Further Study of the Multispectral Equipment based on the First OSI Equipment List

CEN Yi, WANG Yueming, YANG Hong, LV Yongsheng, MENG Yunhe, GAO Yingqian, TAI Li, WU Yuke, and LI Peng

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INTRODUCTION AND MAIN RESULTS

In this work, further study of the multispectral equipment based on the first OSI equipment list has been carried out. An airborne OSI multispectral imaging system covering the core speciffcations of the OSI multispectral equipment has been proposed, with the spectral range from 0.3 to 2.5 μm. Based on the system, a series of field tests to detect the simulated OSI anomalies and artifacts have been carried out. Based on the obtained multispectral image data, OSI-relevant information extraction model has been established, in the meanwhile, data processing and information extraction software platform has also been developed, which can be used for further development of OSI multispectral equipment.

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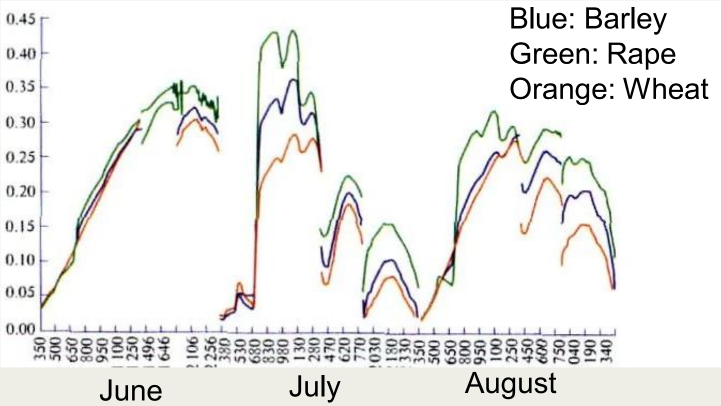
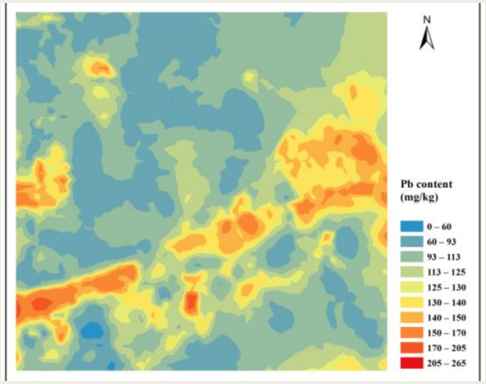
Introduction

Multispectral imaging has become a key technology for identifying potential anomalies related to underground nuclear facilities due to its capability to capture ground object information across multiple electromagnetic spectrum bands. Even when deeply buried, operational underground nuclear facilities generate energy exchange and material metabolism that manifest as detectable surface traces.

