 ± 0.2 milliradians/sec. (man)
Slit Width Range	0.015 to 0.250 inch
Exposure Time	0.29 to 14.4 milliseconds
Resolution (dynamic w/IMC)	135 lines/millimetre. 2:1 contrast, 2 millisecond exposure over 80 percent of the format, 80 percent of the time.
Film Capacity	6,500 feet, any Estar thin-base film

Table 1 presents a brief summary of the KA-80A optical bar camera's physical, functional, and performance characteristics.

Mathematical Analysis

Interior Orientation

The interior orientation of a camera system is defined by its focal length and the location of its principal point (Case, 1966). The simplest interior orientation to understand is that of a typical frame camera. This basic interior orientation is well documented (ASP, 1981). The interior orientations of the KA-80A and the frame camera are very similar. The differences are attributed to the dynamic nature of the KA-80A. For a dynamic camera a separate instantaneous photographic coordinate system may be constructed for each instant of time. The process of constructing each instantaneous coordinate system for the panoramic camera (Figure 5) is identical to the construction process for a frame camera. The origin of the system is located by projecting a line along the optical axis to the instantaneous exposure station. The positive x-axis is along the flight path and the system is right handed. From Figure 5 the following relationships are derived:

$$\begin{aligned} x_i' &= x_i - x_p \\ y_i' &= 0 \\ z_i' &= -f \end{aligned} \tag{1}$$

If the panoramic camera has been calibrated, the principal point offset, x_p, may be modeled as a function of time. Otherwise the offset may be assumed to approximately equal zero.

The next step is to rotate this instantaneous photographic coordinate system into a local nadir system, as shown in Figure 6. The angle, θ, through which the instantaneous photographic system must rotate is defined as

$$\theta = \dot{\theta} \cdot t_i \tag{2}$$

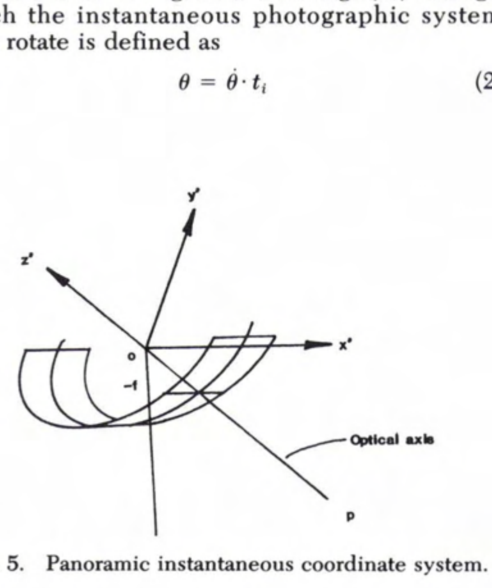

FIG. 5. Panoramic instantaneous coordinate system.

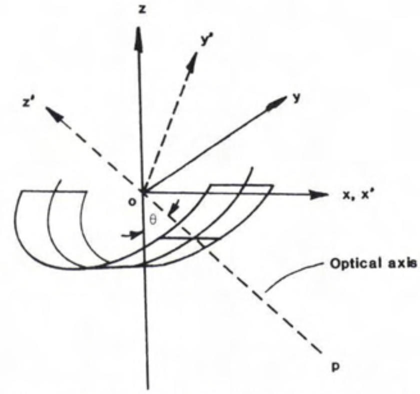

FIG. 6. Panoramic local nadir coordinate system.

where

- θ is the scan angle, referenced to the center of scan;
- $\dot{\theta}$ is the scan rate: and
- t_i is the time at which point i was imaged, with time now referenced to the center of the scan.

The y coordinate of point i determines the time, t_i, at which the point i was imaged. This is an important concept because henceforth in this treatment, time will be represented by a y film coordinate. The y-axis will directly represent time of imaging. Therefore,

$$\theta = \dot{\theta} \cdot y_i \tag{3}$$

where

- $\dot{\theta}$ is the scan rate and
- y_i is the y image coordinate of point i.

