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Side-Looking Radar Restitution

An engineering model restitutor corrects for most of the geometric distortions.

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Introduction

The need for obtaining terrain information accurately under cover of darkness and during all weather conditions has been established during the course of wartime operations, and aerial radar systems have been found to be most suitable for this purpose. However, radar presentations yield neither geometrically correct position information, nor complete image information, for planimetric measurement and mapping because of the inherent characteristics of the radar processes used in obtaining the data. The process of correction or restoration of the radar image to a true ground presentation is called restitution.

Restitution of the Radar Image

The major distortions in an aerial radar presentation result from aircraft motion and the fact that the radar measures slant range rather than ground range. Other factors, such as scaling, earth curvature, sweep delay, terrain relief, and systematic distortion must also be taken into consideration.

A complete, accurate restoration system must include the following flight and ground data reduction operations (Figure 1 shows the flow of data through these operations):

- Terrain profile flights.
- Multiple pass image flights.
- Correlation and data processing of terrain and image flights using navigational data (from SHIRAN, or other such systems) as a base.
- Correction of image films for image flight geometry and systematic distortions.
- Matching of corrected films to eliminate areas lacking terrain information, and contour addition.
- Joining of strips and printing to produce final map.

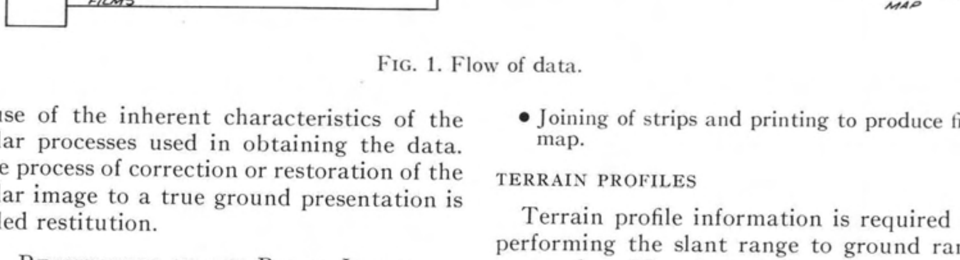

Fig. 1. Flow of data.

Terrain Profiles

Terrain profile information is required for performing the slant range to ground range conversion. Therefore, it is necessary to accomplish the terrain flights before the image flight film is processed. The information is gathered by aircraft utilizing radar altimeters. Theoretical calculations determine the number of passes necessary to define the terrain to the accuracy required.

Image Flight

The image flight provides a slant-range presentation of the terrain on film. As stated previously, this presentation contains geometric, systematic, and other distortions that must be eliminated by restitution. The image

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film is obtained by continuously photographing the side looking radar display while the aircraft flies over the territory to be mapped. A minimum of two passes over the same terrain is required for satisfactory mapping.

DATA PROCESSING

Approximation techniques, curve fitting, adaptive reconstruction, etc., can be used to construct a contour map. An off-line general purpose computer is programmed to perform the approximation and pass data compilation. The computer output can be stored on tape until such time as it is required by the restitutor.

The navigational data for the terrain flights should be meticulously gathered because this data must be correlated with the image flight data. Navigational systems, such as SHIRAN, utilizing fixed ground references can be utilized to perform the stringent task of monitoring aircraft position during passes. The processed and compiled data provides a terrain elevation for each range.

ABSTRACT: *Two data-gathering flights provide ground position information (SHIRAN) and terrain imagery. An engineering model restitutor corrects for most of the geometric distortions including aircraft motion, slant range, earth curvature, sweep delay, terrain relief, shadows, etc. The information is processed by an off-line computer which correlates, compiles, extrapolates contours, and synchronizes the film with the data. The films are restituted and matched to eliminate blank areas and produce a planimetric map. The contours are superimposed on the format and, finally, the strips are joined and printed. A unique scanning technique, involving a high-resolution electroluminescent panel, is developed to speed the restitution process.*

CORRECTION OF IMAGE FLIGHT FILMS

Correction for each of the distortions inherent in the side looking radar presentation is discussed individually in the succeeding paragraphs.