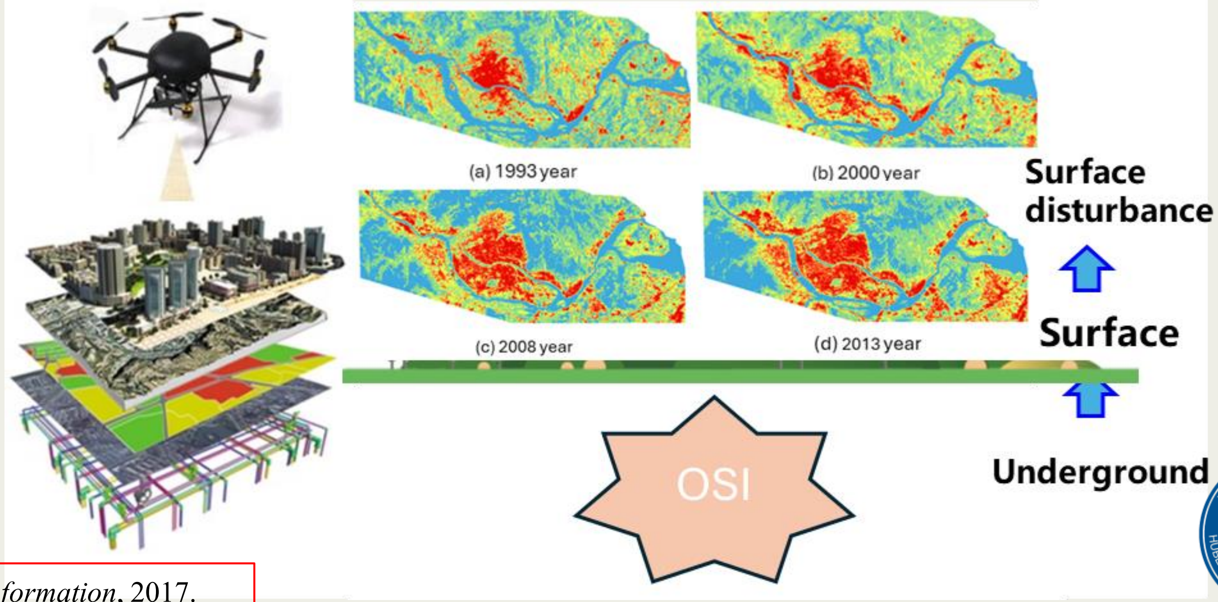
Healthy vegetation exhibits specific spectral characteristics in visible and near-infrared bands, including chlorophyll's absorption of blue/red light and strong near-infrared reflection. When underground nuclear facilities induce soil contamination or groundwater alterations, vegetation growth becomes disrupted—causing spectral changes like increased red-light reflection and diminished near-infrared reflectance—allowing multispectral imaging to precisely identify abnormal vegetation zones. Concurrently, nuclear facility construction disturbs soil structures and compositions, altering reflective spectral properties that enable multispectral data to locate these modified areas and trace facility presence.



Near infrared spectrum of different crops growth stages (X: Wavelength, Y: Reflectance)



Retrieval of soil heavy metal content using shortwave infrared spectral information.[1]



1) Sun Weichao & Zhang Xia*. *International Journal of Applied Earth Observation and Geoinformation*, 2017.

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Methods/data

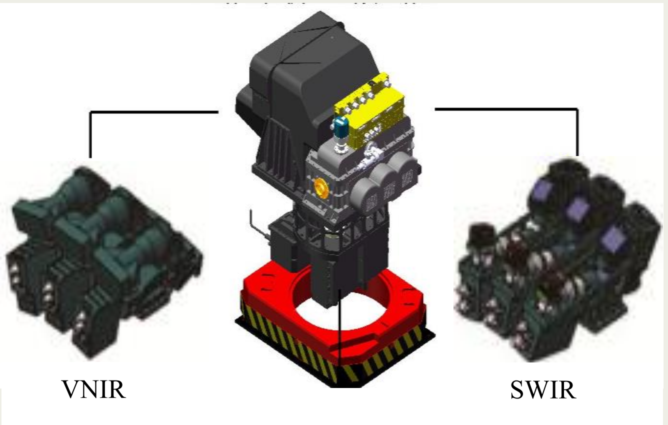
The Shanghai Institute of Technical Physics, Chinese Academy of Sciences, has developed an Airborne Multimodal Imaging Spectrometer (AMMIS).

The system consists of a full-spectrum multimodal imaging spectrometer and a control cabinet. The spectrometer covers both the visible–near infrared (VNIR) and shortwave infrared (SWIR) bands. AMMIS has a field of view (FOV) of 40°, with average spectral sampling intervals of 2.14 nm and 3.03 nm, respectively. Detailed specifications are shown in the figure on the right.

Current studies have employed AMMIS for land cover surveys, pollutant gas detection, mineral exploration, coastal water monitoring, and vegetation investigations, highlighting its excellent performance.

