A STUDY ON IMAGE RESTORATION FOR AIRBORNE CAMERAS

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ABSTRACT

Airborne remote sensing is used for gathering detailed information on the environment. However, there are many distortions associated with images taken by airborne optical sensors which must be corrected for by image restoration if the maximum amount of useful information is to be obtained. The correction of distortion and degradation due to the optical characteristics of the sensor system and the dynamic motions of the sensor platform is one of the most important factors in processing airborne remote sensor images. In this paper, two effective new approaches are applied to the restoration of such images. One is an image restoration scheme based on measuring the optical characteristics of the sensor system; the other is a scheme for correcting for distortions due to platform motion using flight data. These methods have been evaluated by several flight experiments, and some experimental results are presented.

1. INTRODUCTION

Environmental remote sensing from aircraft complements general observation by satellites because it can provide high-definition information on localized areas in a timely manner. Because of its immediacy, remote imaging of sea surface pollutants from aircraft has become very important for pollution monitoring of the marine environment, since detailed and accurate data are needed quickly to respond to pollution incidents.

However, there are various problems peculiar to the analysis of airborne remotely sensed images which do not affect satellite-based observations, including factors related to the sensor system and the dynamic motions of the aircraft. In this paper, methods are examined for compensating for the optical characteristics of the sensing system, and for compensating for aircraft motions and altitude variations based on recorded flight data. These methods have been evaluated and proven by flight experiments, as described below.

2. PROBLEMS OF RESTORATION OF IMAGES FROM AIRBORNE IMAGING SYSTEMS

Compared to satellite-based observation, airborne remote sensing affords the possibility of delivering high-resolution images of different types taken with comparatively simple sensors in a timely manner. For analysis, a universal image restoration system is required which takes into account all the factors which may affect the appearance of the image but which is independent of the actual imaging system used.

Optical lenses are affected by the five aberrations of Seidel, namely spherical aberration, coma, astigmatism, distortion, and curvature of field. Of these, distortion and curvature of field are the most problematic, and for wide angle lenses in particular, curvature of field can result in a dimming of the peripheral parts of the image off the optical axis. In addition, in airborne imaging systems, the image is distorted geometrically by attitude changes of the aircraft platform, and this distortion changes continually due to changing atmospheric conditions and flight course. Each image taken in a sequence will therefore have a slightly different distortion.

To correct for these problems, the following compensations are applied: compensation for optical distortion; compensation for the variation in image brightness due to lens curvature of field; and compensation for the effects of aircraft motion.

3. SYSTEM OUTLINE

The apparatus used in this research is shown in Fig. 1. Flight experiments were conducted using a Dornier Do.228 research aircraft equipped with a flight data acquisition system (FDAS) and flight management system (FMS) (see Flight Research Division , 1991), a range of installable sensors, and imaging systems such as a photographic camera. Analysis equipment include a personal computer for reading digitized photographic images stored on CD-ROM; a workstation and peripherals such as a color printer for image processing; and standard test patterns and a light-integrating sphere for measuring lens characteristics.

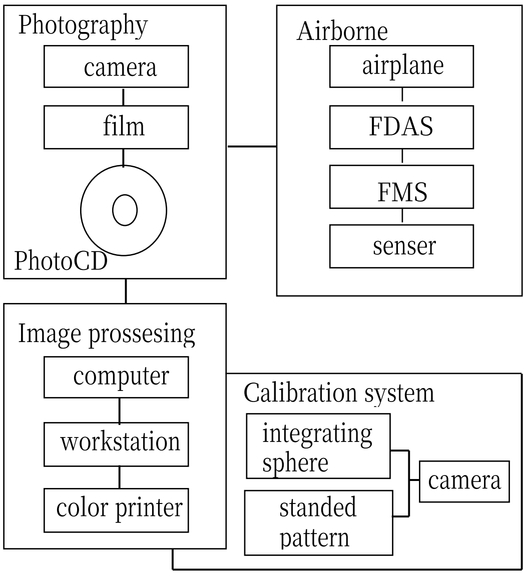


Fig. 1 Image Restoration System

(1) The principal factors affecting imaging are characteristics of the sensor system such as lens resolution and aberrations, angle of view, focal length and aperture, and camera shutter speed, and characteristics of the recording film such as resolution and gamma-characteristics. For processing airborne remotely sensed images, there are also factors peculiar to flight such as speed, altitude, attitude, and time information, derived from the FMS and GPS (Global Positioning System) navigation systems, which must be taken into account. Weather is also an inevitable factor.

(2) For image processing, photographs taken using the airborne camera were digitized and stored on CD-ROM. These digitized images were then read using a personal computer and transferred to a workstation for image processing. Processed images were output on a color printer.