Slant range. The radar presentation is based upon the slant distance from the aircraft to the terrain rather than the true ground range. The distances between targets along a sweep are a function of slant ranges and aircraft altitude. Thus, the resulting distortion of a slant-range presentation is hyperbolic. The region of maximum distortion for flat terrain occurs nearest the nadir.

The slant-to-ground range correction is performed in the restitutor by shifting the optical path of the image. The shift is accomplished by translating a lens along the direction of range while the image film is scanned (see Figure 2). The displacement of the image is slant range minus ground range ($S-G$) (Table I). As part of the restitution process, a scale change is introduced along the range direction in order that the scales along the flight path direction and along the range direction agree.

Denoting the image film scale λ miles/inch and the restituted film scale α miles/inch, the correction, or image shift, is

$$-C = G/\lambda - S/\alpha.$$

Large corrections are undesirable because they give rise to problems related to acceleration of physical components within the restitutor. As the ground range approaches zero, the corrections are approximately equal to $H-K'$ (see Figure 3). Therefore, by shifting the image film by this amount, the initial correction can be reduced to zero. Substituting

$$\epsilon[S^2 - (H - K)^2]^{1/2}$$

for G, and inserting the altitude shift, the correction equation becomes:

$$-C = (H - K')/\alpha + \epsilon[S^2 - (H - K)^2]^{1/2}/\lambda - S/\alpha$$

where

$$\epsilon = R/[(R + K)^{1/2} + (R + H)^{1/2}$$

Defining a new term F as the distance on the image film from the nadir to the target, we can write

$$F = [S - (H - K')].\alpha$$

Incorporation of this value in the correction yields:

$$\cdot C = -F - (\epsilon\alpha/\lambda)\{F^2 + 2F(H - K')/\alpha + [(H - K')/\alpha]^2 - [(H - K)/\alpha]^2\}$$

This represents the complete equation necessary to restitute a radar slant range presenta-

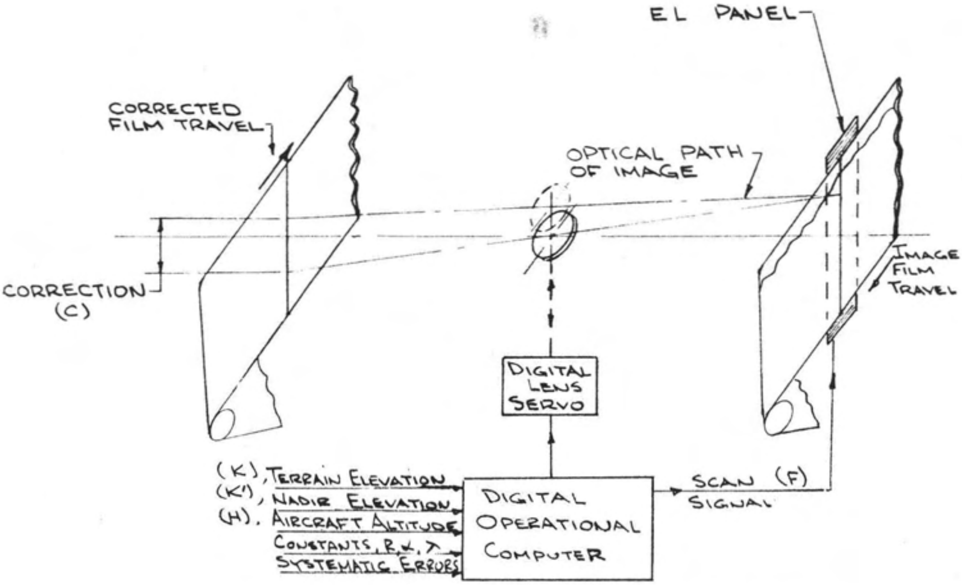

FIG. 2. Mechanization of slant-to-ground range correction.

tion to ground range. In order for the correction equation to be utilized, it is necessary to operate on the film at $F=0$. The earth curvature correction factor, although an integral part of the slant to ground range conversion, is generally treated and computed as a separate entity.

A digital operational computer can be utilized for solving the correction equation. The computer comprises digital mutipliers, counters, and registers. Corrections are applied during the scan interval to eliminate relief errors. Terrain information to implement the corrections is available from preflight data.