Image of the AMMIS

Full-Spectrum Multimodal Imaging Spectrometer



Performance test results of the AMMIS

Specification	Performance	
Wavelength	VNIR	SWIR
Spectral range (μm)	0.40–0.95	0.95–2.50
FOV (°)	40	40
Average spectral sampling interval (nm)	2.14	3.03
Band number	256	512
IFoV (mrad)	0.125/0.250	0.500
Frame frequency (Hz)	160–320/80–160	40–80
Telescope aperture diameter (mm)	33.68	13.20
Focal length (mm)	128	50
f-number	3.80	3.80
Slit length (mm)	33.7	12.8
Grating's groove density (grooves/mm)	30	53
Detector's format	2048 × 256	640 × 512
Pixel pitch (μm)	16 × 16	25 × 25
Quantum efficiency	≥ 61%@248 nm	≥ 70%@average
Dark current	90 ke⁻/pixel/s@298K	< 1fA@120K
Full well (e⁻)	≥ 200 000	2.5 M
Operating temperature (°C)	−20–+50	−40–+70
SNR and NETD	> 600 (ρ = 0.3)	> 200 (ρ = 0.3)
Spectral calibration accuracy (nm)	0.109	0.300
Radiometric calibration accuracy	Relative: ≤ 1.19% Absolute: ≤ 5.91%	Relative: ≤ 2.4% Absolute: ≤ 6.54%
MTF	0.470	0.400
Digitization (bit)	16	14
Geometric calibration accuracy (pixels)	Relative: 1.0; absolute: 3.9	
Image registration accuracy (pixels)	1.0	
VHR (s^{-1})	0.02–0.04	
Mass	Camera module: 98 kg; control module: 54 kg	
Voltage	28 VDC ± 10%	
Power consumption	1680 W	
Stabilization platform interface	General aircraft stabilization platform interface	
Other functions	High-spatial-resolution imaging mode and high-spectral-resolution imaging mode	
Aircraft platform	Y-5, Y-12, XZ-60, and Cessna 208	
Data level	0- to 2-level hyperspectral data after precise geometric being processed	

M: million; ρ: surface albedo; VDC: voltage direct current. ±10%: the permissible deviation range of the voltage.

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Challenges and Solutions in Airborne Platform Hyperspectral Imaging

Challenges

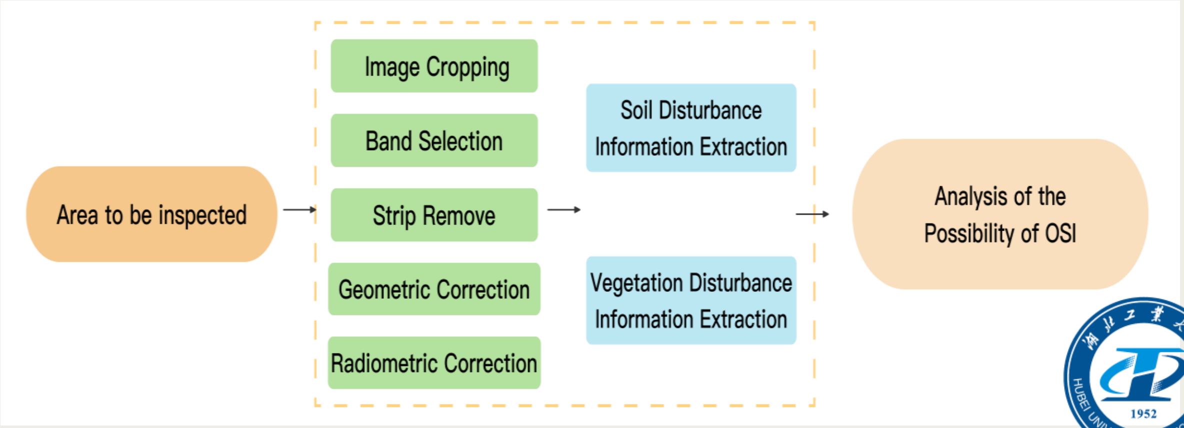
- **Line-scanning imaging mode**
  The instability of the platform leads to severe distortions
- **Inaccurate Radiation Calibration**
  Issues such as image brightness, contrast, and color distortion
- **Stripe Noise**
  Masked the real data information in the image

