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Rotary Focal-Plane Shutter Distortion

The geometric distortion is analyzed, and corrections for that distortion are presented.

ABSTRACT: *The rotary focal-plane shutter has the advantage that it can be run continuously without starting or stopping, which means that power requirements are reduced and that a high shutter speed can be used. However, due to its mode of operation, the rotary focal-plane shutter produces a geometrically distorted image. In this paper the mode of operation of the shutter is considered and the consequent image distortion is analyzed.*

INTRODUCTION

THE AERIAL CAMERA SHUTTER is one of the main components of the aerial photographic camera. It prevents light from striking the film emulsion during the time of exposure. In general, two types of shutters are used with modern frame cameras. These are the intra-lens shutter and the focal-plane shutter.

The intra-lens shutter or between-the-lens shutter is located in the air space between the elements of the lens. It is commonly used in mapping cameras and in some reconnaissance cameras. It admits light to all parts of the negative at one instant when opening, and cuts off the light from the whole negative at the moment when the exposure is completed. This mode of operation allows the image points on the negative to have a precisely defined relationship with all the object points photographed. This is the well-known perspective projection relationship which is the basis for normal photogrammetric operations (American Society of Photogrammetry, 1980).

On the other hand, the focal-plane shutter is located close to the focal plane of the camera. There are two types of focal-plane shutters. These are the parallel-curtain focal-plane shutter and the rotary focal-plane shutter. The former type is commonly used with large-format reconnaissance cameras, e.g., the British F126 and the American KA-30A reconnaissance cameras. The effect of the parallel-curtain focal plane shutter type on the image geometry has already been considered (Aldred, 1968; Nielson, 1975; ElHassan, 1982).

The objective of this paper is to analyze image distortion caused by the rotary focal-plane shutter.

OPERATION OF THE ROTARY FOCAL-PLANE SHUTTER

The rotary focal-plane shutter which has recently been developed, has a circular disk with a slit across its center that sweeps the focal plane, admitting light to pass to the film during the time of exposure (Figure 1).

This most interesting design has the great advantage that it can, if necessary, be run continuously so that there is no starting and stopping, no acceleration or deceleration, no change of direction, etc. This means that power requirements are lessened, that very high cycling speeds are possible, that and ultra-short exposure times can be used (up to 1/15,000 sec in the A.G.I. F139 camera).

The disadvantage of this shutter, however, is that the diameter of the disk must exceed twice the format size, which limits its use to small format cameras (70-mm film size), e.g., the Oude Delft TA-7, Williamson F-134, and A.G.I. F-139 Agiflite cameras.

Another interesting point that merits consideration is that the mode of operation of this shutter, as described above, causes a geometric image distortion. In order to use the photography produced by cameras equipped with this type of shutter for

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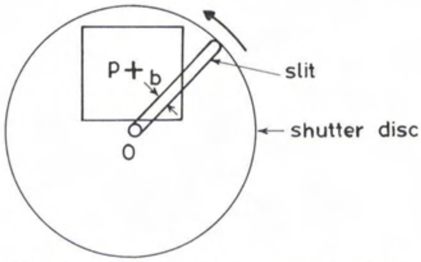

FIG. 1. The rotary focal plane shutter.

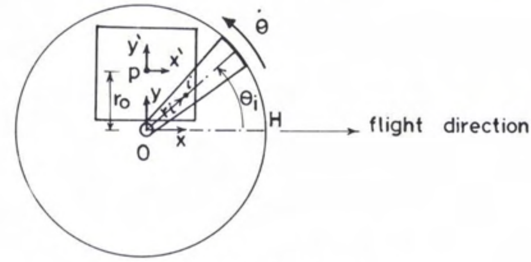

FIG. 3. Coordinate systems.

photogrammetric measurements, this geometric effect should be analyzed and the measured image coordinates should be corrected.

