PRECISION AUTOMATIC PHOTOGRAMMETRIC INTERVALOMETER*

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Abstract

A singularly important parameter requiring close control for aerial photogrammetric work is the pulse repetition rate of the mapping camera. The required rate is directly proportional to the aircraft velocity to aircraft altitude ratio, V/H. When mapping terrain over which this V/H ratio is changing rapidly or abruptly and terrain which has incomplete ground control, the aerial photographer is challenged to maintain rigid tolerances on the forward exposure overlap. The Precision Automatic Photogrammetric Intervalometer (PAPI) is an instrument which utilizes a passive photoelectric detection scanner and an electronic converter to yield a DC voltage level proportional to V/H. This voltage level regulates the pulse repetition rate for operation of the mapping camera. Tests indicate that over irregular mountainous terrain the PAPI can be expected to meet mapping forward exposure overlap tolerances. Provision is made on the unit to select output pulse rate as a function of lens focal length, and to vary the pulse rate to correspond to forward exposure overlap requirement in the range of 50 to 80 per cent.

Introduction

THE Precision Automatic Photogrammetric Intervalometer (PAPI) has been developed by Chicago Aerial Industries, Inc. to accurately control the pulse repetition rate of the airborne mapping camera. Present mapping practices used manual pulsing based on the pinpointing of ground check points or intervalometer operation using a manually computed rate or viewfinder intercept method.

The first of these modes, the pinpointing of ground check points, is undoubtedly the most desirable form of operation. Whenever ground control is available, it is difficult to supplement that information with any other. Often, the ground control is inadequate in varying degrees so that use must be made of one of the other two modes. Over irregular terrain where the elevations are changing rapidly, the aerial photographer is often challenged to maintain the correct exposure interval. The PAPI has been designed to meet this challenge, to do the computation accurately, and to function automatically.

Computational Requirements

Aerial photographic mapping requires that the length of the stereoscopic base line in the line of flight be carefully controlled. An excessive stereo base results in either no coverage or incomplete coverage of the terrain, while a short base reduces the sensitivity of measurement. The desired base is a function of several variables. It is directly proportional to the camera altitude above terrain and the film length in the direction of flight. It is inversely proportional to the camera lens focal length.

Without flying at a prescribed altitude above terrain and when not having adequate ground control, it is not possible to use the base line directly to regulate the exposure interval. It is more convenient to bring in another variable, the forward velocity of the aircraft, to which the exposure interval will be inversely proportional. There is now a variety of factors which influence the exposure interval or its reciprocal, the pulse repetition rate. The required rate for a vertically mounted camera may be stated as follows:

$$\text{Pulse Repetition Rate in Seconds} = \frac{1.689VF}{HP(1-.01K)}.$$

Where:

V = aircraft ground speed in knots
F = camera lens focal length in inches
H = aircraft altitude above terrain in feet
P = format length in direction of flight in inches
K = forward exposure overlap in per cent.

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Of the factors in the foregoing expression, only V and H change during a flight, the other variables being a function of camera characteristics. It is required, therefore, to obtain V and H separately or in combination to insert into the above equation. The ratio of V/H is the angular rate at which terrain objects appear to be moving with respect to the aircraft. The Scanner portion of PAPI detects V/H data and the Discriminator portion alters the nature of the incoming data to a more useable form, completes the computations, and sends out the tripping pulse to the camera.

SCANNER

The Scanner is an electro-optical instrument which utilizes tonal differences of the reflected illumination from terrain objects to generate a frequency proportional to V/H. Figure 1 shows the optical geometry in schematic form. Light from the terrain is imaged on a bar grid in the focal plane of a highly corrected lens. Two identical assemblies within the Scanner are phased so that push-pull operation is achieved, thereby rejecting low frequencies which could result from large terrain patterns of different luminance. An optical condensing system collects the light passing through the grid and focuses it on the photocell. The electrical signal is amplified in the Scanner and, in this form, is used in the input stage of the Discriminator.

The Scanner, the volume of which is 0.14 cubic foot and the weight is 10 pounds, contains internal gyro stabilization of the electro-optical system. Due to the numerically low V/H values in the photogrammetric range, even small variations in aircraft attitude about the pitch axis would either add to or subtract from the real V/H rate and add a significant error to the desired data. The stabilization system erects automatically and rapidly to the Scanner housing when the optical axis of the system reaches 5 degrees from the mean position, whether the angular displacement results from the normal drift of the gyro or from angular deviations of the aircraft.