The instantaneous photographic coordinate system may be rotated into the local nadir system through a rotation of θ about the x-axis; thus,

$$\begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} = \mathbf{R}_\theta \begin{bmatrix} x'_i \\ y'_i \\ -f \end{bmatrix} \tag{4}$$

where the scan angle matrix, $\mathbf{R}_\theta$ is defined as

$$\mathbf{R}_\theta = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & -\sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix} \tag{5}$$

Collinearity Condition

The collinearity condition states that the exposure station, image point, and ground point all lie on the same line. For a frame camera, this condition is mathematically represented by Equation 6; that is,

$$\begin{bmatrix} x_i \\ y_i \\ -f \end{bmatrix} = K\mathbf{R}_0 \begin{bmatrix} X_i - X_c \\ Y_i - Y_c \\ Z_i - Z_c \end{bmatrix} \tag{6}$$

where

x_i, y_i are the photographic coordinates of point i,
f is the focal length,
K is a scaling constant,
$\mathbf{R}_0$ is the ground to photo rotation matrix,
X_c, Y_c, Z_c are the object space coordinates of the exposure station, and
X_i, Y_i, Z_i are the object space coordinates of point i.

The collinearity condition for panoramic camera systems is obtained by substituting the interior orientation of the panoramic camera for the interior orientation of the frame camera in the above equation; that is,

$$\mathbf{R}_\theta \begin{bmatrix} x_i \\ 0 \\ -f \end{bmatrix} = K\mathbf{R}_0 \begin{bmatrix} X_i - X_{ci} \\ Y_i - Y_{ci} \\ Z_i - Z_{ci} \end{bmatrix}. \tag{7}$$

Rearranging,

$$\begin{bmatrix} x_i \\ 0 \\ -f \end{bmatrix} = K\mathbf{R} \begin{bmatrix} X_i - X_{ci} \\ Y_i - Y_{ci} \\ Z_i - Z_{ci} \end{bmatrix} \tag{8}$$

where

$$\mathbf{R} = \mathbf{R}_s \mathbf{R}_0 \tag{9}$$

and

$$\mathbf{R}_s = \mathbf{R}_\theta^{\mathrm{T}} \tag{10}$$
$$\mathbf{R}_0 = \mathbf{R}_\phi \, \mathbf{R}_\omega \, \mathbf{R}_\kappa \tag{11}$$

where

$$\mathbf{R}_\phi = \begin{bmatrix} \cos\phi & 0 & -\sin\phi \\ 0 & 1 & 0 \\ \sin\phi & 0 & \cos\phi \end{bmatrix} \tag{12}$$

$$\mathbf{R}_\omega = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & \sin\omega \\ 0 & -\sin\omega & \cos\omega \end{bmatrix} \tag{13}$$

$$\mathbf{R}_\kappa = \begin{bmatrix} \cos\kappa & \sin\kappa & 0 \\ \sin\kappa & \cos\kappa & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{14}$$

Further,

$$\begin{aligned} X_{ci} &= X_{c0} + \dot{X}_c y_i \\ Y_{ci} &= Y_{c0} + \dot{Y}_c y_i \\ Z_{ci} &= Z_{c0} + \dot{Z}_c y_i \end{aligned} \tag{15}$$

where

X_{c0}, Y_{c0}, and Z_{c0} is the instantaneous position of the camera at the center of scan, time y_0;
X_{ci}, Y_{ci}, and Z_{ci} is the instantaneous position of the camera at point i, time y_i; and
$\dot{X}_c$, $\dot{Y}_c$, and $\dot{Z}_c$ are components of the velocity of the camera.

Two collinearity equations may be written for every image, i, on a frame of panoramic photography; that is,

$$F(1) = x_i' + f\left[\frac{R_{11}(X_i - X_{ci}) + R_{12}(Y_i - Y_{ci}) + R_{13}(Z_i - Z_{ci})}{R_{31}(X_i - X_{ci}) + R_{32}(Y_i - Y_{ci}) + R_{33}(Z_i - Z_{ci})}\right] = 0 \tag{16}$$

$$F(2) = f\left[\frac{R_{21}(X_i - X_{ci}) + R_{22}(Y_i - Y_{ci}) + R_{23}(Z_i - Z_{ci})}{R_{31}(X_i - X_{ci}) + R_{32}(Y_i - Y_{ci}) + R_{33}(Z_i - Z_{ci})}\right] = 0 \tag{17}$$

where the time, t, is implicit in $\mathbf{R}$, X_c, Y_c, and Z_c, and $R_{11}, \ldots, R_{33}$ are the elements of the matrix, $\mathbf{R}$.

