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Development and Application of Hyperspectral Remote Sensing

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Abstract: Since the early 1960s, multispectral imagery has been served as the data source for earth observational remote sensing (RS) in the last thirty years; the advancement of sensor technology had made it accessible to collecting hundreds continuous spectral bands-hyperspectral RS. Hyperspectral RS (HRS) is a new technique for observing the earth, which is different from the multispectral RS because of several hundreds of contiguous spectral bands. With a long history of development, HRS is widely used currently. This review details the development of HRS, data processing, characteristics, imaging mode of hyperspectral sensors and its applications, such as detecting and identifying the surface, monitoring agriculture and forest status, environmental studies, and military surveillance, etc.

Keywords: Hyperspectral remote sensing; Airborne; Space borne; Hyperspectral sensors, Plant ecology surveying

1 Introduction

The advancement and applications of remote sensing (RS) serve as a significant scientific technique in the 20 century. Hyperspectral remote sensing (HRS) is a new technique for observing the earth developed in the 1980's. Hyperspectral imagery is collected with instruments called "imaging spectrometers". The original definition of imaging spectrometry, proposed by Goetz et al. ^[1]. The definition shows that the hyperspectral imaging is different from the multispectral imaging. It needs the sensors to acquire images simultaneously in 100 ~ 200 or even more contiguous spectral bands. Each pixel of a hyperspectral image has a related radiance spectrum. Hyperspectral images, called as hypercube, include three dimensional blocks of data, two spatial and one spectral dimension, and integrate the major features of image and spectroscopy ^[2, 3].

Hyperspectral imaging has had a long history of development. The beginning of imaging spectrometry of the earth is rooted in the launching of Landsat-1 in the 1970's, and the field spectral measurements were taken to underpin the analysis of the Landsat-1 MSS (Multispectral Scanner) data. The field spectrometry, the airborne imaging spectrometer and the space borne imaging spectrometer are developing gradually with the development of the electronics, computing and software [4].

Airborne hyperspectral sensors have made somewhat successes in research and applications in a variety of fields, such as hydrological modeling and analysis platform (HyMap) and project for on-board autonomy (PROBA)-1 [5-12]. Useful and important as HRS is, the development, some techniques and applications related to it will be introduced.

2 The development of the hyperspectral remote sensing

2.1 Airborne hyperspectral remote sensing

Airborne HRS has a long history of development dating back to 1983. Airborne Imaging Spectrometer (AIS) -1, the first generation imaging spectrometer was born in this year. The spectral range is from 0.99 μm to 2.4 μm , at 9.3nm spectral resolution in 64 contiguous spectral bands. The second generation imaging spectrometer was AVIRIS, at the same time, it was the first imaging sensor. The AVIRIS can measure solar reflectance spectroscopy from 0.4 μm to 2.5 μm with 224 bands. It plays an important role in atmospheric correction, ecology and vegetation, snow and ice hydrology, inland and coastal waters, biomass burning, etc.[14, 15]. Subsequently, in 1989 ITRES Corporation, Alberta, Canada introduced a pushbroom imaging spectrograph, Compact Airborne Spectrographic Imager (CASI), which covers the region (0.43~ 0.86 μm) in 288 spectral bans. It primarily monitored and researched the aquatic and terrestrial applications [12, 16]. In 1994, the GER launched the Digital Airborne Imaging Spectrometer (DAIS) series, DAIS3715, DAIS7915, DAIS16115, and DAIS21115, HyMAP has also been developed in Australia in 1996[17]. Following the CHRIS was launched on ESA'S PROBA platform in October 2000 [18, 19].

