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An Assessment of Hyperspectral Imaging and Target detection

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Abstract: Hyperspectral Imaging is a recent trend in the field of remote sensing. Over the past few years hyperspectral imaging has been emerged as rapidly developing technology to process and analyze the images. This technique has gained interest in wide area of applications such as food processing, mineralogy, environment, vegetation, astronomy, surveillance, eye care, chemical imaging, military and so on.. This article presents the overview of hyperspectral imaging, outlines the energy distribution from source to sensor, discussing about the radiation interaction with the earth, summarizing the differences between multispectral and hyperspectral data and finally briefing the hyperspectral imaging algorithms in target detection.

Keywords: Hyperspectral Imaging, multispectral, electromagnetic radiation, target detection.

I. INTRODUCTION

In 1970's multispectral imaging were broadly used to measure the radiance of the materials at very few wide wavelength bands [4]. Over the past decades the development in remote sensing has made it possible to measure hundreds of bands. This technology is known as hyperspectral imaging. From these measurements continuous spectrum for each image pixel can be found [10] . Imaging spectrometers are developed to measure the electromagnetic radiation reflected by each pixel at large number of wavelength bands. Processing and analyzing the hyperspectral images are known as imaging spectroscopy [11]. Hyperspectral imaging is generally referred to as spectral imaging which divides the spectrum into many more bands. It provides the spectral information or the intensity of wavelength of all the pixels in the image to distinguish the materials uniquely. Hyperspectral system collects quite a lot of hundred spectral bands over a narrow, contiguous spectral range which produces spectral data of all pixels in the image Hyperspectral Imaging (HSI) measures the amount of radiation as reflected , absorbed or emitted within each pixel at very large number of narrow, contiguous spectral bands. These quantitative and qualitative measurements lead to identify and discriminate the materials distinctively. This motivates to apply the hyperspectral imaging techniques in remote sensing than any other traditional imaging systems. This paper gives an overview of hyperspectral sensors in section II. Section III gives an outline about electromagnetic spectrum. Differences of multispectral and hyperspectral imaging are highlighted in section IV and section V is focused on usage of hyperspectral imaging algorithms in target detection. Disadvantages and conclusion are presented in section VI and VII.

II. HYPERSPECTRAL SENSORS

Images are collected by hyperspectral sensors and represented as a range of electromagnetic spectrum. These images are united together to form a three-dimensional hyperspectral data cube for processing and analyzing [14].

Hyperspectral sensors are advanced digital color cameras provides both spatial and spectral details of images [7].It collects hundreds of bands and measures the reflected radiation in each band. The primary characteristics of hyperspectral sensors are spectral and spatial resolution .Spectral resolution can be determined by the range of spectral bands which are used to measure the radiation. Spatial resolution depends on the size of the object. But all the sensors are limited to spatial, spectral, radiometric and temporal resolution. The following Figure1 gives the outline structure of the energy distribution from source to sensor. The solar energy passes through the atmosphere which is modified and interacts with the imaged surface materials. The energy that is reflected, transmitted or absorbed by the material will again reverse back through the atmosphere which undergoes some spectral changes and reaches the sensor. The sensor measures the intensity of energy in various parts of the spectrum. These measurements are used to identify the materials present in the pixel [6].

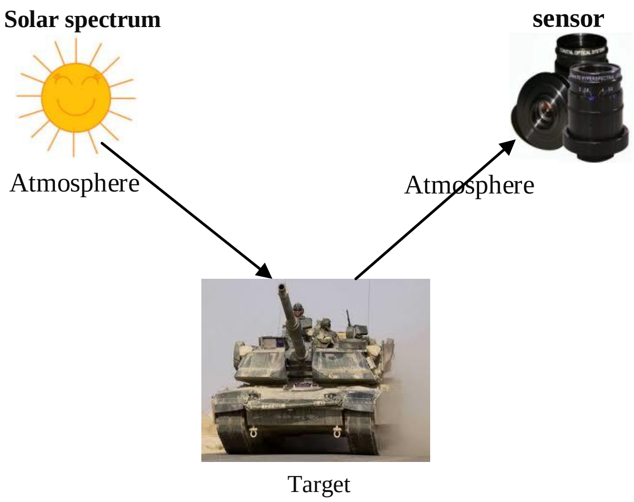

Fig. 1.Energy distribution from source to sensor

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III. ELECTROMAGNETIC SPECTRUM

Electromagnetic Spectrum is the range of all possible frequencies of electromagnetic radiation. The types can be broadly classified as Gamma radiation, X-ray radiation, Ultra violet radiation, visible radiation, Infrared radiation, Terahertz radiation, Microwave radiation and Radio waves. The following Figure 2 shows the wavelength regions of each band [13].