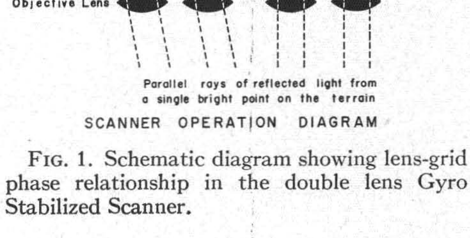

FIG. 1. Schematic diagram showing lens-grid phase relationship in the double lens Gyro Stabilized Scanner.

DISCRIMINATOR

The Discriminator is shown schematically in Figure 2. Electrical waveforms, where applicable, have been chosen to describe the operation. The clipper section eliminates the peaks to the incoming signal and adjusts the operating level. Both the high level multivibrator and the precision pulse generator receive the clipped signal but use it in different manners. The pulse generator discharges a condenser, through diodes, into the input of the computing and holding amplifier. The coulomb discharge per pulse is constant, and the rate for circuit convenience is double the Scanner frequency. Thus, the input current to the computing amplifier is proportional to the Scanner frequency.

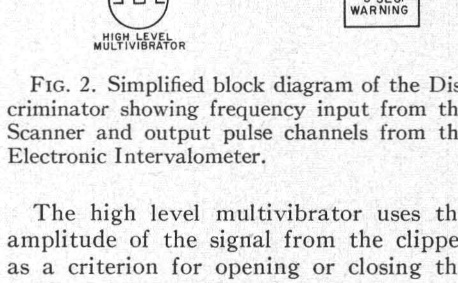

FIG. 2. Simplified block diagram of the Discriminator showing frequency input from the Scanner and output pulse channels from the Electronic Intervalometer.

The high level multivibrator uses the amplitude of the signal from the clipper as a criterion for opening or closing the holding relay. When the signal to the multivibrator is oscillating between prescribed limits, signifying good incoming signal amplitude from the Scanner, the relay contacts are maintained closed, allowing the pulsating current from the preci-

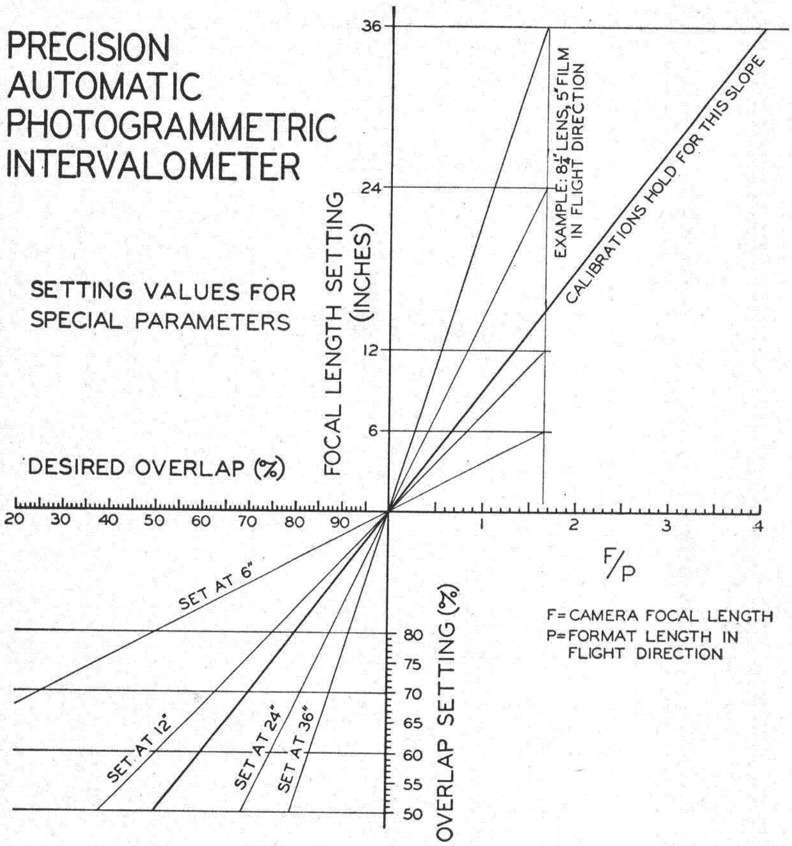

FIG. 3. Nomograph for extending overlap range and for obtaining setting values for special parameters.