China began to develop hyperspectral imaging system in 1980's, the first Modual Airborne Imaging Spectral (MAIS) ran in 1991. It is a sign that China has made a great breakthrough in technology and applications of airborne imaging spectral. And then, the Chinese Academy of Sciences successfully developed operational modular imaging spectrometer (OMIS) on the basis of MAIS, including OMIS-1 and OMIS-2, which belonged the Pushbroom Hyperspectral Imager (PHI), with 128 and 68 spectral bands from visible to TIR wavelength at the spectral region 0.46~12.5 μm they were primarily used in geology, agriculture, forest, ocean, etc.[20]. Chinese Moderate Resolution Imaging Spectrometer (CMODIS), as an ocean color satellite measure spectrometer, was launched on 25

March 2002 onboard the “Shenzhou-3” spaceship^[21]. In addition, the interference imaging spectrometer, researched by Xi’an institute of optics and precision mechanics of Chinese Academy of Sciences (CAS), was lift off onboard Chang’E-1 in October 2007, the Environmental disaster reduction satellite (Env-DD) in September 2008, and the GF-5, will be taken in the near future. A variety of imaging spectrometers in our country, OMIS and PHI represent the technical level of the imaging spectrometer in Asia, and also occupy an important position in the world.

2.2 Spaceborne hyperspectral remote sensing

The history of spaceborne HRS is shorter than airborne HRS, the first HRS satellite launched in 1997 named LEWIS (Failure). The plans of high resolution imaging spectrometer (HIRIS) and Orbview-4 were also failed. However, it develops very well in recent 30 years, and its value has been put forward.

MODIS was launched successfully in December 1999, every 1 to 2 days, the MODIS pay a return visit the earth and acquires data, the spectral range of which is from 0.4 μ m to 14 μ m with 36 bands. These data can help us to well comprehend the global dynamics of earth.

ASTER is an imaging instrument flying on Terra. The goal of ASTER is to discover how the earth is changing by observing and modeling the earth system, and understand the importance of life on earth. MightySat-II was launched on 19 July 2000, which was the third generation imaging spectrometer, sun-synchronous orbit^[22].

The space technology of China develops rapidly, the HJ-1A satellite was launched in September 2008. The hyperspectral imager provides earth imagery at 100m spatial resolution and 5nm spectral resolution, and its spectral range is from 0.45 μ m to 0.95 μ m. Tiangong-1(TG-1) spacecraft with the spaceborne hyperspectral Image of China was lunched from the Jiuquan spaceport boarded the Changzheng-2F rocket in September 29, 2011. The spaceborne hyperspectral image has the highest spectral and spatial resolution, and its spectral region is from VIS to SWIR. The hyperspectral images data are widely used in various fields, such as in land resources investigation, forestry, agriculture, exploration of oil and gas, mineral, marine, urban heat island effect, detection of atmospheric and environment, materials science and so on.

3 The characteristics of hyperspectral remote sensing images

Different from the multispectral images, the HRS images have the following characteristics ^[24-26]. (1) Hypersectral images have a wide range of spectral response and high spatial resolution. The electromagnetic wavelength of imaging spectrometer is from VIS to NIR, and the spectral resolution reaches to nm level. (2) Combining the image and spectral. In the hyperspectral images data, the whole

data of hyperspectral image is an image cube (Fig 1), including spatial information and spectral information, and each pixel of image corresponds to a spectral curve (Fig 2). (3) There are usually three kinds of models in hyperspectral images: image, spectrum and characteristic. (4) Due to huge quantity of data and high correlation between spectral bands, the information redundancy increases with bands, data and correlation between bands. (5) The signal-to-noise ratio (SNR) of hyperspectral image gets low. When the SNR of hyperspectral images data increases, the noise increases, simultaneously the difficulty of data processing increases.