A unique scanning technique has been developed by the Electro-Optics Division of Belock Instrument Corp. The scanner is an electroluminescent panel. The panel, see Figure 4, consists of a substrate upon which a number of copper conductors are placed; the number of conductors determines the resolution of the panel. An electroluminescent phosphor is deposited upon the conductors, and a transparent conductive coating is applied on the phosphor. A scan line is produced when the conductive coating and a single conductor are energized. Belock Instrument Corp. has produced high resolution

TABLE 1. MATHEMATICAL SYMBOLS

λ	Image film scale
α	Restituted film scale
C	Slant-to-ground range correction
G	Ground range
S	Slant range
H	Altitude above sea level
K	Target elevation
K'	Nadir point elevation
ϵ	Earth curvature factor
R	Radius of earth
F	Image film distance from nadir point
G_1	Ground range at target elevation

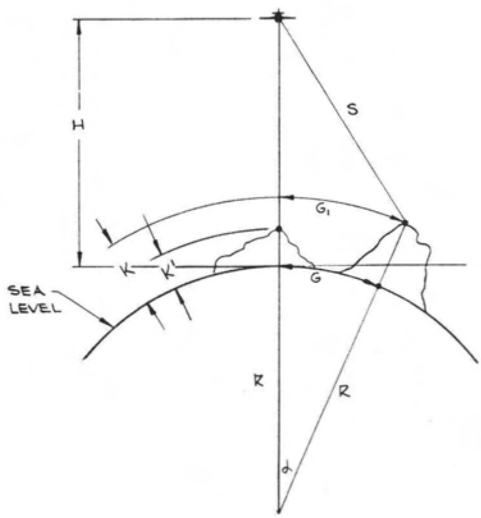

FIG. 3. Geometric relationships.

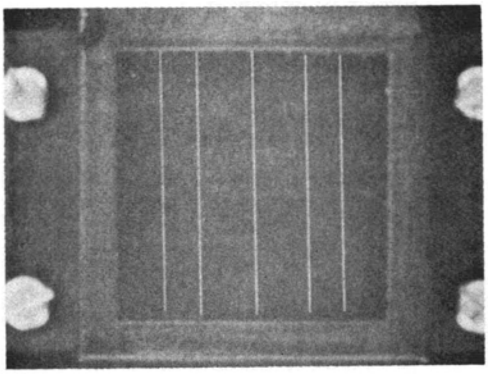

FIG. 4. High-resolution EL panel with five individual lines energized. Photographed in high ambient light.

panels; i.e., in the order of hundreds of lines per inch. The EL panel increases the versatility and speed of restitution. The selection of individual lines at programmed intervals can be useful in controlling the exposure and certain corrections such as systematic distortions.

Formerly, the scanning technique controlled the rate of the correction process, and, for some corrections, the lens acceleration was extremely high. The digital characteristics of the EL panel permit the correction process to control the rate of the scanner. Now the lens can be displaced slowly and the appropriate line or lines on the EL panel illuminated rapidly to perform the scan. This technique greatly speeds the restitution process.

Sweep delay and altitude band. Sweep delay is introduced by the operator in order to eliminate the altitude band and maximize use of the CRT display area. The magnitude of sweep delay introduced is assumed constant for a given flight, and is related to the programmed altitude for the flight. However, since the actual aircraft altitude and terrain elevation vary during the flight, the sweep delay generally introduced is in the neighborhood of 80 per cent of the programmed altitude. The restitutor must correct for differences between the constant sweep delay and varying altitude between the aircraft and the nadir.

Aircraft-motion distortion. This distortion is introduced by motion of the aircraft during flight. These movements may be in-flight line, cross-flight line, or they can be changes in altitude. Yaw distortions are non-existent because the antenna is stabilized in this axis. The distortion resulting from these motions is shown in Figure 5 where the slant range actually measured is less than the true slant range.

Squint-angle correction. In some radar systems, the antenna is placed so that the scan is not orthogonal to the flight path to avoid a high standing wave. This rotation of the antenna is called *squint* and is a function of altitude and yaw.

