An airborne pushbroom hyperspectral imager with wide field of view

Peixin Hu (胡培新)[1,2], Qimin Lu (卢绮闵)[1,2], Rong Shu (舒 嵘)[1], and Jianyu Wang (王建宇)[1]

[1]*Shanghai Institute of Technical Physics, Chinese Academy of Sciences, Shanghai 200083*

[2]*Graduate School of the Chinese Academy of Sciences, Beijing 100039*

Received August 10, 2005

An airborne pushbroom hyperspectral imager (APHI) with wide field (42° field of view) is presented. It is composed of two 22° field of view (FOV) imagers and can provide 1304 pixels in spatial dimension, 124 bands in spectral dimension in one frame. APHI has a bandwidth ranging from 400 to 900 nm. The spectral resolution is 5 nm and the spatial resolution is 0.6 m at 1000-m height. The implementation of this system is helpful to overcome the restriction of FOV in pushbroom hyperspectral imaging in a more feasible way. The electronic and optical designs are also introduced in detail.

OCIS codes: 300.6320, 110.0110, 220.4830.

Hyperspectral imager was brought up in 1970s. It has more spectral bands and higher resolution. Hyperspectral imager is an innovation in remote sensing field because of its potential in mine finding, pollution examining, atmosphere researching, etc.. Just as its name implies, hyperspectral imager can record spatial and spectral information of target at the same time.

Hyperspectral imager is classified by the architecture into spatial scanner, spectral scanner, and pushbroom imager. Because of its long staring time, high spatial and spectral resolution, small mechanism pushbroom imager has been paid more attention to during these years in remote sensing. But restricted by dimension of imaging sensor and optics designing difficulties, field of view (FOV) of pushbroom hyperspectral imager cannot be larger than 30°[1]. So in normal application, its work efficiency is not sufficient. In order to match the efficiency of airborne photography, larger FOV is necessary.

To get a larger FOV, a simple way which puts two imagers with smaller FOV together is used to enlarge the FOV of pushbroom hyperspectral imager. The method avoids the restriction of FOV of pushbroom hyperspectral imager. There are two main design keys of the system. The first is optical adjustment. Two splits of pushbroom hyperspectral imagers should be adjusted on the same line to reduce the requirements of image mosaic. The second is electronic system design. Because the imagers are independent and data rate is double, the control and data acquisition system needs to adapt this architecture. Electronic system should provide higher performance to sustain two imagers. So there is not similar system in internal field.

By using spot lamp scan, two imagers are adjusted on the same line in half pixel discrepancy. Master/slave architecture are applied in the control and data acquisition system design. To improve the practicability and flexibility, Ethernet is used for electronic system integration in airborne hyperspectral imager system. Figure 1 shows the layout of the wide FOV pushbroom hyperspectral imager.

The spectrograph of hyperspectral imager is based on the ImSpector of Spectral Imaging Ltd.. ImSpector is a direct sight imaging spectrograph that can be quickly combined with a broad range of monochrome matrix cameras to form a spectral imaging device. The ImSpector employs a new direct sight (on-axis) optical configuration and a volume holographic transmission grating[2]. This grating is used in a patented prism-grating-prism (PGP) construction which provides high diffraction efficiency and good spectral linearity. It is nearly free of geometrical aberrations due to the on-axis operation and independent of incoming light polarization due to the use of transmission optics only. The construction and operating principle of the direct-vision, dispersing PGP element are illustrated in Fig. 2.

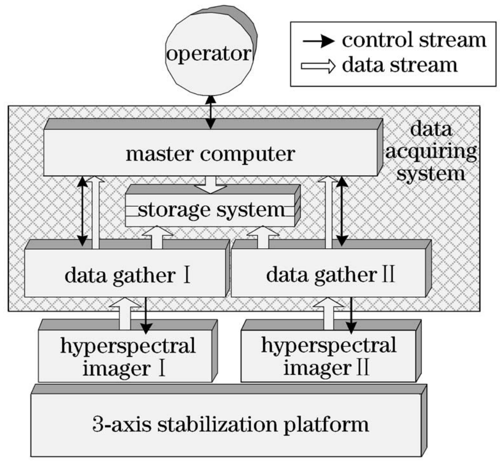

Fig. 1. Layout of airborne pushbroom hyperspectral imager (APHI).

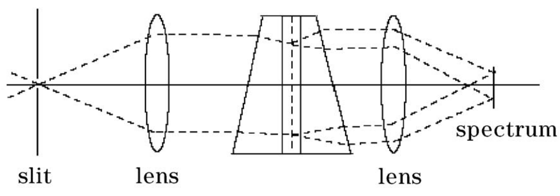

Fig. 2. Basic principle and one possible layout of the PGP spectrograph.

Based on the PGP, ImSpector captures a line image of a target and disperses light from each line image pixel to spectrum. Each spectral image then contains line pixels in spatial axis and spectral pixels in spectral axis. In consequence it is possible to acquire full spectral information for each line image acquired from the target. Since ImSpector sequentially captures images of the moving target or by moving itself, a two-dimensional (2D) spectral image can be formed. This technology allows diversified opportunities to analyze the target accurately based on its spectral features.

The optical design is based on the division FOV with two separated camera lens to get higher modulation transfer function (MTF) (about 0.7)[3]. It can also reduce the difficulty of optical design. Figure 3 shows the optical architecture of the system.

But this configuration will introduce aperture aberration and geometrical aberration. It must be considered when pre-processing the image.