IMAGE MOTION COMPENSATION (IMC)

If the camera were stationary, the only film motion would be due to the scanning action of the camera. However, the image is really exposed over a finite period of time. During this period of time the camera is moving forward through space. Assurances must be made that over this finite period of time the same image is exposed on the same section of film. If this condition is not met, the image of an object will appear blurred. One method of meeting this requirement is to nod the camera about an axis perpendicular to the direction of flight, at a constant rate, $\Delta\dot{\phi}$. $\Delta\dot{\phi}$ is defined such that a constant angular velocity is maintained. If the vehicle is traveling at a constant velocity, V, over the period of time, $t_o \rightarrow t_i$, $\Delta\dot{\phi}$ is modeled by

$$\Delta\dot{\phi} = \frac{V}{H} \tag{18}$$

where

V is the vehicle's velocity and
H is the flying height.

Again, the y film coordinate directly represents the time, t_i, at which point i was imaged. For any given frame, t_0 is defined as the time the center of the scan was imaged and, therefore, is set to zero. Therefore, the total displacement, $\Delta\phi$, is $\Delta\dot{\phi}$ integrated over the time of imaging; that is,

$$\Delta\phi = \frac{V}{H} y_i. \tag{19}$$

Finally, the angle ϕ, which is the primary rotation around the y-axis, is a combination of ϕ_0, at the center of the scan, and the IMC correction.

$$\phi = \phi_0 + \Delta\phi \tag{20}$$

where

ϕ_0 is ϕ at the center of scan and
$\Delta\phi$ is the IMC corrections.

In order to compute IMC, we must first define the vehicle velocity. Because the KA-80A optical bar camera operates in two different modes, we must consider each case.

Case I. Vertical mode, 55 percent ground overlap. When in the vertical mode the vehicle must travel 45 percent of the along-track format between exposures. The film travels $2\pi f$ metres. From this, the velocity, V, is computed as follows:

$$V = \frac{d}{t} \tag{21}$$

where d is the distance on the ground traveled over time t. Again, the image coordinate, y_i, will yield the time point i was imaged; that is,

$$V = \frac{d}{y_i} \,. \tag{22}$$

Because the vehicle travels 45 percent of the format during one scan of $2\pi f$, the following proportion results:

$$\frac{0.45W}{f} = \frac{d}{H} \text{ or } d = \frac{0.45WH}{f} \tag{23}$$

where

W is along-track format,
f is focal length in metres,
d is ground distance in metres, and
H is flying height in metres.

Substituting Equation 23 into Equation 22, one obtains

$$V = \frac{0.45WH}{2\pi f^2} \tag{24}$$

or

$$V = \frac{KH}{f^2} \tag{25}$$

where

$$K = \frac{0.45W}{2\pi} \,. \tag{26}$$

Case II. Stereoscopic 10 percent ground overlap of consecutive forward or aft photographs. When the camera operates in the fore-aft mode, the vehicle must travel 90 percent of the along-track format during a scan of twice $2\pi f$. The velocity is computed as follows:

$$V = \frac{0.90WH}{4\pi f^2} \tag{27}$$

or

$$V = \frac{KH}{f^2} \tag{28}$$

where

$$K = \frac{0.90W}{4\pi} \,. \tag{29}$$

Equation 29 equals Equation 26, indicating that the constant, K, is independent of the mode of operation (fore and aft or vertical).

ATMOSPHERIC REFRACTION

Atmospheric refraction causes the light ray connecting the exposure station, image location, and ground location of an arbitrary point to follow a curved path instead of the ideally straight line. Therefore, a correction is necessary for the condition of collinearity to hold true.