(3) To correct for optical system deficiencies, it is necessary to determine the characteristics of the lens. Lens distortion was measured using a test pattern composed of regularly spaced lines. Lens curvature of field results in a decrease in image off-axis brightness and was measured using the integrating sphere by changing the illumination incident on the lens. The light source for this measurement must emit light rays parallel to the lens axis (Fig. 2).

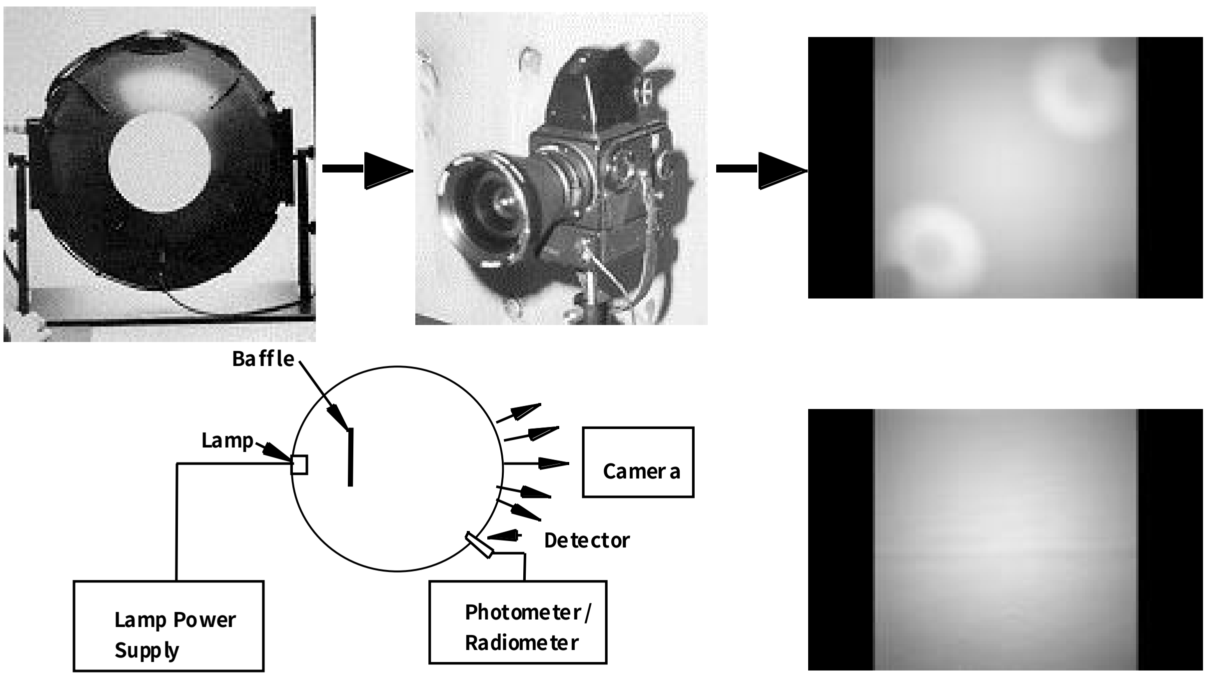


Fig.2 Luminance measurement

4. CORRECTING OPTICAL DISTORTIONS

There are a number of techniques for correcting for image degradation due to optical aberrations, variations in image brightness due to weather conditions, and so forth. Techniques were selected for this application based on their convenience and adaptability.

For images taken from an airborne camera, it is necessary to correct for factors such as optical system deficiencies and the motions of the aircraft. Such corrections include 1) corrections for the optical characteristics of the sensor system; 2) compensating for reduced image brightness due to weather conditions at the time of taking; 3) compensation for the motion of the aircraft at the time of taking; 4) corrections when joining overlapping or abutting images; etc.

The following conditions were assumed for the unprocessed images: 1) the optical axis of the lens passes through the image; 2) optical distortion and variation of lens transmission due to curvature of field are symmetric about the optical axis; 3) aberrations on or near the optical axis are negligible and can be disregarded; 4) the variation of lens transmission manifests as a variation in brightness over the image.

4.1. Compensation for Distortion

Compensation for distortion was made using the measured geometric distortion characteristics of the optical system. Distortion is symmetric about the lens optical axis. If R denotes the radial distance of a point from the optical axis and if F is a function which expresses the distortion of the optical system, then the distance r from the optical axis to the point which moves to as a result of the distortion can be described by:

$$r = F(R) \tag{1}$$

Expressing this in terms of the inverse (correction) function f, we obtain:

$$R = f(r) \tag{2}$$

The form of this distortion correction function f is given by:

$$f(r) = \Sigma C_n r^n \quad (n=0,1,2,\cdots) \tag{3}$$

Coefficients C_n can be found by least-squares approximation, and the distortion can then be corrected using these coefficients.

4.2. Correcting for Non-Uniform Lens Transmission

Compensation was made for the decrease in image brightness off-axis due to curvature of field aberration using measured optical system characteristics.