Solutions

- **High-Precision GPS/INS**
  Used to solve the exterior orientation elements of each frame of data
- **Complete preprocessing system**
  Remote sensing data preprocessing adapted to different situations
- **Improved Moment Matching Method**
  Based on Moving-Window filter

A software platform for data processing and information extraction has been developed in the Windows environment, using a hybrid Python+C++ language, with Visual Studio as the development tool, combined with the .NET Framework and SQL Server database. This platform features functions such as data format conversion, baseline correction, characteristic wavelength screening, image stitching, and data statistical analysis, and can be used for preprocessing and application of data collected by OSI multispectral equipment.

Flow Chart of Data Processing and Information Extraction



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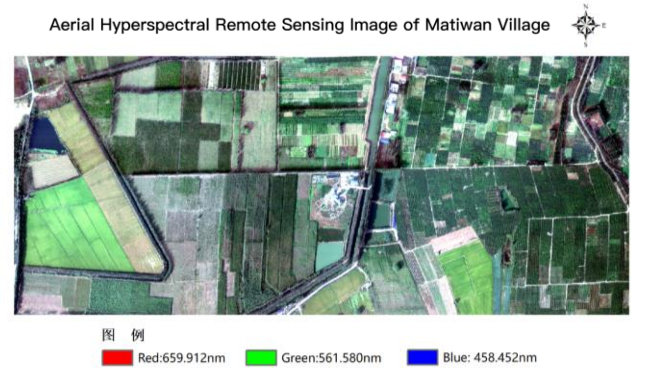
Geometric Correction

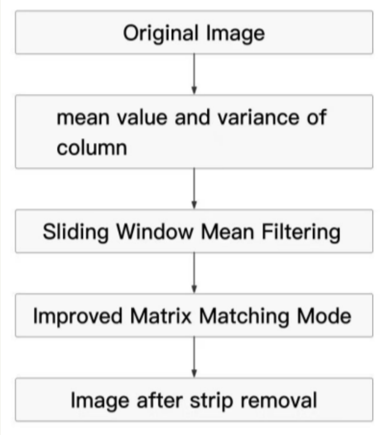
pos data-processing → Match POS data with image data → Solve the exterior orientation elements → Use the collinear equation to solve → Resampling

Mosaic Map of Airborne Hyperspectral Data Geometric Correction for Xiong'an New Area (Formed by two flight strips)

