AJCSE ASIAN JOURNAL OF COMPUTER SCIENCE ENGINEERING

www.ajcse.info

Asian Journal of Computer Science Engineering 2016; 2(1): 06-10

REVIEW ARTICLE

Hyperspectral Imaging

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Received on: 25/10/2016, Revised on: 20/11/2016, Accepted on: 14/12/2016

ABSTRACT

Imaging refers to capture, storage, manipulation and display of images. Spectral imaging is a branch of spectroscopy in which a complete spectrum or some spectral information is collected at every location on image plane and is processed. Image cube, a type of data cube is used to represent the spectral images. Hyper spectral imaging and Multispectral imaging falls under Spectral Imaging. Imaging spectrometers are used to produce these hyper spectral Images. There are various applications of Hyper spectral Imaging in Agriculture, Astronomy, Chemical Imaging, Eye Care, Remote Sensing, Surveillance and many more. The work focuses on introduction, data acquisition techniques and challenges in Hyper spectral Imaging

Keywords: Cube , Hyperspecral Imaging, Snapshot Imaging, Spatial Scanning , Spectral Sacnning , Spatio Spectral Scanning

INTRODUCTION

Hyperspectral images are collected using Hyperspectral remote sensors. These sensors collect images in dozens or hundreds of narrow, adjacent spectral bands. Hyperspectral imaging refers to collecting and processing information from the electromagnetic spectrum. Its purpose is to obtain the spectrum from each pixel in the image of scene, for detecting objects, identifying materials. Spectral imaging divides spectrum in many more bands rather than red , green and blue. Fig. 1 shows two dimensional projection of Hyperspectral cube.In Hyperspectral imaging , data cubes or narrow spectral bands at each pixel are produced. The number of pixels depends upon the sensors. Hyperspecral system initially samples the light , then it passes through a slit then disperses it. Hysperpectral imaging differs from Multispectral imaging depending upon number of wavelength bands and narrowness. Multispectral imaging produces two dimensional images of a few to hundred wavelength bands whereas Hyperspectral imagining obtains a large three dimensional cube of hundred or even thousands of images with dimensions (x, y, λ) where x and y indicates spatial dimensions and λ indicates spectral dimension as shown in Fig. 2, each representing only a few nanometers in range. Multispectral imaging processing is faster and easier with its smaller data set whereas Hyperspectral imaging having larger complexity of data, higher resolution spectra and it is more versatile having various emerging applications. Fig 3. Shows difference between Multispectral and Hyperspectral Imaging.

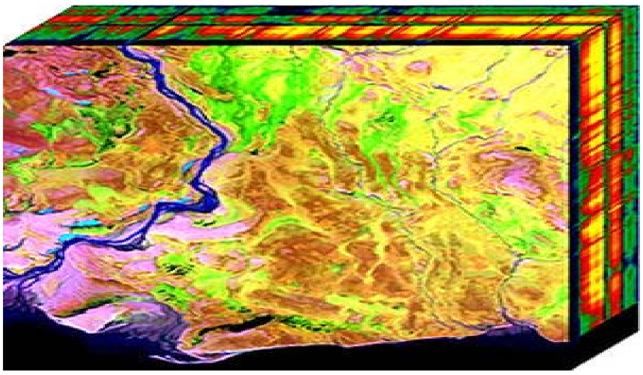

Fig. 1. 2-D projection of Hyperspectral cube[8]

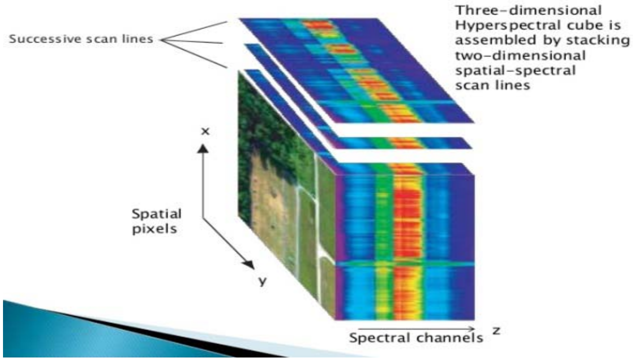

Fig. 2. 3-D Hyperspectral cube[8]

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AJCSE, Jan-Feb, 2017, Vol. 2, Issue 1

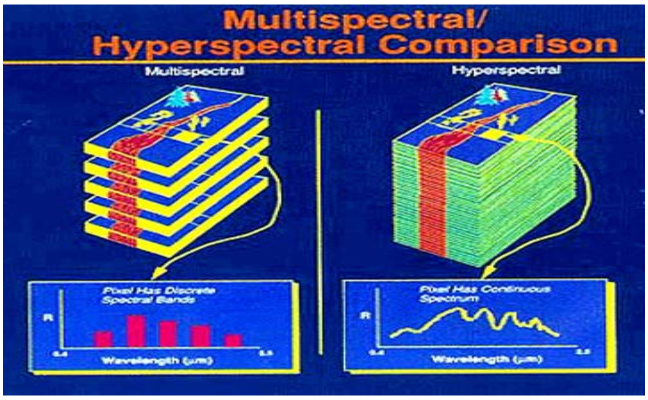

Fig. 3. Difference between Multispectral and Hyperspectral Imaging[8]

This paper focuses on basics of Hyperspectral Imaging, its techniques and future challenges in it. Section II focuses on related work by authors on Hhyperspectral Imaging. Technologies for Hyperspectral Data Acquisition are discussed in Section III. Challenges in Hyperspectral Imaging are summarized in Section IV followed by Conclusion and future work in Section V.