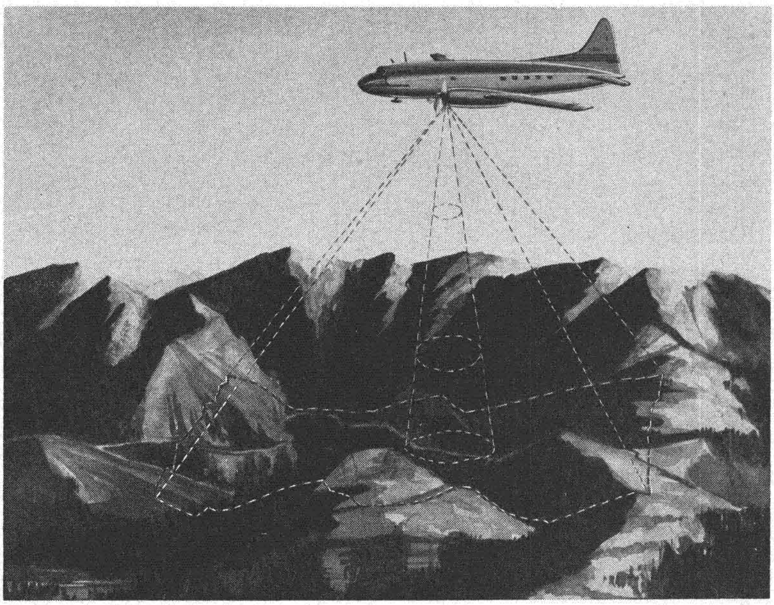

FIG. 4. Ground coverage of a 6 inch focal length 9 by 9 inch format size mapping camera and ground coverage of the Gyro Stabilized Scanner.

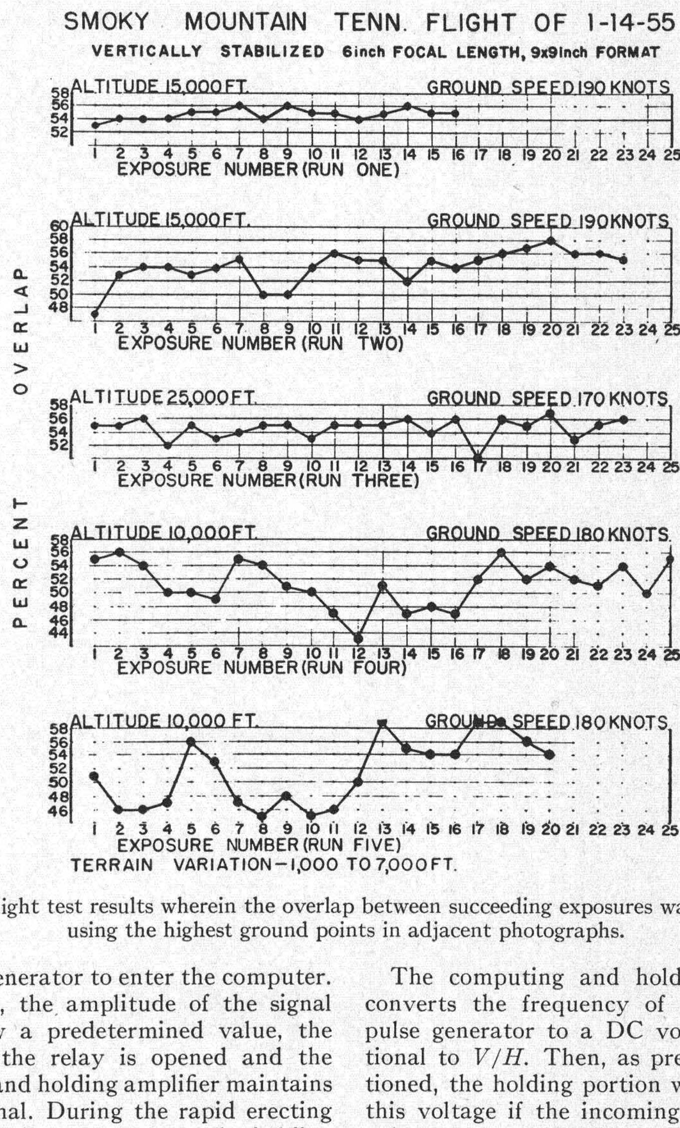

FIG. 5. Flight test results wherein the overlap between succeeding exposures was obtained using the highest ground points in adjacent photographs.