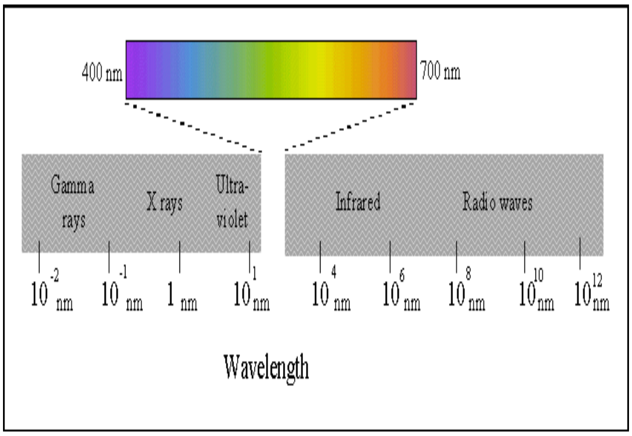

Fig . 2. Wavelength regions of each band [18]

Radiation Interaction with the Earth:

Three forms of interaction can takes place due to the radiation (a) Reflection (b) Absorption (c) Emission.

A. *Reflection*

Reflection occurs when energy is redirected as it reaches the surface or materials. It can be calculated by the intensity of radiation reflected by the materials

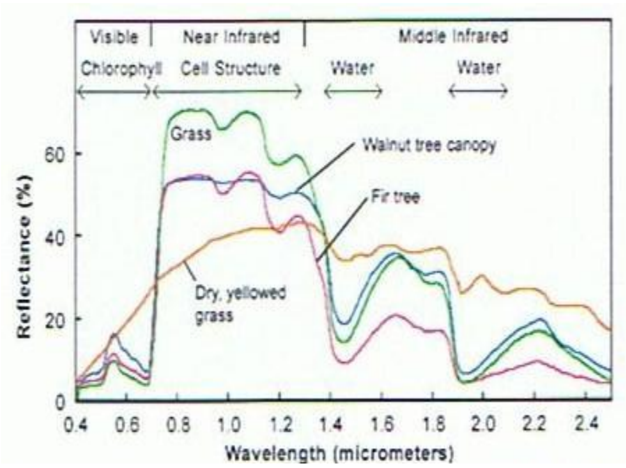

Fig .3. Reflectance spectra of different types of green vegetation compared to spectral signature for dry, yellowed leaves [21]

The above Figure 3 shows the average reflectance curves for grass, dry, yellowed grass, walnut tree canopy and Fir tree. For e.g. In between red and near infrared wavelengths, the reflectance arises sharply for grass. The spectral curve for dry, yellowed grass shows the less reflectance then grass. Normally a plant leaf will reflect around 40 to 50% and the remaining energy is transmitted.

B. *Absorption*

It can be calculated by the intensity of radiation that passes through the sample.

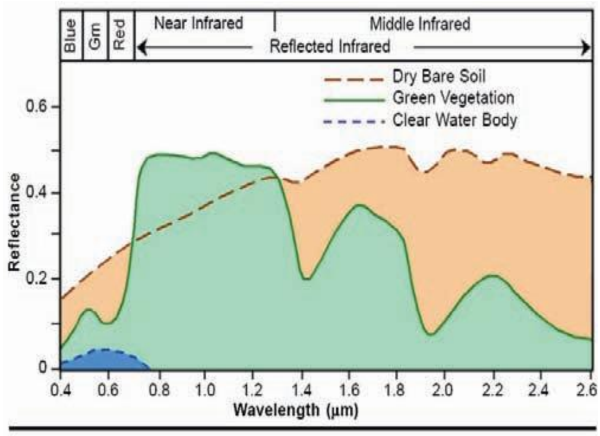

Fig. 4. The spectral signatures of green vegetation, dry bare soil and clear water [16]