RELATED WORK:

Hyperspectral Imaging is used in variety of applications. Researchers are working on various aspects of Hyperspectral Imaging like their techniques, analysis, and applications. Basics of Multivariate and Hyperscpectral images is covered in a book by Hans F. Grahn and Paul Geladi[2]. This book also focuses on applications of Multivariate and Hyperscpectral images in various fields. It also covers techniques and analysis of Multivariate and Hyperspectral Imaging.

Peg Shippert[3] in "Introduction to Hyperspectral Image Analysis" presented basics on Spectral Images followed by Hyperspectral Data. Also summarized Current and Recent Hyperspectral Sensors and Data Providers. Lastly applications of Hyperspectral Image Analysis were presented.

José M. Bioucas-Dias, et al[4] focused on "Hyperspectral Remote Sensing Data Analysis and Future Challenges". The presented work carried on Hyperspectral and remote sensing with Hyperspectral processing techniques, Hyperspectral unmixing , Classification, Hyperspectral Target Detection , Fast Computing and which are the challenges for this.

Detecting vehicle in satellite images has attracted extensive research interest with wide spreading applications. The main challenge lies in the difficulty of labeling sufficient training instances (vehicle rectangles) across all resolutions and imaging conditions of satellite images, which degenerates the performance of vehicle detectors trained correspondingly. To tackle this challenge, Liujuan Cao, et al[1] proposed an intelligent and labor-light scheme for large-scale training of vehicle detectors.

Various challenges in Hyperspectral Imaging are presented by Minaji , Sulehria , Babakhani , Kardan[5] in "Super Resolution Challenges in Hyperspectral Imagery".

A survey of landmine detection using Hyperspectral Imaging is presented by Ihab Makki , et al[6]. Their work focused on work done in landmine detection using Hyperspectral Imaging and different mathematical methods used in Hyperspectral data treatment.

"Fast and Lightweight Rate Control for Onboard Predictive Coding of Hyperspectral Images" by Diego Valsesia and Enrico Magli[7]focused on Predictive coding for compression of hyperspectral images onboard of spacecrafts in light of the excellent rate-distortion performance and low complexity of recent schemes.

Next section describes technologies for Hyperspectral Data Acquisition, followed by challenges in Hyperspectral Imaging.

1. **TECHNOLOGIES FOR HYPERSPECTRAL DATA ACQUISITION:**

   Four basic techniques for acquiring the three dimensional (x,y,λ) dataset of hyperspectral cube are used. Here hyperspectral data cube is visualized as a section of two spatial dimensions (x,y) and one spectral dimension lambda(λ). Depending upon specific application technique is selected.

a. **Spatial Scanning**: In this type of technique each two dimensional sensor output represents a full slit spectrum (x,λ). As shown in Fig. 4, two dimensional (x,λ) output is representing a full slit spectrum .Slit spectra is obtained by using Hyperspcetral Imaging devices by projecting a scene onto a slit and then dispersing the slit image by using prism or a grating. This technique is having disadvantage of image analyzed per lines using push broom scanner (Line scan system).In Line scan systems the spatial dimension is collected using platform movement or scanning which requires stabilized mounts or accurate pointing of information to construct the image again. Line scan systems are used in remote sensing, to scan materials moving on a conveyor belt.Point scanning (using whisk

AJCSE, Jan-Feb, 2017, Vol. 2, Issue 1

broom scanner) is a special case of line scanning where a one dimensional sensor is used instead of two dimensional and point like aperture is used instead of a slit.

b. **Spectral Scanning:** In this type of technique each two dimensional output represents a single colored that is monochromatic spatial (x,y) map of the scene. As shown in Fig. 4, a single colored map of image is shown for blue color. For this type of scanning Hyperspectral Imaging devices being used are typically based on band pass filters which are either tunable or fixed. The scene is spectrally scanned by exchanging of filters whereas as platform used must be stationary. Advantage of using this technique is being able to choose spectral bands having a direct representation of two spatial dimensions of the scene. Disadvantage of this technique is spectral smearing can occur if there is movement in the scene invalidating spectral correlation or detection.