The fourth edition of the *Manual of Photogrammetry* (ASP, 1981) states that the angle, $\Delta\alpha$, between the theoretical straight ray and the tangent to the actual ray at the exposure station may be determined as follows:

$$\Delta\alpha = \xi \tan \alpha \tag{30}$$

where

$$\xi = \left[\frac{2410\,H}{H^2 - 6H + 250} - \frac{2410\,H}{h^2 - 6H + 250}\right]\frac{h}{H} \tag{31}$$

and

H is the elevation of the instantaneous exposure station in kilometres and
h is the ground elevation, above sea level, also in kilometres.

Now for any point on a panoramic photograph,

$$\mathbf{R}_0{}^{\mathrm{T}}\mathbf{R}_s{}^{\mathrm{T}}\begin{bmatrix} x_i \\ 0 \\ -f \end{bmatrix} = \begin{bmatrix} A \\ B \\ C \end{bmatrix} \tag{32}$$

where

A, B, C are direction numbers for point i, relative to the nadir.

Now compute α:

$$\alpha = \tan^{-1}\left[\frac{A^2 + B^2}{C^2}\right] \tag{33}$$

The new departure angle, α', corrected for atmospheric refraction is defined as

$$\alpha' = \alpha - \Delta\alpha \tag{34}$$

Compute the new direction numbers

$$A' = \epsilon\, A \tag{35}$$

$$B' = \epsilon\, B \tag{36}$$

where

TABLE 2. SYSTEM SOLUTION, PHOTO NUMBER 1, ID = 29442 ICHIP = 57

Parameter	Final Approximation	Initial Approximation	Standard Deviation
XC (M):	.22080E 04	.23936E 04	.47299E 02
YC (M):	.41725E 04	.49073E 04	.10845E 03
ZC (M):	.20462E 05	.18290E 05	.27685E 02
XC VEL:	−.20494E-01	.13111E-12	.99997E 00
YC VEL:	.37592E-03	.37591E 03	.99990E 00
ZC VEL:	.56327E-02	.00000E.00	.99999E.00
PHI (D):	.11607E 02	.12500E 02	.34693E 00
OMEGA (D):	−.49298E 00	.00000E.00	.14953E 00
KAPPA (D):	.90398E 02	.90000E.02	.49756E-01
SCAN RATE:	.16425E 01	.16425E 01	.14100E-05
V/H RATIO:	.20553E-01	.20553E.01	.14100E-04

$$\epsilon = \frac{\tan \alpha'}{\tan \alpha}. \tag{37}$$

Further,

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = \mathbf{R}_s \mathbf{R}_0 \begin{bmatrix} A' \\ B' \\ C' \end{bmatrix} \tag{38}$$

Except for scale, a, b, and c are the image vectors corrected for atmospheric refraction. Next, scale the system by $-f/c$ in order to preserve the unit focal length; that is,

$$\begin{bmatrix} x_i - x_a \\ -y_a \\ -f \end{bmatrix} = \frac{-f}{c} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \tag{39}$$

Finally, extracting the atmospheric refraction corrections,

$$x_a = x_i + f\,\frac{a}{c} \tag{40}$$

$$y_a = f\,\frac{b}{c} \tag{41}$$

As described above, the developed KA-80-A mathematical model is dependent on the following parameters: X_{c0}, Y_{c0}, Z_{c0}, $\dot{X}_c$, $\dot{Y}_c$, $\dot{Z}_c$, ω, ϕ, κ, $\dot{\theta}$, V/H, X_i, Y_i, Z_i where

- X_{c0}, Y_{c0}, Z_{c0} represents the instantaneous position of the camera at the center of scan,
- $\dot{X}_c$, $\dot{Y}_c$, $\dot{Z}_c$ represents the velocity of the camera,
- ω, ϕ, κ represents the instantaneous attitude of the camera at the center of scan,
- $\dot{\theta}$ represents the scan rate,
- V/H represents the camera's velocity/height ratio, and
- X_i, Y_i, Z_i represents the coordinates of the ground points.

The coordinates of the ground points and the coordinates of the instantaneous vehicle position are referenced to a local space rectangular system. The origin of this system is set arbitrarily at the average latitude and longitude of the control points. The Y axis of the local space system is orientated north to south with the X axis east to west. The flight line is assumed to be straight but not necessarily level. No vehicle rotation rates are included in the system and the focal length is assumed to be known and constant. Also, the scan rate is assumed to be constant.