The above Figure 4 shows the spectral signatures of green vegetation, dry bare soil and clear water [16].In green vegetation the visible portion of the spectrum the curve shape shows the absorption effects. Chlorophyll absorbs blue and red wavelengths and reflects green. So the plants appear to be in green colour. As there is decrease in chlorophyll production, the absorption will greatly decreases in red and blue wavelengths and reflection will be high in red wavelength. The spectral curve shapes and strength of absorption bands can be used to recognize and differentiate different materials. In clear water the absorption takes place in near infrared wavelength and beyond that. The absorption bands of clear water are noted at 1400, 1900, and 2100 nm. The reflectance is affected due to presence of organic and inorganic materials in water.

C. *Emission*

It occurs when the radiation passes from sun at shorter wavelength to earth that has been absorbed and redirected at longer wavelength. The sensor records the energy absorbed by the earth and re-emitted energy as thermal infrared radiation [13].

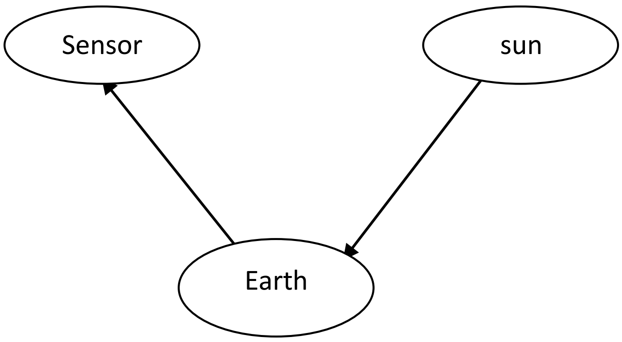

Fig .5. Radiation absorbed by earth and emitted as thermal energy to sensor

The following Figure 6 shows the emission spectra for different forms of silicon (si). Here photons are emitted when substance get excited .Each compound element has different emission spectra.

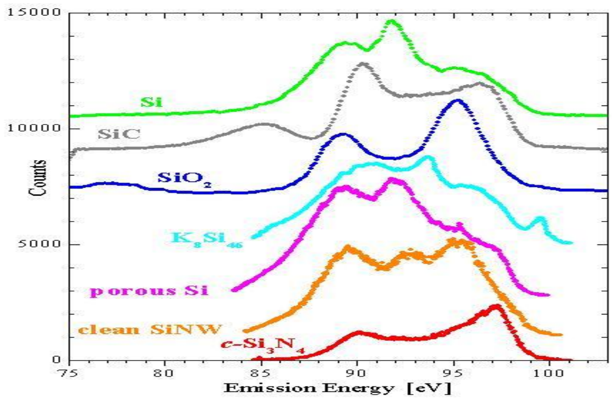

Fig .6 . Emission spectra of different forms of silicon(si) [24].

IV. DIFFERENCE BETWEEN MULTISPECTRAL AND HYPERSPECTRAL IMAGING

Multispectral systems (MSS) can generate only 2-20 images within visible to middle infrared region of electromagnetic spectrum and records energy with moderate discrimination. This spectral classification limits the usage of MSS. Multispectral images produces discrete spectral signatures.

Hyperspectral systems (HSS) process more than 20 images per dataset simultaneously in hundreds of narrow adjacent spectral bands and produces detailed spectral data which results in highest discrimination. In Hyperspectral images the spectral signatures are contiguous [19].

V. HYPERSPECTRAL IMAGING TECHNIQUES IN TARGET DETECTION

A. Target detection

HIS systems are being applied to number of areas including the environment, land use, agricultural monitoring and defense. Hyperspectral imaging plays vital role in military domain by searching and detecting objects in land ,sea and air like trucks, tanks, explosives, ships, flights etc as shown in Figure 7. Finding the desired pixels in a picture based on spectral facts of the specified target is the hyperspectral target detection [1], [23] .

One of the most significant applications of hyperspectral remote sensing is detecting man-made targets. Target detection is mostly depends on spectral variability and sparseness of data. The target spectra and the background data in the hyperspectral image can be united into a detector design process to enhance the performance of the detection. But the factors such as atmospheric conditions, spectral and spatial variability, noise, mixed pixel will leads to performance degradation of the detector [20].