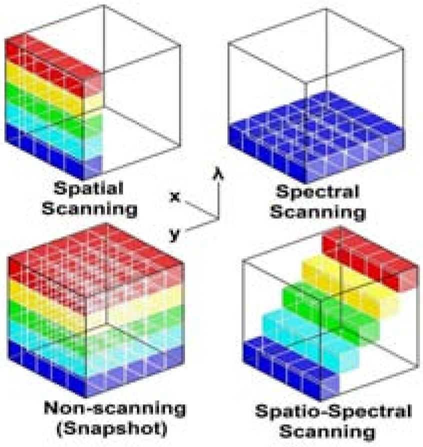

Fig. 4 Technologies for Hyperspectral Data Acquisition[8]

c. **Snapshot Hyperspectral Imaging**: Snapshot Hyperspectral Imaging is also known as Non scanning. In this type of technique a single two dimensional sensor output contains all spatial(x, y) and spectral (λ) data. As shown in Fig. 4, a single snapshot represents non scanning Hyerspectral Imaging. A single snapshot represents a perspective projection of a data cube from which a three dimensional structure is constructed. For this type of scanning Hyperspectral Imaging devices being used are hyper pixel Array Camera, Snapshot Image Mapping Spectrometer. Advantage of this technique is in this type of technique all spectral and spatial attributes of the scene are captured in a single frame that is higher light throughput and shorter acquisition time.Disadvantage of this technique is high manufacturing costs and computational effort.

d. **Spatio spectral scanning:** In this type of technique each two dimensional sensor output represents a rainbow colored spatial map of the scene. This technique yield a series of thin diagonal slices of data cube as shown in Fig. 4. Here each image represents two spatial dimensions one of which is wavelength coded. For this type of scanning Hyperspectral Imaging devices consists of a camera at some non-zero distance behind a slit spectroscope. Spatio spectral scanning as the name indicates combines two types of scanning spatial and spectral and hence has combined advantages and disadvantages of these two techniques. Imaging done using this technique is valuable for irregular or irretrievable scanning movements and also yields high spatial and spectral resolution. Fig. 5 shows images obtained for four different techniques of Hyperspectral Imaging. From left to right, First image shows Spatial Scanning using slit spectrum which contains two dimensions (x,λ) In the second image Spectral Scanning using single color for green is shown which is monochromatic spatial (x,y) map of the scene. In the next image Snapshot Scanning is shown that is n perspective projection of hyperspetral cube. And in the last image combination of spatial and spectral scanning is shown which is Spatio Spectral scanning.

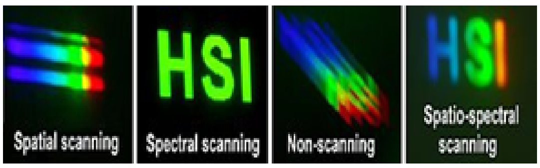

Fig. 5 Images using different hyperspectral technologies [8]

2. CHALLENGERS IN HYPERSPECTRAL IMAGING

Hyperspectral Imaging system provides hyperspectral images which consist of numerous spatial image planes of the same object at different wavelengths. The resulting hyperspectral image is achieved using the superimposition of the spatial images collected by the hyperspectral sensors thus creating a three dimensional data cube called hypercube which is then further analyzed and illustrated. This hypercube is constructed using area scanning, point scanning and line scanning. The information acquired by a Hyperspectral Imaging system carries spatial and spectral information. Spatial and spectral resolution enhancements are two different approaches for different applications but super resolution is needed in this two for better quality results.

Hyperspectral Imaging system has many challenges depending upon the applications.

These challenges are summarized below:

- High dimensionality of hyperspectral data:
  As hyperspectral images are collected in three dimensional cubes having high dimensionality which needs to be reduced.
- Hyperspectral image Classifications:
  Hyperspectral images are collected through hyperspectral sensors and are to be classified depending upon applications and requirement.
- Improvement in data processing methods:
  As thousands of images are collected they need to be processed and hence improvement in data processing method is required in terms of complexity, optimization and accuracy.
- Developing a super resolution algorithm capable of producing high quality results on general image sequence:
  The information acquired by Hyperspectral Imaging contains spatial as well as spectral information, for both of these super resolutions; enhancement is required for different applications and generating high quality results.
- Computational complexity of super resolution algorithms needs to be improved to achieve high standards in image processing
- Retrieving hyperspectral images with high accuracy is one the challenge in Hyperspectral Imaging
- Parallel algorithm implementations are needed that will able to speed up algorithm performance and to satisfy high computational requirements
- Lossy hyperspectral data compression
  Hyperspectral data is high dimensional data so for optimization and high speed processing lossy hyperspectral data compression is needed.
- Spectral unmixing for hyperspectral data analysis hyperspectral data contains mixed pixels and these pixels are to be separated for hyperspectral data analysis depending upon applications.

CONCLUSION AND FUTURE WORK

Hyperspectral Images are being widely used in variety of applications. Different hyperspectral devices are used to produce these images. These images are represented by using data cube having three dimensions as (x, y, λ). Four techniques are used for hyperspectral data acquisitions having different features and they are selected based on particular application. Hyperspectral imaging system having different challenges which can be considered for working in future to improve performance of hyperspectral imaging system.

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AJCSE, Jan-Feb, 2017, Vol. 2, Issue 1