The most probable values for the described parameters are obtained by the method of least squares (Leick, 1978). A full weighting scheme allows the physically derived a priori standard deviations for the camera parameters, and statistically derived a priori standard deviations for the ground control information to be incorporated into the mathematical solution. Standard deviations associated with photographic coordinate measurements are also incorporated.

TEST PROCEDURES

The test area is located in Colorado with the south edge on the Colorado-New Mexico border. The topography is very rugged and mountainous with little culture. This test area consists of two fifteen-minute quadrangles, Platoro and Chama Peak. The mission was flown by a NASA U-2 from Ames Research Center in support of the Earth Resources Program. NASA acquired the photography in the convergent stereo mode using high definition Aerochrome infrared SO-131 film. The photography consists of two north-south flight

TABLE 3. SYSTEM SOLUTION, PHOTO NUMBER 2, ID = 29442 ICHIP = 62

Parameter	Final Approximation	Initial Approximation	Standard Deviation
XC (M):	.21618E 04	.20105E 04	.45956E 02
YC (M):	−.16436E.04	−.42957E 04	.11012E.03
ZC (M):	.20608E 05	.18290E 05	.22142E 02
XC VEL:	.11390E.01	.13111E-12	.99997E 00
YC VEL:	.37589E 03	.37591E.03	.99988E.00
ZC VEL:	.28321E-03	.00000E.00	.99999E.00
PHI (D):	−.44845E 01	−12500E 02	.34960E 00
OMEGA (D):	.26611E 00	.00000E.00	.14576E 00
KAPPA (D):	.90094E 02	.90000E 02	.48952E-01
SCAN RATE:	.16425E 01	.16425E 01	.14100E-05
V/H RATIO:	.20552E-01	.20552E-01	.14100E-04

Solution converged in 6 iterations
Sigma A-posterior is: .9508
Date: 5 29 81

lines. Approximately six panoramic models will cover a 7.5 minute quadrangle.

The test area is used in a current project for compilation of maps in 7.5 minute quadrangles from standard vertical frame photography. This project is being conducted by the U.S. Geological Survey's (USGS) Rocky Mountain Mapping Center (RMMC). Compilation from the normally vertical frame photographs will be compared to the compilation from panoramic photographs to evaluate the accuracy of the panoramic system. The contour interval for the test area is 40 feet.

PRELIMINARY RESULTS

The results at the time of this report are only preliminary. Two representative convergent stereo frames were choosen and set on the APPS-IV analytical stereoplotter located at the U.S. Army Engineer Topographic Laboratories (USAETL). The APPS-IV, a medium accuracy stereoplotter (Greve, 1980) built by Autometric Inc., is part of the Computer Assisted Photo Interpretation Research (CAPIR) project (Lukes, 1981) at USAETL. The only control available to date is that interpolated from existing 15 minute and 7.5 minute USGS quad sheets. No precisely surveyed control data has been used as of yet. The control was picked to span the entire model area when set up on the analytical stereo plotter. Upon reaching a convergent solution, the statistics listed in Tables 2, 3, and 4 were computed.

DISCUSSION OF RESULTS

The criterion for convergence of the present solution is based upon reaching minimized correction vectors to the ground control points and camera system parameters. When the components of the correction vectors are significantly small, the solution can be said to converge. At this point the model is considered linear and an error propagation for system parameters and ground point coordinates computed. The solution presented indicates that the math model fits the ground control.

The average horizontal error is approximately 3 metres and the vertical 6 metres. However, it must be remembered that all the control was scaled from a 1:24,000 quad sheet. The control consisted of jeep trails, stream intersections, and other natural features.