The brightness I' of a point at a radial distance r from the optical axis due to aberration can be expressed as a function G of distance r off-axis and of I, the brightness of the point if there had been no aberration.

$$I' = G(r, I) \tag{4}$$

The function G thus shows the degree of brightness attenuation versus distance from the optical axis. The G-curve is obtained by measuring the brightness of the output of an integrating sphere while changing the input voltage of the light source. Since the light source is uniform in the integrating sphere, the least squares approximate coefficients are obtained for each value of incident illumination I based on the equation (5).

$$G(r, I) = \Sigma D(n, I)\, r^n \tag{5}$$

It can be proven that if the degree of the approximate curve obtained by plotting brightness against distance r from the optical axis agrees closely with G(r, I), then the term n in equation (5) is the “original” (undistorted) brightness I of the point. However, if the curve does not agree with G(r, I) , then the undistorted brightness is not obtained.

If G is required for all values of brightness I, although it is possible to obtain the original brightness for a given r directly, in practice it is difficult to do so. Instead, if the curve G is obtained for ten values of I at regular intervals, $G(r, I_k)$ (k=1,2,3, …, 10), the change in brightness within each interval is approximately linear. If the brightness I’ corresponding to distance r is within the interval between $G(r, I_k)$ and $G(r, I_{k+1})$, then the value of the original brightness I is between I_k and I_{k+1} and can be interpolated using the ratio dividing $G(r, I_k)$ and $G(r, I_{k+1})$ according to the following equation:

$$I = \{G(0, I_{k+1})-G(0, I_k)\}\{I'-G(r, I_k)\} / \{G(r,I_{k+1})-G(r, I_k)\} + G(0, I_k) \quad (6)$$

where $G(r, I_k) \leqq I' \leqq G(r, I_{k+1})$.

By applying these corrections, the joins of a series of aerial photographs of an oil effluence were treated using an affine transformation to make the GCP point in each image a standard value, as described in section 6.1 below.

5. CORRECTING DISTORTION DUE TO AIRCRAFT MOTION

Distortion due to the effects of aircraft attitude is a large problem in aerial imaging, since the surface resolution is greater than for satellite images, and compensation for this is an inevitable problem in aerial image analysis. Corrections can be made if the aircraft attitude at the time of taking is known. Images have been restored on the basis of attitude information recorded by the FDAS which has been developed by our laboratory, the shutter trigger time being synchronized with the FDAS record. Attitude interpolation is also introduced to allow flexibility in selecting the camera mounting system.

Equations (7) below show projection transformations for rotations about each of the three body-fixed aircraft axes (yaw angle κ, pitch angle ϕ, roll angle ω), where c is a scale factor (see Fig. 3):

$$
\begin{aligned}
x_\kappa &= \cos\kappa\, x_\kappa + \sin\kappa\, y_\kappa \\
y_\kappa &= -\sin\kappa\, x_\kappa + \cos\kappa\, y_\kappa \\
x_\phi &= (x + c\tan\phi)/(1-(x/c)\tan\phi) \\
y_\phi &= (y\sec\phi)/(1-(x/c)\tan\phi) \\
x_\omega &= (x\sec\omega)/(1+(y/c)\tan\omega) \\
y_\omega &= (y - c\tan\omega)/(1+(y/c)\tan\omega)
\end{aligned}
\quad (7)
$$

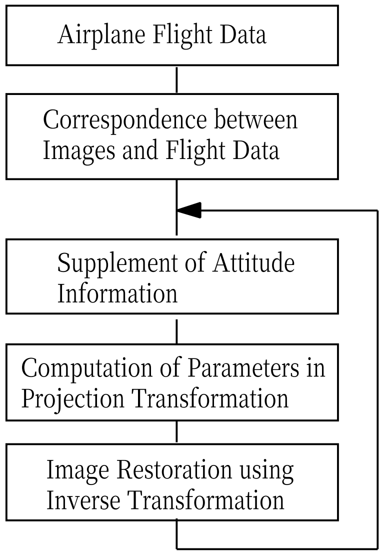


Fig. 3 General Flow for Restoration of Images Distorted by Flight Dynamics

6. IMAGE RESTORATION APPLICATION EXPERIMENTS

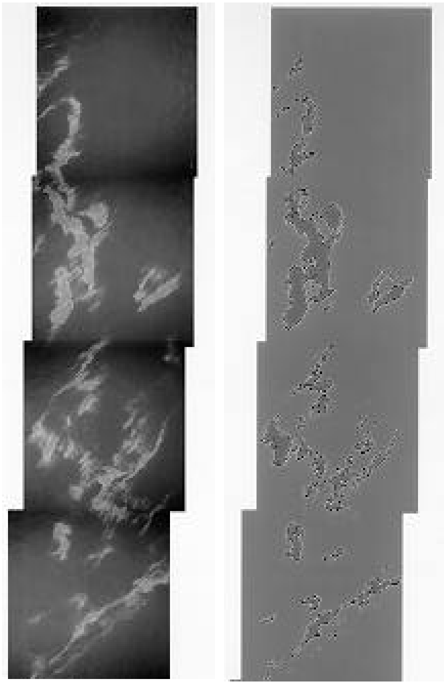
6.1. Application to Aerial Photographs of a Heavy Oil Effluence