sion pulse generator to enter the computer. If, however, the amplitude of the signal drops below a predetermined value, the contact of the relay is opened and the computing and holding amplifier maintains the last signal. During the rapid erecting operation of the scanner gyro, the holding relay is also opened so the rates generated by the caging operation will not yield erroneous V/H information. The amplitude of the Scanner signal may drop below a useable value when the light and dark areas imaged on the grid are so phased that they produce poor signals. From an analytical statistical analysis, it is known that this may happen occasionally. From an operational point of view, it is known that the period of time without useable signal is brief. A uniformly reflecting cloud layer, which may intervene between the aircraft and the terrain, may yield the same effect.

The computing and holding amplifier converts the frequency of the precision pulse generator to a DC voltage proportional to V/H. Then, as previously mentioned, the holding portion will remember this voltage if the incoming Scanner signals are not useable.

The electronic intervalometer uses the $E(V/H)$ signal to control the repetition rate of the train of nominal 0.080 second wide camera trip pulses. By means of a frequency divider in this last stage, the PAPI can make a variety of pulse rates available. Figure 2 shows the outputs as applying to any camera or cameras having focal lengths of 6, 12, 24, and 36 inches. These values of focal length are based on a 9 inch format dimension in the direction of flight. If 5 inch or 70 mm. film were used, these focal lengths would be divided by 2 or 4 respectively. To further add to the flexibility of the PAPI, a continuously variable overlap control is provided, calibrated between 50 and 80 per cent. Various users of aerial photogrammetric photogrammetric photography desire the mean overlap to be 56 per cent, 57 per cent, 60 per cent, etc. These values can be set in with an external knob on the PAPI. If camera lens focal lengths are used which are different than 6, 12, 24, or 36 inches, and/or if the format length in the direction of flight is different than 9 inches, the aerial photographer can adjust the set-in data to obtain a wide range of overlap values. The graph shown in Figure 3 illustrates one possible procedure. On the abscissa in the first quadrant, the camera characteristics of focal length and format length define a ratio. This ratio, together with one of the four output channels on the ordinates, gives a point in the first quadrant. A line is then extended from this point through the origin into the third quadrant. The desired overlap may then be read on the abscissa as a function of the set-in overlap. In the example shown, that of an $8\frac{1}{4}$ inch lens and 5 inches of film in the flight direction, any value of overlap between zero and approximately 92 per cent may be obtained.

Three seconds before a pulse is sent out on any of the channels, a preliminary pulse suitable for operation of a 28 volt lamp is available from the PAPI. This warning is often helpful to the pilot as it will indicate when the aircraft should be held to a straight and level flight attitude.

Repair and maintenance of the Discriminator is simplified through the use of modular plug-in electronic packages. The size of the Discriminator, exclusive of the vibration isolator base, is .29 cubic foot and the weight is 18 pounds. Design and constructional methods have resulted in a product which is operationally suitable over a vast range of temperature, altitude, humidity, vibration, and shock conditions.

Performance and Range

Let us now go further into the performance capability and range of the PAPI. As has been mentioned, the instrument has been designed to give automatic opera-

