Light-Weight Aerial Hyperspectral Imaging remote sensing system for regional geological and mineral resources surveys

Peng Zhang1,2, Taixia Wu1, Lifu Zhang1*, and Qingxi Tong1
1Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing, China
2University of Chinese Academy of Sciences, Beijing, China
*Corresponding author: zhanglf@irs.ac.cn

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ABSTRACT: Hyperspectral imaging can provide both continuously spatial and spectral information of the Earth's surface that allows us mapping of the regional geological and mineral resources information. One of the most successful applications of hyperspectral imaging remote sensing identified was regional geological and mineral resource surveys. A light-weight airborne hyperspectral imaging system (LAHIS) has been developed in China. The hardware of the compact LAHIS include hyperspectral VNIR imaging sensors, a hyperspectral SWIR imaging sensors, high resolution optical remote sensor and a POS (IMU and DGPS). The weight of the system is less than 23kg. The VNIR hyperspectral imaging sensors measures incoming radiation in 250 contiguous spectral channels in the 400–1000 nm wavelength range with spectral resolution of better than 2-3 nm and creates images of 334 pixels for a line of targets with a nominal instantaneous field of view (IFOV) of ~1 mrad. The SWIR hyperspectral imaging sensors measures incoming radiation in 256 contiguous spectral channels in the 1000–2500 nm wavelength range with spectral resolution of better than 6 nm and creates images of 320 pixels for a line of targets with a nominal instantaneous field of view (IFOV) of ~2 mrad. The 400 to 2500nm spectral range provides abundant information about the regional geological and mineral resources information. Two ground mineral scan experiment and an UAV carried flying experiment has been done. The experiment results show the LAHIS have achieved relative high performance levels in terms of signal to noise ratio and image quality. The potential applications for light-weight airborne hyperspectral imaging system in the regional geological and mineral resources survey are tremendous.

1. INTRODUCTION

Imaging spectroscopy began a revolution in remote sensing by combining traditional two-dimensional imaging remote sensing technology and spectroscopy (A. F. H. Goetz, 1995; A. F. H. Goetz, 2009; A. F. H. Goetz, G. et al., 1985), allowing for the synchronous acquisition of both images and spectra of objects. Hyperspectral images contain a wealth of geo- and radiometric information as well as abundance spectral information for narrow spectral bands (typically about $10^{-2}$ λ) from the ultraviolet and visible to shortwave infrared for each pixel. Due to the unique advantage, many advanced aircraft hyperspectral imaging have been designed and developed since the 1980s, such as AVIRIS (1987, USA), CASI (1989, Canada), ROSIS (1992, Germany), HYDICE (1995, USA), HYMAP (1997, Australia), SASI (2001, Canada). China has also made great achievements in the development of airborne hyperspectral sensors with the support of various national major projects, including the Operational Modular Hyperspectral imaging (OMIS-I and OMIS-II, 1985), the Pushbroom Hyperspectral Imager (PHI, 1990), and the Modular Airborne Hyperspectral imaging (MAIS, 1991). The above-mentioned instruments have been used successfully in numerous applications including precision agriculture, forestry monitoring, food security, natural resources surveying, vegetation observation, and especially the regional geological and mineral resources survey.

However, these airborne hyperspectral sensors, mainly installed on the manned aircraft and are too heavy. So it cannot fully meet the increasing demand for emergency precise monitoring of natural disasters and frequent mineral survey owing to their operational cost, complex and inflexible. In order to solve such problems, a light-weight airborne hyperspectral imaging system (LAHIS) has been recently designed and assembled in China. The LAHIS include two hyperspectral imaging sensors (a VNIR hyperspectral imaging sensors and a SWIR hyperspectral imaging sensors) as well as high resolution optical remote sensor and a POS. The weight of the overall system is less than 23kg, so that the LAHIS could be installed on the Unmanned Aerial Vehicle (UAV). Compared to traditional aircraft hyperspectral payloads on manned aircraft, the main advantages of the LAHIS are more flexible, cost-effective, light-heavy, which makes it possible to carry out frequent monitoring of agriculture, forestry, water resources, and the regional geological and mineral resources survey by providing high spatial, spectral, and temporal resolution images. The LAHIS is fast moving into the mainstream of remote sensing and therefore is an appealing research topic.
2. INSTRUMENT