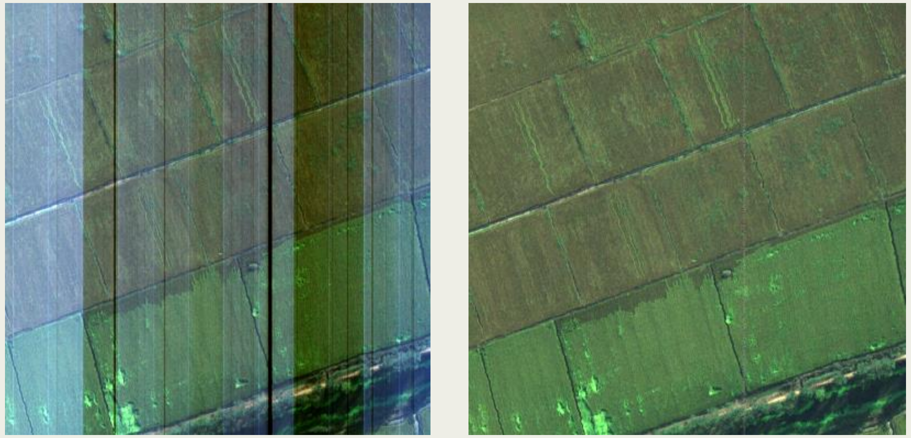


Results Display

Image Quality Improvement

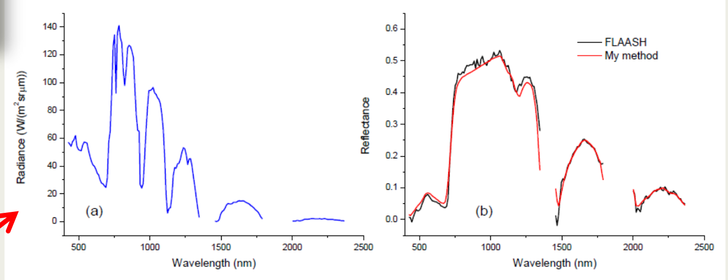


Flow Chart of Stripe Removal

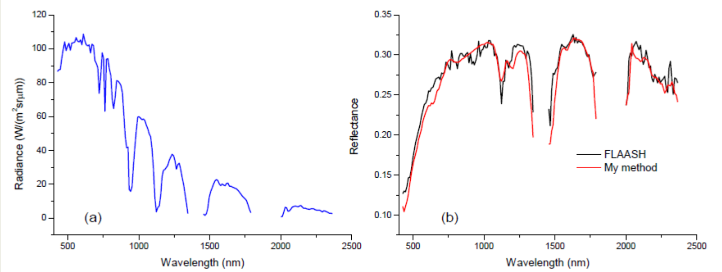


Comparison of Airborne Hyperspectral Images Before and After Stripe Removal