This is an example of the application of the image restoration techniques to aerial photographs taken for marine pollution monitoring of a heavy oil effluence in the Sea of Japan. The planned flight path was input into the Do.228's FMS in advance, and position, attitude, height, azimuth and time information were recorded from a GPS navigation system. The heavy oil effluence was photographed using a Hasselblad camera equipped with a motor drive.

Fig. 4 shows that a wide area of open sea north-northwest of the Noto Peninsula was surveyed to confirm the site of the oil effluence. Darkening observed in the original photographs due to optical aberration (left photograph) has been restored, and the part showing the oil contamination has been made clearer.

6.2. Flight Verification Experiment

An experiment was carried out to evaluate the correction of image distortions caused by aircraft motion using the Hasselblad camera system for which the optical characteristics had been determined and our institute's Do.228 research aircraft. A sequence of images was taken in which a trigger pulse was used to synchronize the camera's shutter with the FMS. After the flight, the images were joined using multiple GCPs. Because the shutter trigger times did not perfectly coincide with the sampling times of the roll, pitch and yaw data, the flight data were tabulated and attitude information



Airborne Raw Images　　Processed Image
Fig.4　Restoration of Ocean Pollution Image Distorted by Optical Distortion

was interpolated. The images were then corrected based on the projection transformations described in section 5.

In this flight verification experiment, a comparatively simple, well-defined surface feature was selected as a target object and photographs were taken from a height of between 1,640 ft and 1,700 ft with the attitude of the aircraft varied
in increments of 5 degrees of pitch angle and 5 degrees of roll angle. The results of the experiment are shown in Figs. 5 and 6, the left side showing the joined original aerial photographs and the right side showing the result of corrective processing.

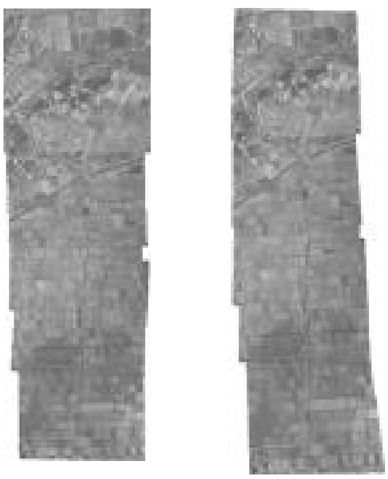
7. CONCLUDING REMARKS

The system described in this paper forms the basis of a system for image restoration which can deal with distortion due to changes in sensor platform attitude angle, a problem which is inherent in airborne imaging systems. The system is universally applicable to all airborne imaging systems. Such an image processing system which uses flight dynamics information is expected further to increase the timeliness of observation data.

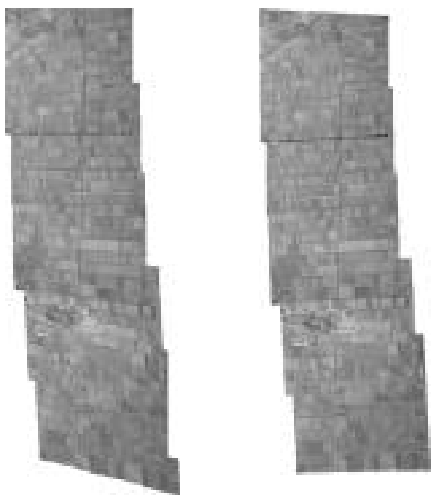
The efficient systemization of the corrective processing and the substantive verification of flight parameters are future problems. The image restoration system must be automated as much as possible to eliminate bottlenecks from the processing, to secure objectivity, and to reduce workload on the analyst. The digitization of analog information of photographic film and the acquisition of accurate parameters necessary for performing image corrections are also of fundamental importance. The identification of further flight and optical system parameters which can affect imaging and their application to the corrective processing are future problems.

REFERENCES

Flight Research Division , 1991. NAL Dornier 228-200 Flight Research Airplane、Technical Memorandum of National Aerospace Laboratory、TM637.



Airborne Raw Images　　Processed Image
Fig.5 Image Restoration of Airborne Image Distorted by Attitude Deviation (Pitching Angle=5deg)



Airborne Raw Images　　Processed Image
Fig.6 Image Restoration of Airborne Image Distorted by Attitude Deviation (Rolling Angle=5deg)