The small FOV hyperspectral imager selected for this system is pushbroom hyperspectral imager II (PHI-II) in Fig. 1, which has 652 pixels in spatial dimension and 124 bands in spectral dimension. It covers visible band from 400 to 900 nm which has been developed for remote sensing from airborne platform. The imager has been designed to acquire the full spectrum at high spectral resolution (5 nm) and the full image swath at high spatial resolution (0.6 m at 1000 m) simultaneously. The hyperspectral images are digitized to 12 bits and the frame rate is 50 frames per second.

When optically adjusting, a little light spot horizontally scans two imagers. By calculating the luminance, the spot position in the pixel can be estimated down to half pixel. When being adjusted on the same line, two imagers are fixed on the rigid table. There are 21° between them. The overlap rate is measured for data pre-processing.

Hyperspectral images include both spatial and spectral redundancies[4]. So it requires huge high speed data acquiring system. The APHI produces more than 16 MB data per second. To fulfill the requirement of data acquisition system, master/slave architecture is introduced. The master is a high performance computer, the kernel of whole system. It is the control center and provides

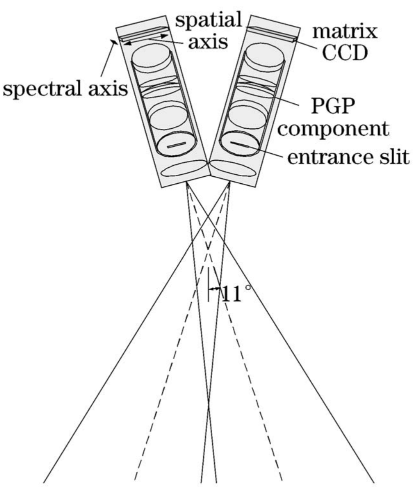

Fig. 3. Optical system.

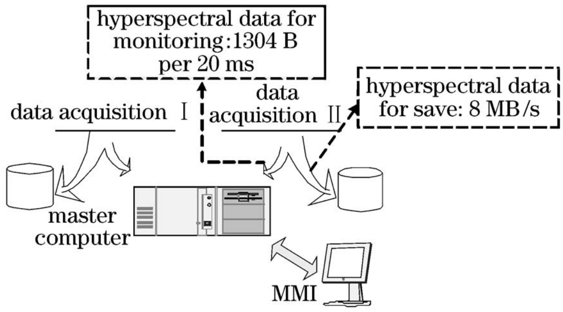

Fig. 4. Data acquisition system of APHI.

man-machine interface (MMI) and system monitoring.

As shown in Fig. 4, data acquiring system consists of a master computer, a storage system and two data acquisition units. The data acquisition units are bare systems. They are controlled by the master computer. The functions of them are only to capture image data of the cameras and to save them into removable storage system via ultra160 small computer system interface (SCSI).

Because of its practicability, expandability, and high speed, 100-M industrial Ethernet is used to connect master computer and data acquisition units.

The data acquisition system can offer 40 MB/s recording rate. Storage system contains up to 8 SCSI hard disks. Its capability is 584 GB maximum and can store data continuously for ten hours. Removable storage system simplifies ground data transfer.

The APHI specifications are summarized in Table 1. In the lab imaging, the system provides high quality wide breadth images. It indicates that the optical adjustment

Table 1. General System Specifications

Spectral Coverage (nm)	400—900
Spectral Number (bands)	124
Spatial Number (pixels)	652 × 2
FOV (deg.)	42
Frame Rate (Hz)	50

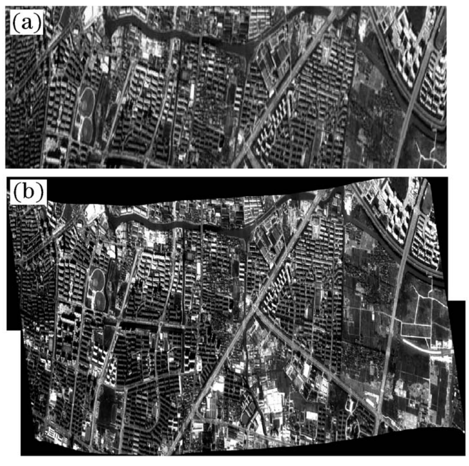

Fig. 5. Images obtained by using normal (a) and wide FOV (b) pushbroom hyperspectral imager.

and master/slave electronic system are successfully applied. The APHI breaks the restriction in the hyperspectral imager, providing 42° of FOV.

The wide FOV pushbroom hyperspectral imager is used in the pollution examining and city planning. Figure 5 shows two gray images obtained by using APHI and a small FOV hyperspectral imager for Shanghai Pudong.

APHI with wide FOV can increase the efficiency of pushbroom hyperspectral imagers. This will enlarge the range of its applications. And wider FOV can match the airborne photography better. So APHI with wide FOV can get more information in one flight. It can reduce the cost of airborne remote sensing. The main application of APHI includes larger area airborne remote sensing work such as marine supervision, cropper evaluation, and so on.

This work was supported by the National "863" High Technology Project of China (No. 2001AA131019). P. Hu's e-mail address is px_hu@21cn.com.

References

1. H. Shao and Y. Xue, *Development of Infrared Photo Electricity Technology* (in Chinese) (Shanghai Institute of Technical Physics Press, Shanghai, 1998) p.157.
2. Spectral Imaging Ltd., *ImSpector Imaging Spectrograph User Manual Version 2.21* (2003) Chap.1, 5.
3. X. Z. Han, *Space Remote Sensing CCD Pushbroom Imaging System* (in Chinese) (Harbin Institute of Technology Press, Harbin, 1990) chap.4.
4. J. Wu and C. Wu, Chin. Opt. Lett. **2,** 325 (2004).