Radiometric Correction



Radiance of Vegetation (a)
Reflectance of Vegetation (b)



Radiance of Bare soil (a)
Reflectance of Bare soil (b)

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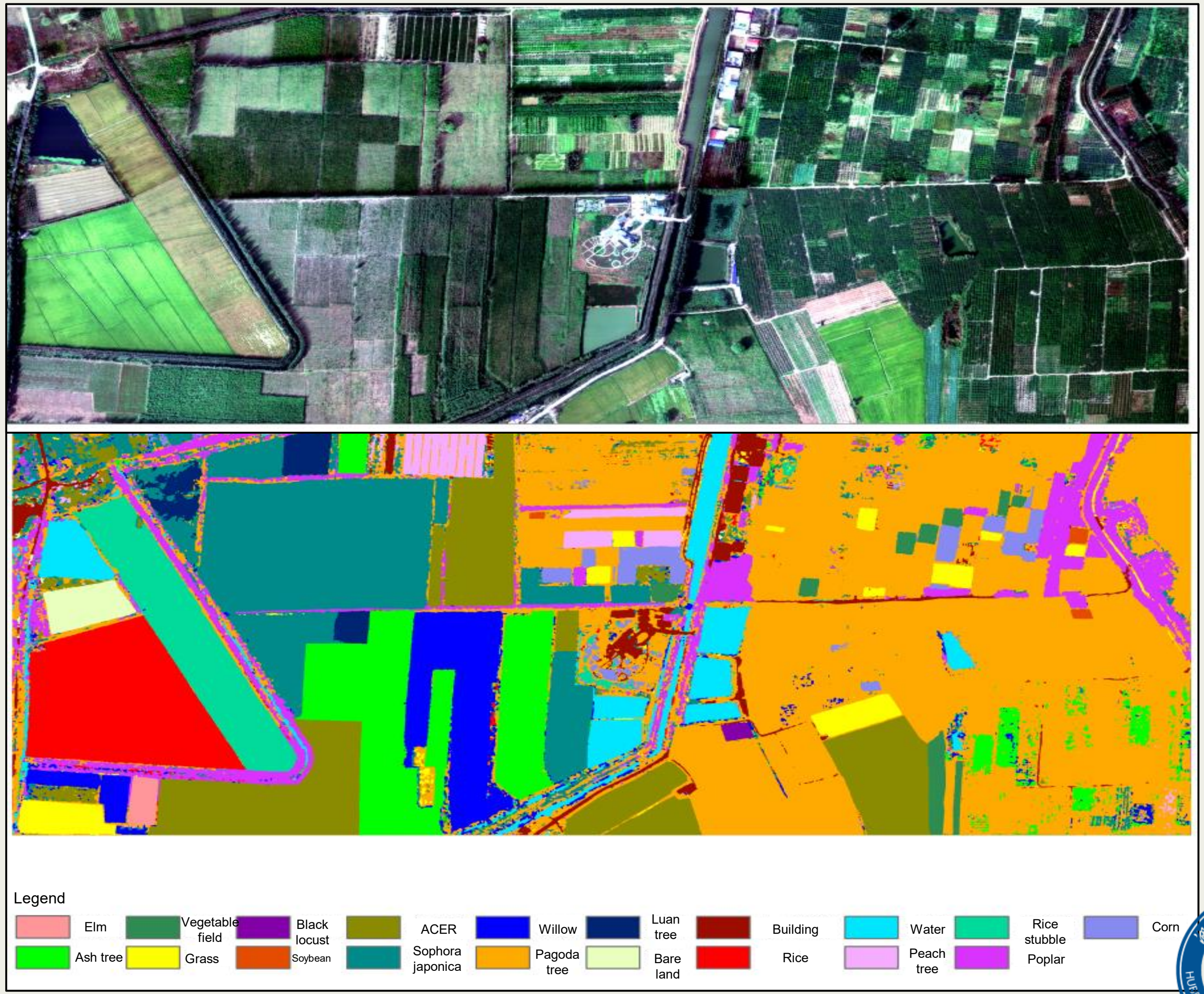
Results