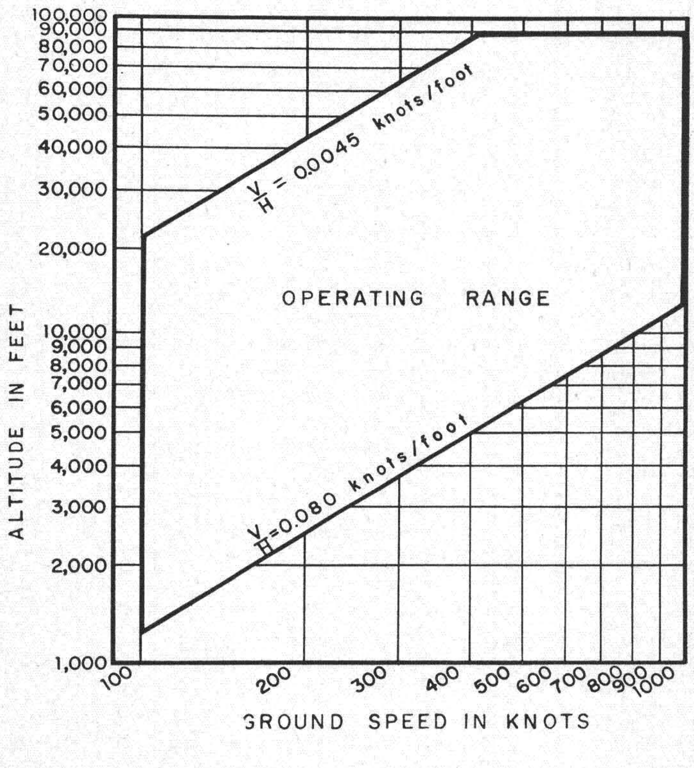

FIG. 6. PAPI operational range diagram.

tion over mountainous terrain. This, of course, is the most challenging type of operation. Level or gently sloping terrain presents no problem and except to state that plus or minus 2 percentage points about a mean overlap can be held, no further mention will be made of level terrain photography.

Figure 4 shows the type of terrain which is difficult to map without using the PAPI. The ground coverage of the 6 inch, 9 by 9 inch mapping camera has been shown together with the field of view of the gyro stabilized Scanner. The picture illustrates that for accurate operation, the height of terrain irregularities should be relatively small when compared with the altitude. The Scanner cannot anticipate the terrain irregularities which are being imaged by the camera forward of the nadir. It must adjust the rate when these irregularities come into its field of view.

In Figure 5 are shown the results of a number of photogrammetric runs over the Smoky Mountains in Tennessee. In the region photographed, the terrain was very irregular with elevations ranging between 1,000 and 7,000 feet. Five exposure runs between 10,000 and 25,000 feet above sea level were made in this region. Figure 5 graphically illustrates the resultant overlap. The PAPI was set for 54 per cent verlap on a 6 inch focal length 9 by 9 inch format size mapping camera. The overlap was measured using as a criterion the highest point in adjacent photographs. If, as some agencies direct, the photographs were measured using any two points in the adjacent pictures, the overlap variation would be markedly less. The important thing illustrated by these results is that when the *Delta* H/H is relatively small, the deviation of the overlap value from the mean is correspondingly small. In the lower altitude runs, the height above terrain varied a factor of 3 while in the high altitude run, the variance was but a factor of $1\frac{1}{3}$. Most photogrammetric operations will favor this latter figure and typically, the factor will be even closer to unity.

A V/H range of nearly 18:1 is incorporated into the PAPI. Restricting the range to this value has permitted the precision necessary for photogrammetric work. The graph of Figure 6 shows the operating range between the V/H values of 0.0045 and 0.08 knot per foot. Virtually all the photogrammetric operating range of ground speed and altitude combinations fall within the clear area and within the operating capability of the PAPI.

NEWS NOTE

Use of Airphotos in Highway Location

The Cornell University Airphoto Center will give a three-week course January 7–28, to State Highway Engineers on applying airphoto analysis to highway location projects. This is the first in a series that the Center will offer during 1956 for such specialists as water, gas and oil pipeline engineers, power transmission engineers and county highway engineers. The Center will also arrange special courses in any of these fields for groups of 10 or more from one organization. Director of the series is Prof. Theodore A. Cheney.

The Highway Engineers will spend half their time on learning how to identify kinds of bedrock and soils, and the balance in actual practice in laying out highways, taking into account topography, geology, soils and construction materials in the area. Facts the engineers can use every day will be emphasized, according to Professor Donald J. Belcher, Director of the Center, The engineers are urged to bring stereoscopic photographs from their own area to study.

Airphoto analysis and interpretation—sometimes called armchair surveying—is often faster, easier, less expensive and more accurate than studies made from ground observations alone. Not only can a broader view be obtained from the air, but frequently land patterns that show up clearly on airphotos escape detection on the ground. Vegetation, drainage and other patterns are clues to, and the direct result of, what lies below the surface.

The Airphoto Center, established in 1950, has undertaken a wide variety of projects—plotting airport locations, highways, wells, mineral resources, and industrial site locations.

It is too late to register for the Highway Engineers' course. For information on other planned courses write to Professor Cheney at the Airphoto Center, Lincoln Hall, Cornell University, Ithaca, N. Y.