2.1 Sensors

The LAHIS is developed by Chinese Academy of Sciences. The weight is less than 23 Kg and can be installed on light-weight airborne, airship or unmanned aerial vehicles. The specifications of hyperspectral imaging of LAHIS are determined by the availability of dispersion compensations and detectors. With optical throughout and light-weight considered, convex grating hyperspectral imaging is chosen in our LAHIS. Figure 1 depicts components and relative locations in the system.

Figure 1. A light-weight airborne hyperspectral imaging system

The main sensors of the system are VNIR hyperspectral imaging sensor and SWIR hyperspectral imaging sensor. Other instruments, such as POS and high resolution optical remote sensor are accessory hardware serving for the hyperspectral imaging sensors. VNIR hyperspectral imaging sensor are from HeadWall Corporation, covering 400-1000nm, with 25μm slit and corresponding 2-3nm spectral resolution. It has 250 spectral bands and 344 spatial bands. SWIR spectrometer covers 1000-2500nm wavelength range, with 25μm slit and corresponding 8-12nm spectral resolution. The spectrometer has 256 spectral bands and 320 spatial bands. SWIR detector is sensitive to temperature change. So HgCdTe detector and control and communication electronics are all packed in one compact house. Four stages thermo-electrically cool method is used to cool the entire house. Therefore the instrument will perform high spatial and spectral resolution, high signal-to-noise (SNR) with low stray light.

A high resolution optical remote sensor is also mounted into LAHIS system. The high resolution image is used to location flight area quickly. A contax 645 camera with a Phase One 645 digital back and an 80mm planar objective lens is used to capture images. The digital back has a 40.4×53.9mm large sensor with 8984 × 6732 pixels to provide high detailed information of the target area. Cameras used in this UAV platform should have the highest frame rates with desired resolution. Creating imagery of a scene with multiple images stitched together. With reliable Camera Shutter, high frame rate will provide more overlap and will make image mosaicking easier.

Table 1. The main technical parameters of the LAHIS system

<table>
<thead>
<tr>
<th>Model Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Spectral Coverage</td>
<td></td>
</tr>
<tr>
<td>VNIR</td>
<td>400-1000nm</td>
</tr>
<tr>
<td>SWIR</td>
<td>1000-2500nm</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td></td>
</tr>
<tr>
<td>VNIR</td>
<td>2-3nm</td>
</tr>
<tr>
<td>SWIR</td>
<td>8-10nm</td>
</tr>
<tr>
<td>Band number</td>
<td></td>
</tr>
<tr>
<td>VNIR</td>
<td>250</td>
</tr>
<tr>
<td>SWIR</td>
<td>256</td>
</tr>
<tr>
<td>Spectroscopic methods</td>
<td>convex grating</td>
</tr>
<tr>
<td>Field of view</td>
<td>&lt;2.0mrad</td>
</tr>
<tr>
<td>Digitalizing bit</td>
<td>12</td>
</tr>
</tbody>
</table>
2.2 System Calibration