The images on the right show the data of Xiong'an New Area acquired by AMMIS. The image was obtained in October 2017. It contains 19 land cover types. Excluding artificial structures, water bodies, and bare land, there are 16 vegetation types.

Based on the spectral signatures of land cover acquired by the device, detailed crop spectra can be extracted, enabling high-precision intra-class classification. The first three principal components of the image, eight corresponding spatial texture features (including mean, variance, homogeneity, contrast, heterogeneity, entropy, second-order moment, and correlation), and NDWI and NDVI were used to extract the features of different land covers. And The Random Forest was used here to construct the classification model. The performance of the results showed the classification accuracy of 97% and the Kappa coefficient of 0.98.

It is indicated that the remote sensing images obtained by AMMIS can effectively support intra class classification of vegetation. This also indicates that the data obtained by this device can effectively monitor vegetation disturbances during OSI events and provide data basis for OSI event inspection.



Land cover classification

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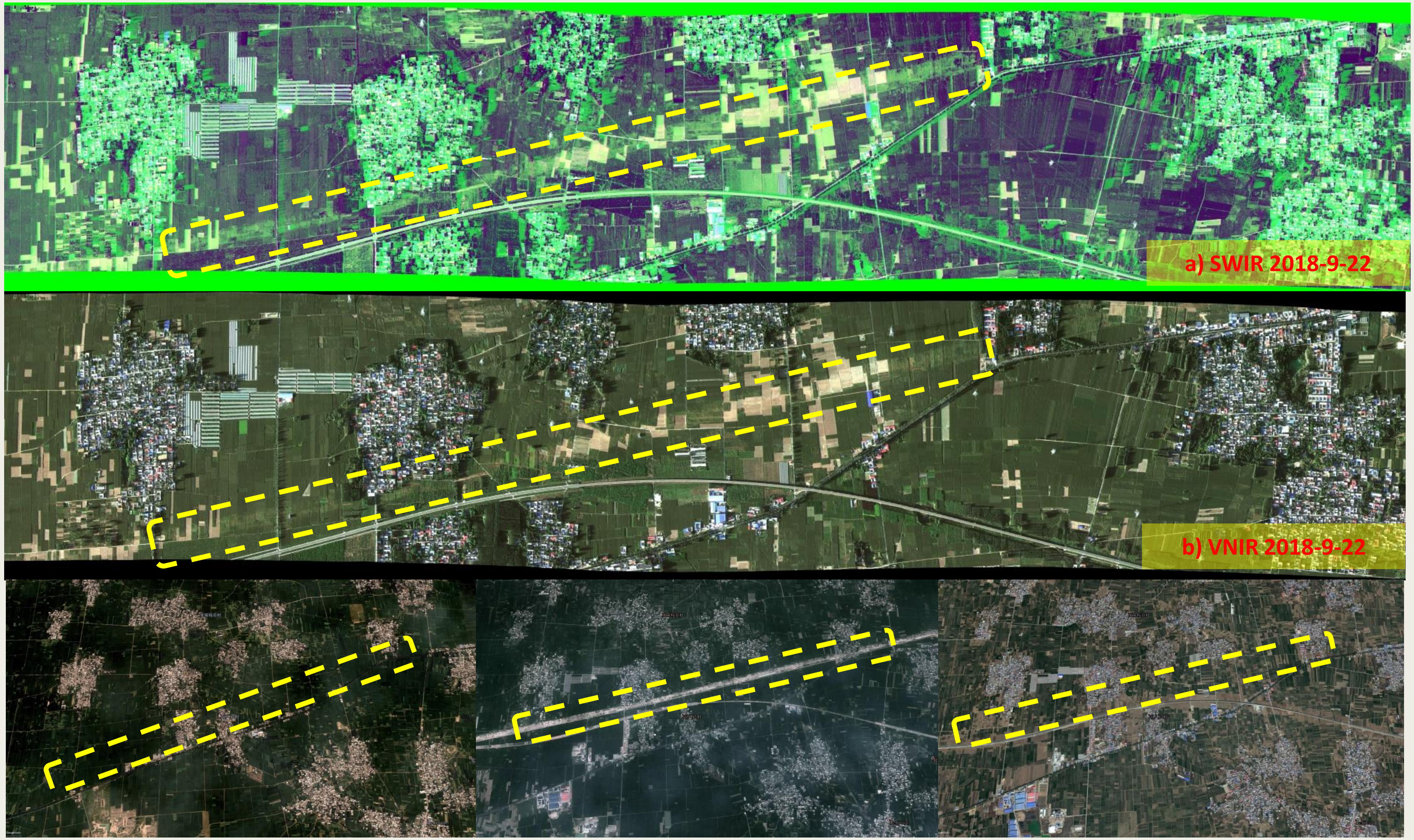
Results

The figure a and b showed the false-color images of the North China Plain acquired by AMMIS on September 22, 2018. Image a shows the image of shortwave infrared band, while Image b shows the image of visible–near-infrared band.

As shown in image a and b, there exists a distinct strip within the farmland, highlighted by the yellow dashed box. The difference is not obvious in the visible–near-infrared band, but it is much more pronounced in the shortwave infrared band.

By comparing with Google Earth time series images, it was found that an underground trench was excavated in 2011 and backfilled in 2016. Since then, no abnormalities have been found in the optical images. However, in the 2018 images, the spectral differences of surface vegetation still clearly reveal the historical soil disturbance in this region.

This case demonstrates the capability of the AMMIS in monitoring soil disturbances and provides strong technical support for the detection of OSI events.



c) Google Earth Image 2007-8-21

d) Google Earth Image 2011-9-27

e) Google Earth Image 2016-4-3

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Conclusion

An airborne multimode imaging spectrometer (AMMIS) developed by the Shanghai Institute of Technical Physics, Chinese Academy of Sciences was introduced in this study. A software platform for data processing and information extraction was also developed to analyze the surface disturbances of OSI event.

The results of land cover classification and soil disturbances detection demonstrated the potential capability of the AMMIS for OSI purposes.

In future research, we will conduct more OSI-related field experiments to verify the effectiveness of the equipment and establish standard operation procedures for OSI activities.