The squint-angle correction, as well as the aircraft motion (latitude and cross flight) and sweep delay corrections, are implemented by translation or rotation of the appropriate film magazines in the restitutor. The cross flight correction is accomplished by translating the magazine holding the unexposed film in the range direction of the film. Altitude and sweep delay corrections are performed by translating the image film magazine in the range direction. Squint corrections are produced by rotating the image film magazine about the initial scan position.

In-flight corrections are difficult because they contain either overlap information or no information at all. This correction requires rather complex mechanization. The exposed film is advanced or retarded to compensate for in-flight variations. This provides the proper positional data, but interrupts the continuity of the terrain by displaying lines or spaces between the scans. By varying the scan width on the exposed film, or, in essence, the magnification, the lines can be eliminated. As it is probable that only compression will be required, the previous technique, with aperture gating, can be used to eliminate the lines.

Shadows and equal slant-range blur. In mountainous terrain, two different ground ranges can produce equal slant ranges (see Figure 6). These returns, when recorded on film are multiple exposures of different ter-

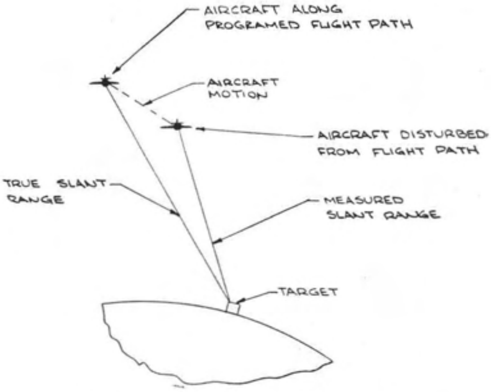

FIG. 5. Aircraft-motion distortion.

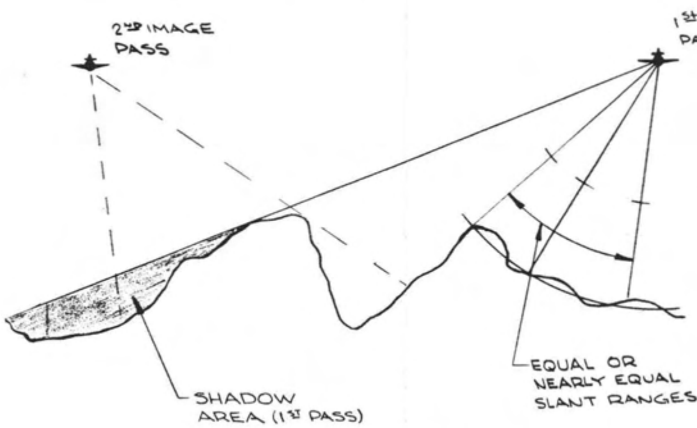

FIG. 6. Shadow and equal-slant-range blur.

rain locations. (Essentially large surface areas are compressed into a small film space.)

Although shadows and equal slant-range returns are useful for determining relief configurations, they are detrimental to the purposes of planimetric mapping because portions of the terrain are obscured.

In order to define mountainous terrain completely, a minimum of two radar passes are necessary where the passes are spaced apart and where altitudes are selected to minimize the effects of shadows and blur while maintaining resolution and accuracy. Each of these passes will contain both types of distortions, but at different terrain locations. If the passes are selected properly, the two should completely define the area to be mapped. This is illustrated in Figure 6. By combining the information contained in each of the passes, a useful map can be reconstructed.

Systematic distortions. The distortions resulting from the non-linearity of the electronic sweep, curvature of the cathode ray tube face, and lens aberrations, affect the accuracy of the radar map.

Systematic distortions are, in essence, a slant-range displacement of the radar terrain due to equipment irregularities. The establishment of the distortions is a tedious process, but only has to be accomplished once for each particular system. The digital operational computer, with its inherent versatility used in conjunction with the line scanning EL panel, can incorporate an exact systematic correction effectively.

Relief distortions. Distortions will result if the terrain relief is not accounted for, and a mean terrain altitude is utilized for each range scan in the restoration process.