In order to determine the center wavelength and the FWHM for each spectral channel, a DK-242 monochromator was used for the VNIR hyperspectral imaging and SWIR hyperspectral imaging spectral calibration respectively. The two cascaded monochromator with the exit slit of the first monochromator functioning as the entrance slit of the second. This instrument and self-developed spectral calibration software was provided by the Anhui Institute of Optics and Fine Mechanics, Chinese Academy of Sciences. An integrating sphere was used as an indoor light source to fill the entire field of view of the LAHIS. A well-calibrated SVC HR1024 spectrometer was placed close by (spectral resolution < 3 nm; spectral sampling bandwidth 1.5 nm within the region 350 – 1000 nm). By changing the radianc of the integrating sphere (i.e., by controlling the number of bright and dark standard lights within the integrating sphere; a total of 17 levels), we established a quantitative relationship between the entrance radianc at the pupil of the LAHIS and the digital number. The SVC HR1024 spectrometer was used to cross-calibrate the LAHIS system. To simplify the experiment, the integration time and CCD cooling temperature were set to constant values respectively, which are consistent with the actual measuring conditions. Figure 2 shows the indoor radiometric calibration experiment set-up.

Both the spectral calibration and radiometric calibration experiments were carried out in a dark optical laboratory. Calibration results showed that the spectral range of the VNIR hyperspectral imaging is 437-902 nm, the channel number is 250, and the spectral resolution of each channel is better than 4 nm(L. Zhang et al., 2011); and that the spectral range of the SWIR hyperspectral imaging is 1000-2500 nm, the spectral resolution of each channel is better than 6 nm. For the radiometric properties, the LAHIS has achieved preferable results with less than 5% absolute radiometric calibration error for each band and with signal to noise ratio (SNR) greater than 500 for most spectral bands.

3. EXPERIMENT

To test the effectiveness of the LAHIS system, two ground mineral scan experiment (indoor and outdoor experiments) and an UAV carried flying experiment has been conducted. Because the system designed for mineral surveys, we mainly test the SWIR hyperspectral imaging.

3.1 Field Experiment

3.1.1 Indoor Field Experiment

Halogen lamp is used as the light source in the indoor field experiment. The halogen lamp cover the spectral range from 400nm to 2500nm, which could meet the requirement of the experiment. In this experiment, we use a gray reference panel with approximately 50% reflectance to conduct the object’s reflectance. We acquire the SWIR
A hyperspectral image of the six kind of minerals sample, including calcite, gypsum, albite, anorthose, Tremolite and montmorillonite. The preprocessing workflow is shown in Figure 3. As is shown in Figure 4, we compared the spectral curve with the USGS spectral library.

**Figure 3. Preprocessing Workflow of FISS-SR Data**

**Figure 4. Comparison of FISS-SR Spectra and USGS Spectra**

3.1.2 Outdoor Field Experiment

The study area of the field experiment is an abandoned golden mine located at Pingquan, Hebei Province, China. The weather on the experiment day was a little cloudy, which caused some bad effects on the data quality. The condition of the study area is shown in Figure 5.

![Figure 5. condition of the study area](image)

The 3D Cube of SWIR field experiment data is shown in Figure 6. As shown, the data has both high spatial resolution and spectral resolution.

![Figure 6. 3D Cube of SWIR field experiment data](image)

Using the Spectral Angle Mapper tool in ENVI 4.8 software (F. Kruse et al., 1993), four kinds of minerals were extracted from the SWIR hyperspectral image. As shown in Figure 7, four kinds of minerals are extracted from the image, including hectorite, montmorillonite, rectorite, and vermiculite. Similarly, we compared the spectral curve with the USGS spectral library.

![Figure 7. Comparison of FISS-SR Spectra and USGS Spectra (a: FISS-SR; b: USGS)](image)
3.1.3 Date Analysis

Whatever in the indoor or Outdoor field experiment, the spectral shapes are similar with the standard spectra’s from UGSS spectral library, especially the strong water absorption features near 1400nm and 1900nm. The intensity of reflectance curve of our image is lower than that of USGS spectra. This mainly caused by the pixel intensity, observation geometry, particle size, mixture, and some other factors. However, the shape and the absorption position are almost at the same, this intensity different does not influence the accurate identification of minerals.