Many algorithms have been developed for target detection provides accurate information contained in hyperspectral imagery. The analysis methods compares pixel spectra and target spectra. According to Monolakis the algorithms are classified to four categories1) target/anomaly detection 2) change detection 3) classification 4) spectral unmixing. This paper concentrates on target detection algorithms.

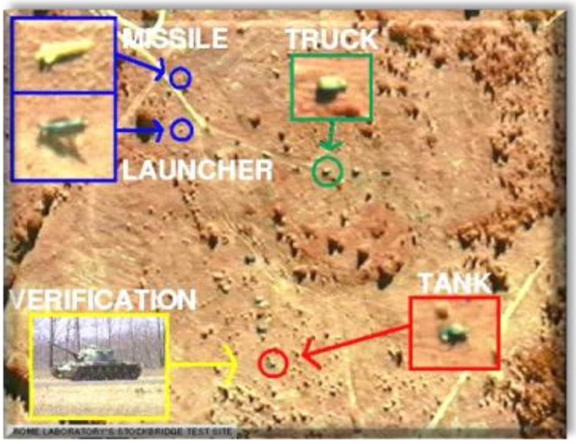

Fig .7. Shows various military targets [12]

B. Target detection Algorithms

In this section an overview of target detection algorithms are discussed.

1) *Spectral Angle Mapper (SAM):*

It is developed by Boardman. It derives spectral angle between each pixel and each target spectra. If the angular difference is small then it indicates the more similarity between the pixel and the target spectra [9], [15]. The following figure 8 shows the angular difference between pixel and target.

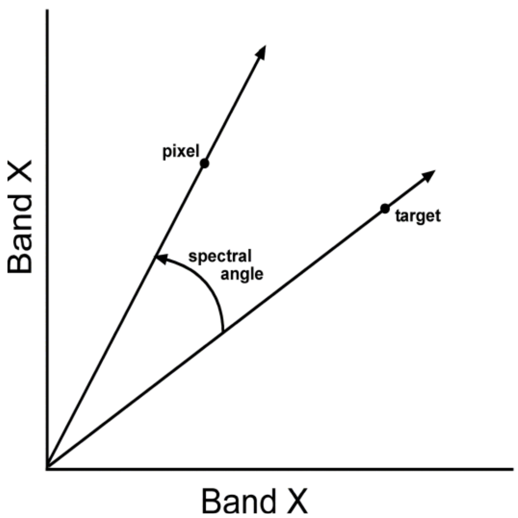

Fig .8. Spectral angle mapper[18].

It is computationally low-cost. It is subjected on spectral shape of the object but independent of the size difference between the target and the pixel.

2) *Adaptive Coherence Estimator (ACE):*

ACE is a stochastic detection algorithm which utilizes the background covariance matrix of the image. It is a derivative of Generally Likelihood Ratio Test (GLRT). ACE does not depends on the knowledge of all the end members in the scene [26].

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3) *Constrained Energy Minimization (CEM):*
It is one of the supervised target detection algorithms. This algorithm is used to maximize the desired target signature and minimizing the background energy [22].

4) Covariance Calculation:
In target detection covariance calculation leads to time consuming process. So the covariance matrix can be computed by selecting a part of pixels as representing the total pixels in the image. The number of pixels used to calculate should be equal or more than the bands, or else singularity problem exists [3].

5) *Orthogonal Subspace Projection (OSP):*
It is a geometric matched filter algorithm. By using this technique the target pixels and the background pixels are split up by projecting information onto a subspace orthogonal to background vectors in the image [7], [22].

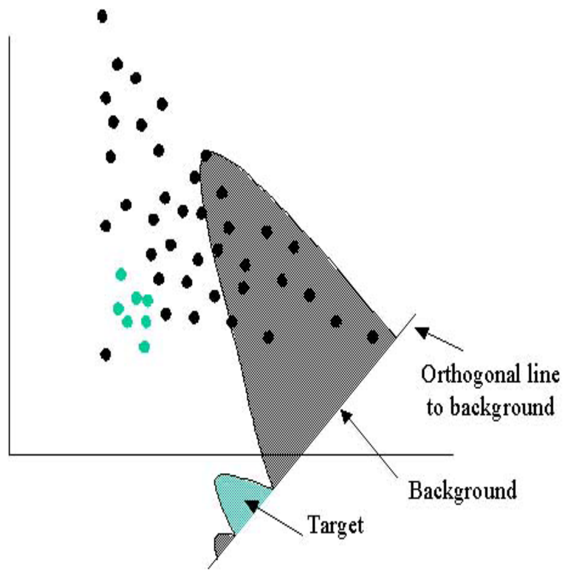

Fig. 9. OSP projection onto subspace orthogonal to background [1].