National map accuracy standards dictate that the features on the map sheet must be within 12.20 metres horizontally of their true position for this scale quad sheet. The results of the solution presented indicate that the model has adjusted to within the accuracies of the map sheet used to compute control. Further investigation of the final

TABLE 4. FINAL PLATE RESIDUALS, LEFT PHOTO ID = 29442 ICHIP = 57, RIGHT PHOTO ID = 29442 ICHIP = 62

Point	Photo	X-RES (MIC)	Y-RES (MIC)
1	1	0.5890	3.3485
1	2	0.3215	−3.2771
2	1	1.3993	−3.6518
2	2	−1.47682	5.4801
3	1	−0.1089	−18.9491
2	2	2.0820	16.9995
4	1	−5.7877	31.6870
4	2	−8.4236	−35.7290
5	1	1.5817	−4.8577
5	2	4.6639	8.4034
6	1	−1.1461	−4.9057
6	2	1.4180	3.4912
7	1	0.9326	6.9516
7	2	0.4132	4.2151
8	1	1.6946	−4.9557
8	2	−0.2009	4.4881
9	1	0.8362	−4.6670
9	2	1.2294	4.3608

plate residuals indicates an essentially parallax-free model in y. The low y-plate residuals predict a stereo model is maintained over the entire format of the model. The low x-residuals indicate that the model solution will contribute a minimum of error to elevation determination. The large plate residual on Point 4 indicates that the point was either measured incorrectly or the wrong ground control coordinates were entered for it. Upon investigation of this large discrepancy it was found that the point, as displayed on the quad sheet, was difficult to identify on the imagery.

Conclusions

A rigorous dynamic parameterization of the Itek KA-80A optical bar panoramic camera has been developed. The parameterization presents the panoramic frame as a series of infinitesimal and constantly changing framelettes with each framelette adhering to the properties customarily associated with the conventional frame mapping camera. The results of the solution presented and the associated error propagation tend to indicate the model developed adequately reproduces the imaging event. The plate residuals confirm the ability to maintain a parallax free model on an analytical stereoplotter. Further testing of the model will include the use of surveyed ground control.

References

ASP, 1981. *Manual of Photogrammetry,* Fourth Edition, American Society of Photogrammetry, Falls Church, Virginia.

Case, James B., 1966. The Analytical Reduction of Panoramic and Strip Photography, *Photogrammetria,* August 1966, pp. 127-141.

Eav, B. B., R. D. Dillman, J. C. Prill, and R. E. Hinkle, 1979. Mountain Pine Beetle Surveys with High-Altitude Panoramic Photography, *Fall Proceedings of the American society of Photogrammetry,* Fall 1979, 14 pages.

Greve, C. W., 1980. The APPS-IV Analytical Plotter, *Proceedings of the Analytical Plotter Symposium and Workshop,* American Society of Photogrammetry, April 1980, pp. 79-85.

Gyer, Maurice S., and Niles N. Haag, 1971. *Analytical Aerotriangulation with Panoramic Photography,* DBA Systems, Incorporated. RADC-TR-71-240 Final Technical Report, November 1971, 224 pages.

Itek, 1970. *Familiarization and Integration Manual for Prototype Panoramic Camera for Scientific Instrument Module,* Itek Optical Systems Division.

Leick, A., 1978. *Adjustment Computations,* University of Maine at Orono class notes.

Lukes, G. E., 1981. Computer Assisted Photo Interpretation at USAETl, *Society of Photo-Optical Instrumentation Engineers (SPIE),* Volume 281, April 1981, pp. 85-94.

Peterson, Charles G., 1973. Compilation of Lunar Pan Photos, *Photogrammetric Engineering,* Vol. 39, No. 1, pp. 73-79.

(Invited 7 August 1981; revised and accepted 20 February 1982)

Harvard Computer Graphics Week 1982

Hyatt Regency Hotel, Cambridge, Massachusetts
25-30 July 1982

Sponsored by the Laboratory for Computer Graphics and Spatial Analysis, Graduate School of Design, Harvard University, the focus this fifth year will be on computer mapping, image processing, graphic communication, and information resources. The conference will include presentations at three levels of detail to meet the needs of (1) individuals having no prior experience with computer graphics, (2) current users of computer graphic capabilities, and (3) professionals within the focus disciplines.

For more information please contact

Ann Quenin
Laboratory for Computer Graphics
and Spatial Analysis
48 Quincy Street
Cambridge, MA 02138
Tele. (617) 495-2526