Earth curvature. These distortions are due to the assumed sphericity of the earth. The value of the earth's curvature factor at sea level is

$$\epsilon = R/(R + K)^{1/2}(R + H)^{1/2}$$

PROCESSING IMAGE FLIGHT FILMS

Certain references are necessary to perform the restitution process. These are as follows.

In order to determine the system errors, pulses must be generated at equal time intervals and displayed on the CRT in the range direction. The image film of the CRT, if distortion free, should exhibit equal distances between pulses. Any deviation from these equalities are systematic.

In-flight navigation reference marks are essential to correlate the film, and the navigational and terrain data.

The input data necessary to perform the required corrections for restitution are:

- Slant range presentations on film (two required)
- Altitude above nadir
- In-flight deviations
- Cross-flight deviations from reference flight line
- Squint angle
- Sweep delay constant
- Radar presentation scale
- Terrain information
- Radar timing marks on film in range direction
- Navigational reference marks

An engineering model restitutor for side-looking radar presentation images has been constructed by Belock Instrument Corporation. This model corrects for the majority of the major geometric distortions discussed. This paper was partially formulated on the basis of design criteria and evaluation tests on that engineering model.

FILM MATCHING

From the correction processes discussed, accurate planimetric films are produced. However, the presentations contain voids, or equal slant range overlays with poor resolution. Combining of image films will eliminate or fill these voids.

A combining process, similar to the map matching technique, will fill the voids produced in each of the image films to produce one film that combines the terrain of both. The correlation technique will automatically match small areas of film sequentially and expose a new film. The two restituted image films can be registered by a nutation technique, and the films will be simultaneously scanned to determine areas that are not identical by density threshold techniques. The equipment will discriminate, by means of photo cells, which of the image films contains terrain information to be projected on the new film. Areas that are identical can be exposed directly on the new film from either of the restituted films. The device will essentially pick off the unrelated information from a particular film and related information from either film, producing a single film that contains a complete restituted planimetric display of the terrain.

During this process, it may also be desirable to impose contour lines on the planimetric film, producing a topographic format. The contour lines are established from the terrain flight digital computer processing and can be exposed on the new film by a scanning EL panel, programmed to produce the contours.

The final process comprises joining of the film strips and printing of the combined map.

SUMMARY

The entire process consists of two data-gathering flights which provide the ground position information, the altitude, and the terrain imagery. This information is processed by a ground reduction system which correlates, compiles, extrapolates contours, and synchronizes the film with the data. The films are restituted and matched to eliminate blank areas, producing a planimetric map which is a complete, correct ground presentation. The contours are superimposed upon the format, providing a topographic map. Finally, the strips are joined and printed to produce the map. The entire process can be separated into three major categories. These are:

- Flight data gathering
- Data processing
- Restitution (which includes the process of film matching and contour printing).

Tokyo Symposium—*Continued from page 210*

- *H. Fujimori* (Japan), "Analysis of Japanese Sword by Photogrammetry."
- *T. Maruyasu* and *T. Oshima* (Japan), "Stereo Cameras Designed for Measurement of Objects in Motion and Some Examples of Its Actual Use."
- *I. A. Harley* (Australia), "The Calibration of Camera for Non-Topographical Photogrammetry."
- *A. J. Brandenberger* (Canada), "Close-Range Photogrammetry Applied to Space Science."
- *E. Santoni* (Italy), "Surveys of Automobile-Body Models and Car Parts Photographed from Various Distances."

The symposium was exceedingly well conceived, planned, organized, and run. The huge success of this International Meeting reflects high credit, indeed, on the Japanese photogrammetrists and on Japan in general. In addition to a smoothly functioning mechanism, the Symposium was characterized by the "human touch" extended so naturally and so freely by our Japanese colleagues. The hospitality of the hosts of the Symposium was simply overwhelming and beyond words. The serene, relaxed, and friendly atmosphere throughout the symposium, coupled with a most efficient organization resulted in a most productive and a most enjoyable experience to all participants. The Symposium of Commission V, I.S.P., is an excellent example of the clever way with which the Japanese people blend the oldest and most esteemed traditions with the newest and most advanced techniques in various walks of life. The success of this Symposium certainly qualifies Japan as one of the most serious contenders for one of the forthcoming I.S.P. congresses.