In other words extracting the desired target signals and removing all undesired background pixels by using a matched filter technique.

6) *Adaptive Subspace Detector(ASD):*
This detection technique is recommended for low probability and anomaly detection. It is one of the most appropriate detectors for sub pixel target detection [17].The mixture of linear unmixing model and the subspace model will results in sub pixel target detection. The irrelevant factors such as target abundance noise variance, target abundance distribution, dimension of the target subspace will greatly decrease the power of ASD [25].

7) End member calculation:
Hyperspectral images consist of mixed pixels. By applying spectral unmixing techniques pure spectral signatures can be separated from the mixed pixels. These pure pixels are called as end members of the image. Pure pixels referred to as particular material's radiance values. The end members can be calculated by finding the number of basis vectors of the image. By applying several techniques, the most extreme end members can be identified to represent the data [2].

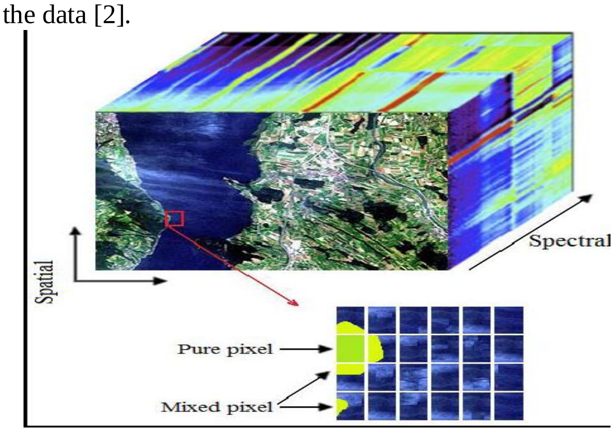

Fig. 10. Pure and mixed pixels form HSI data, where a pure pixel includes a single surface material and a mixed pixel contains multiple materials [7].

Some of the existing end member detection algorithms are

- *Purity Index (PPI)*

PPI is familiar technique to identify the pure pixels in the scene. The output values of PPI will often be used as input to other end member extraction algorithm. PPI algorithm involves projecting all the data pixels into a random unit vectors by passing on pixel purity value to every pixel. Initially the value of pixel purity for all the pixels will be zero [7], [8].Then the process is repeated and pixel purity values are updated for N iterations to determine the highest end members pixels in the image.

- *N-Findr*

This method is used to search the end members within a given hyperspectral data scene [1].The technique involved here is by choosing randomly a set of pixels as initial end member set. Then each end member is exchanged by the other image pixels in the scene. Then the total number of volume of space will be calculated by the existing set of end members. This process will be continued until there is no need for exchange of pixels.

8) Invariant Algorithm:
Invariant algorithm uses a model to generate target subspace. MODTRAN (MODerate resolution atmospheric TRANsmission) is used to determine the transmittance and radiance at medium spectral resolution. It generates a great amount of target signals to construct target subspace. Target spectral reflectance information should be known in advance to generate target subspace model [25].

VI. DISADVANTAGES

Hyperspectral data is usually stored in large multidimensional data cubes needs high storage capacity. The cost of fast and reliable systems, sensors, processors, capacitors will be quite expensive when compared to the other existing systems. These factors limit the usage of HIS systems.

VII. CONCLUSIONS AND FUTURE WORK

The usage of hyperspectral data plays vital role in detecting the targets of interest by providing high spectral resolution data with wide, narrow, contiguous spectral bands. Hyperspectral imaging is best suitable for applications which rely on spectral information than spatial data. This overview highlights the need for hyperspectral imaging and procedures to detect the targets. The efficiency of those algorithms can be compared and explained with various military targets in future.

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