3.2 Unmanned Aerial Vehicle Experiment

3.2.1 The Experiment Condition

The platform used in this airborne experiment is an unmanned aerial vehicle (UAV). UAVs have several advantages, such as less costly, flexible and simple maintenance. It can acquire hyperspectral image data with sub-decimeter spatial resolution because of rather low flight height. The UAV flight platform we used is an intermeshing rotor UAV. Intermeshing rotors on a helicopter are a set of two rotors turning in opposite directions, with each rotor mast mounted with a slight angle to the other, in a transversely symmetrical manner, so that the blades intermesh without colliding. The arrangement allows the helicopter to function without a tail rotor, which saves power (J. G. Leishman, 2006). The UAV mount with the LAHIS system is depicted in Figure 8. This UAV platform was provided by the Yanzhou Dekeda Technology Ltd.

![Figure 8. LAHIS system mounted at UAV platform](image)

The experiment was conducted in Pingyin Civilian Airport on 9 September 2013. The airport is located on Jinan, Shandong Province. The study area is 30km × 11.25km in extent, which lies in the east of the airport, as showing in figure 8. The elevation within the Pingyin County is about 37 meters. The land cover consists of residential areas, water bodies, forests and agricultural fields. LAHIS data were collected from 12:44 to 14:35 local time, resulting in 8 flight lines under predominately clear sky conditions. Table 9 shows the LAHIS flight configuration used in the study.
3.2.2 Date Analysis

Preprocessing steps of the raw LAHIS data include image denoising and time converting of hyperspectral imagery, coordinate transformation and temporal match of POS data. Then the individual flight lines had been geometrically corrected using polynomial approach, in which each of pixels were calibrated according to selected GCPs to with low values of Root Mean Square Error. Finally, a nearest neighbor resampling was performed as it did not change the pixel values. Fig. 10 is an example of geometric correction results. As we can see, the LAHIS image depicts details of the features very well and its positional accuracy and spatial information has been improved. However, with the vibration of aircraft, internal image geometry had been changed. To solve this problem, the methods of combining the external orientation data recorded during flight with interior orientation and elevation model will be developed in future work.

Figure 9. (a) Location of the Pingyin Civilian Airport. (b) LAHIS Fight Lines Marked on the Field Sites.

Table 2. LAHIS Flight Configuration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Flight Configuration</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>VNIR</td>
</tr>
<tr>
<td>Altitude(m)</td>
<td>~1500</td>
</tr>
<tr>
<td>Speed(m/s)</td>
<td>~160</td>
</tr>
<tr>
<td>Swath width (m)</td>
<td>760</td>
</tr>
<tr>
<td>Spatial resolution (m)</td>
<td>1.5</td>
</tr>
<tr>
<td>Frame rate (Hz)</td>
<td>38</td>
</tr>
<tr>
<td>F-number</td>
<td>5.6</td>
</tr>
<tr>
<td>FOV(°)</td>
<td>73</td>
</tr>
</tbody>
</table>

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Figure 10. (a) The raw LAHIS image in false color (R: 177, G: 80, B: 50), with the resolution of 2m. (b) Geometrical correction of LAHIS data after merged VNIR and SWIR bands together with RMSE=1.58 and 1.68 respectively, which has the resolution of 1.5m. (c) Geometrical correction of digital camera with RMSE=1.57, the resolution of which is 0.15m.
4. CONCLUSION

In this paper, a light-weight airborne hyperspectral imaging system (LAISS) for mineral application has been developed in China. The hardware of the compact LAHIS include a VNIR hyperspectral imaging, a SWIR hyperspectral imaging, a high resolution camera and a position and attitude device. The weight of the system is less than 20kg. The ground mineral scan experiment has showed the hyperspectral imaging both has high spatial resolution and spectral resolution. It also indicated the spectral shapes of LAHIS are very similar with the standard spectra’s from UGSS spectral library. It has the ability for mineral exploration. The airborne experiment shows the LAHIS have achieved relative high performance levels in terms of signal to noise ratio and image quality. The potential applications for light-weight airborne hyperspectral imaging system in mineral exploration are tremendous.

REFERENCES