GEOMETRIC DISTORTION DUE TO THE ROTARY FOCAL PLANE SHUTTER

In the rotary focal-plane shutter the slit performs a circular motion while the exposure is taken. The slit speed, u_i, at any point, i, along the slit at radial distance, r_i, from the center of the slit motion, O, is given as

$$u_i = \dot{\theta}\, r_i \tag{1}$$

where $\dot{\theta}$ is the angular speed of the slit (radians/second). The exposure time, t_e, to expose the image point, i , is given as

$$t_e = \frac{b}{u_i} = \frac{b}{\dot{\theta}\, r_i} \tag{2}$$

where b is the width of the slit.

It is clear from Equation 2 that, if the slit width, b, is kept constant, the exposure time would vary from one part of the photograph to another due to the different speed of the slit at different radial distances from its center of rotation. However, the exposure time could be kept constant if the ratio, b/u_i, is kept constant (i.e., increasing the width of the slit, b, as the radial distance, r_i, increases). This leads to the use of a wedge-shaped slit as in the A.G.I. F-139 camera (see Aeronautical and General Instruments Ltd., 1977). This is illustrated by Figure 2.

Now, consider a coordinate system with the x-axis in the direction of flight, the y-axis perpendicular to the direction of flight, and with the center of motion of the slit, O, as origin (see Figure 3).

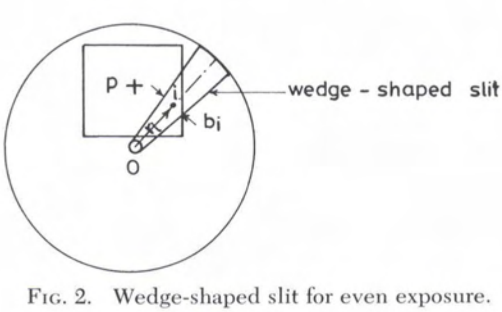

FIG. 2. Wedge-shaped slit for even exposure.

The slit would start its motion from the horizontal position OH, along the x-axis, in the counterclockwise direction. If the time taken by the slit to move from position OH to any point, i, is t_i (known as the shutter transit time), then the image distortion in the direction of flight caused by the craft motion during this time is

$$dx_i = \frac{V}{s}\, t_i \tag{3}$$

where V is the craft speed and $1/s$ is the photo scale.

If the angle between the x-axis and the slit position when point i is exposed is θ_i (in radians), then the shutter transit time, (t_i), to expose point i is

$$t_i = \frac{\theta_i}{\dot{\theta}} = \frac{\tan^{-1}(y_i/x_i)}{\dot{\theta}} \tag{4}$$

Therefore, Equation 3 can be written

$$dx_i = \frac{V}{s}\, \frac{\tan^{-1}(y_i/x_i)}{\dot{\theta}} \tag{5}$$

For the photo-coordinate system with the principal point, p, as origin and the x'- and y'-axes along and across the flight direction, respectively (Figure 3), Equation 5 would be expressed as

$$dx_i = \frac{V}{s\dot{\theta}} \tan^{-1} \frac{(y'_i + r_o)}{x'_i} \tag{6}$$

where r_o is the distance between the center of motion of the slit, O, and the principal point of the photograph, p.

CONCLUSION

Although high exposure times with low power requirements could be achieved using the rotary focal-plane shutter image distortion is introduced due to the mode of operation of the shutter. This distortion would be significant for large scale photography and high flying speeds. However, the measured photo-coordinates can be corrected using Equation 6. The information required is the photographic scale, the flying speed, and the angular speed of the slit.

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New Sustaining Members
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digitized and interfaced directly with minicomputers. Great Basin also performs their own off-line orthophoto profile scanning for the Wild OR-1 production system.

Analytic aerotriangulation using the bundle method of adjustment is done in-house using a one micrometre comparator, zoom PUG, and HP 1000 F minicomputer. This system is equipped with double disc drives, and magnetic and paper tape read and write capabilities with 512K bytes of random access memory. The computer section is also equipped with a 48 in. by 72 in. automatic plotting table and a multiple terminal environment.

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