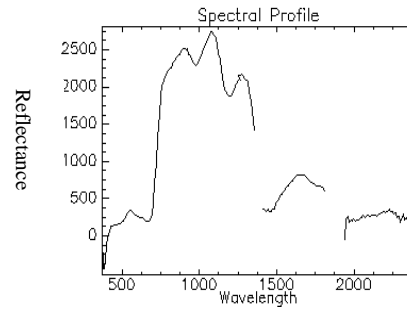
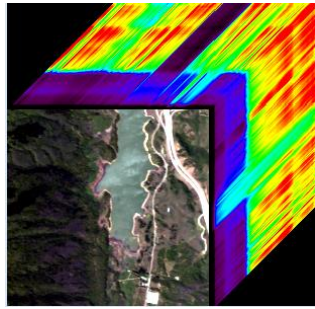


Fig. 1. 3D cube of hyperspectral images **Fig. 2.** Spectral curve of hyperspectral image

The HRS data, comparing with the wide-band panchromatic and multispectral rRS data, both spectral and spatial resolution, have been improved, significant advantages as following [27, 28]: (1) Hyperspectral images contain approximate contiguous spectral information of surface features, spectral reflectance curve of surface features can be obtained after rebuilding the spectral reflectance of hyperspectral image. The laboratory spectral analysis model can be applied in the RS with matching the measured values. (2) The identification ability of surface cover is greatly improved. The material with diagnostic spectral absorption characteristics can be detect, which can accurately distinguish the types of surface vegetation cover, material of road paved, etc. (3) In hyperspectral images, the terrain elements can be quantitatively or semi quantitatively classified, various parameters of surface cover can be estimated, and the accuracy and reliability of quantitative analysis can be improved. (4) Various algorithms are proposed for the classification of HIS. The traditional classification algorithms after dimensionality reduction, include Bayes classification method, decision tree(DT), neural network, support vector machine (SVM), kernel fisher discriminate (KFD), and so on.

4 The imaging mode of hyperspectral remote sensing

In general, the imaging mode of HRS has five kinds as following: Linear scanning mode, Whiskbroom scanning mode, pushbroom scanning mode, Spectral and spatial crossed scanning mode, optical path difference scanning mode [24, 29, 30].

(1) Linear scanning mode. The spectrometer with this mode can obtain a whole scene image using a single detector.

(2) The whiskbroom scanning mode. This mode belongs to opto-mechanical system, the spectrometer of this scanning mode uses line-array detectors, it gains

parallel scanning line set by several detectors, arraying along the courses. Now, the whiskbroom scanning mode is used in full spectrum spectrometer, the wide of spectral form visible to infrared, such as Deadalus series, AVIRS, MAIS, OMIS, MSS, Thematic Mapper (TM) and FengYun (FY) meteorological satellite, etc.

(3) The pushbroom scanning mode. This mode belongs to solid-state system. Now, the pushbroom spectrometer, including a two dimensional matrix detectors, one dimensional used as a spectrometer and another as a line array, has been widely used in spaceborne HRS. It generates a line image once a time without mobling components. At present, the pushbroom spectrometers are used in VIS/NIR bands, such as AIS-1, AIS-2, CASI, hyperspectral digital imaging collection (HYDICE) and PHI, etc.

(4) Spectral and spatial crossed scanning mode. The imaging spectrometer with this scanning mode scans spectral dimension used the rotation of rotating filter plate or gradient filter. It is easy to achieve due to its simple design, but difficult to register the images owing to the spectral record respectively.

(5) Optical path difference scanning mode (Fourier interferometric spectral scan). The imaging spectrometer with this scanning mode obtains spectral bands time-sharing and the Fourier spectrometer scans the spectral information. At present, this spectrometer is still in the experimental stage, such as the Fourier Transform Visible Hyperspectral Imager Spectrometer (FTVHIS) developed by U.S. Department of Defense, has 256 bands in 0.44~1.15 μm , with 0.6nm spectral resolution and 0.6mrad spatial resolution.

5 Processing and analysis technique of hyperspectral data

According the processing procedure, the processing of hyperspectral data is segmented into three stages: data preprocessing, analysis and application.

Data preprocessing, obtaining high accuracy spectral curve, reflects the spectral features of ground objects, is the main purpose. The major work of this stage is: radiometric calibration, atmospheric correction, geometric correction and image mosaic. Data analysis primary obtain feature information about applications. Hyperspectral data contains spatial information, spectral information and multi temporal information, etc. Data processing mainly includes: spectral feature extraction, feature parameter, etc. Data application, primary interprets the analysis results to meet the requirement of data application. At present, the studies focus on dimensionality reduction and classification.

5.1 Dimensionality reduction of hyperspectral data

An important factor restricting the development of HRS is the huge quantity of data, high correlation between bands. This makes it difficult in data transmission, storage and management. In order to solve the problem of high dimensionality, feature extraction and selection are usually applied to reduce the dimension.

Feature selection choose some effective bands from the original bands, without any change, and the feature extraction transform one or several original bands into new synthetic feature according specific function^[31]. There are a number of methods in dimensionality reduction of hyperspectral data, including^[25, 32] minimum noise fraction (MNF), spectral absorption feature parameter (SAFP), spectral encoding (SE), principal component analysis (PCA), spectral derivative (SD), spectral absorption index (SAI), segmented principal components transform (SPCT), etc..

5.2 Classification of hyperspectral images

The classification algorithms of hyperspectral images are divided into supervised classification and unsupervised classification according to the training samples. The algorithms of unsupervised classification commonly include parallelepiped, clustering, splitting, dynamic clustering, K-means, etc. Training samples of supervised classification can be extracted from ROI or the spectral library. Supervised classification of a priori knowledge has higher classification accuracy than unsupervised. The algorithms of supervised includes correlation coefficient method, minimum distance classification (MDC), fisher linear Discriminant (FLD), spectral information divergence, and so on^[33,34]. In addition, some other methods are also used to classify, e.g. fuzzy classification, decision tree classification, least squares classification (LSC), maximum likelihood classification (MLC)^[34], etc..

6 The application of the hyperspectral remote sensing

HRS has been extensively used in earth studies. With the development of HRS, there is a growing interest in the researches and applications in a variety of fields such as in coastal and inland water studies, disaster mitigation, geology, astronomy, urban studies, land cover, pharmaceuticals, medicine and military uses^[2,35-40]. This paper primarily introduces the applications in plant ecology surveying, atmospheric environmental assessment, geological prospecting, water quality monitoring, atmospheric environmental assessment and military application.

6.1 Plant ecology surveying

In agricultural study, it is significant to timely and precisely monitor crop growth status at large scale. Koppe et al. developed a model to forecast and reckon crop parameters based on multi- and hyperspectral satellite data^[41]. The evaluation of chlorophyll content and the leaf area index (LAI) using RS technology can be estimated in precision agriculture^[42]. Galvao et al., used the hyperspectral data to discriminate five important sugarcane varieties in Brazilian^[6]. An Australian

shows the results similarity with field observations who predicted the soil organic carbon (SOC) using Hyperion data. This technique will facilitate the implementation of digital soil mapping ^[43], and the similar result was found in mapping soil organic matter (SOM) using HRS images and multi-source data ^[44].

In addition, HRS is applied in vegetation^[13], map post fire vegetation recovery^[45], assess species diversity in homogeneous and heterogeneous forest and discriminate different forest tree species^[46]. John et al. investigated HRS technology to determine whether it can be used to accurately measure and the indicators of plant hazardous waste sites ^[47].

6.2 Atmospheric Environmental assessment

The application of HRS, atmospheric environmental RS is one of the most important contents, it primarily monitor the O₃, CO₂, N₂O, CO, O₂, CH₄ in the 400~2500 spectral range, aerosol. The studies showed that these could be detected in two atmospheric windows, in the visible range of 400 ~ 750nm and the 0.85nm, 1.06nm, 1.22nm, 1.60nm, and 2.20nm spectrum bands of NIR and MIR ^[48-51]. Bassani et al. presented a new physically-based method to obtain aerosol optical thick at 550nm from hyperspectral image data, who only used the radiative information inherent in the VIR/NIR spectral domain^[48]. Gao et al. computed the approximately values of NO₂ transmittances and reflectance near 400nm over variety targets^[49] and found that clouds could be detected and separated at the 1380nm and 1500nm by analyzing the spectral imaging data over arctic regions^[52].

6.3 Geological prospecting

HRS has been efficiently used in geological prospecting too, such as mineral exploration, hydrocarbon exploration, mineral resources exploration, mining environmental monitoring, mine ecological restoration and evaluation^[53]. HRS technology can finely identify mineral by tens or hundreds of recorded bands in images and construct a complete reflectance spectrum of every pixel.-. Harris et al. used hyperspectral data to lithological map between VIS and NIR - SWIR range in southern Baffin Island, and successfully discriminated one major lithological group and three compositional units^[8]. Merucci et al. demonstrate the efficacy of using the TIR image of the DASI hyperspectral datasets in lithological mapping ^[54].. Bishop et al. used the HRS technology to explore the porphyry-type deposits in various environmental ^[54].

6.4 Water quality monitoring

HRS images have been widely used to monitor the water quality of open water aquatic ecosystems. Those researches are mainly about the monitoring and estimating the organic matter content of water. Vos et al. used the hyperspectral

data to obtain chlorophyll-a concentrations [55]. Koponen et al. used airborne hyperspectral spectrometer and simulated MERIS data for classification of Secchi depth, turbidity, chlorophyll and detected total phosphorus in three water quality [56]. Politi retrieved the chlorophyll-a concentrations and secchi discdepth (SDD) from eutrophic lakes using Terra and Aqua MODIS data [57]. Tilley et al. obtained the total ammonia concentrations using the narrow spectral bands hyperspectral reflectance of emergent macrophytes in wetland in south Texas, USA. Froidefond et al. observed high concentration mineral particles in surface water on the Mahury River by changing remote sensing reflectance [58]. Pulliainen et al. retrieved chlorophyll-a concentration using a semi-operative approach and showed the change of the spectrum shape characteristics and trophic of the lake water [59]. Since hyperion afforded sufficient sensitivity for detecting optical water quality, Vittorio and Arnold retrieved the chlorophyll concentrations, suspended matter and colored dissolved organic matter in Moreton Bay [60].

6.5 Military applications

The hyperspectral data have been the main reconnaissance mean in military field and gradually replaced the multispectral RS. In the field of military reconnaissance, camouflage identification and battlefield environment reconnaissance are possible using the HRS, according to the different spectral characteristics of the targets, the composition and state of targets surface can be obtained. The real military targets (military vehicle or missile launching frame) of camouflage and stealth in the green vegetation and desert can be detected and identified from camouflage material and background, using the airborne and space reflection spectra data of AVIRIS, CASI or Hyperion [7,15,61-63], etc.. Tiwari et al. extracted five targets (aircrafts) from synthetic images of the AVIRIS sensor generated and the single AVIRIS image [7]. Gu et al. detected three planes in each region of the AVIRIS images and OMIS images with the spatial resolution 3.5*3.5m [63]. White et al. analyzed various spectral wavelengths to coastal temperate forest characterization in Canada, that could help to identify the disguising artificial targets [63]. In addition, in military action, it is often overcome the influence of multiple targets moving for capturing and tracking in complex background. However, since the quickly changing of targets position, it is difficult to be tracked, and sometimes the tracked object is similar to the target tracking. In this case, the ordinary reconnaissance technology will do not play a role. The hyperspectral images can use the tracking method by capturing the contour of target, removing the noise signal and finally locking the tracked target [62].

7 Conclusion

Over the past 30 years, big advance has been made in the development and

application of new RS technologies, that is being applied in agriculture, environment, vegetation, coastal and inland water studies, disaster mitigation, geology prospecting, astronomy, etc., pharmaceuticals, medicine and military uses. New materials and techniques should be used to improve the capabilities of the hyperspectral sensors, especially the spectral and spatial resolution. At the same time, the standard spectral library on the earth surface should be built. Thus the HRS will be applied more extensively.

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