A Study on Recognition of Subsidence Basin Water using Hyper-Spectrum Full Fractal Characteristic

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***Abstract* - This paper takes EO-1 satellite HYPERION hyper-spectrum images and appropriate data processing to extract hyper-spectrum curves from natural water and coal mining subsidence water, and then the algorithm of circle spectrum fractal value is employed to distinguish two types of water after equal interval re-sampling. The results show that this method can effectively identify two types of water. The fractal values of Natural water are bigger than that of subsidence basin water. Through the system clustering, the classification accuracy by single index of fractal value is higher than by original spectral curve. It's an effective means for subsidence dynamic monitoring. The reasons why the difference exists are discussed.**

Keywords - coal mining subsidence area, hyper-spectrum of water, circle spectrum fractal value, recognition

Ⅰ. INTRODUCTION

Coal mining causes large area of land subsidence [1], which becomes a serious problem for sustainable development. In Huainan and Huaibei of Anhui province ,China, the subsidence regions are with high groundwater level, which is often filled by water, the area is bigger than 67km^2[2]. The remote sensing monitoring of subsidence area is widely used currently, but usually with multi-phase data combined with the existing coal mining map, and the goals is to delineate the boundary of subsidence basin water[3,4,5] by manual interpretation or by image classification method. Those research only concerns on the boundary extraction accuracy and dynamic characters of boundary changes. It's a challenge to distinguish the subsidence basin water from the natural water such as lakes and rivers.

Existing researches try to apply shape index $SI = \frac{4\pi A}{P^2}$ (A is the area of a single subsidence basin. P is the perimeter of a single subsidence basin) to distinguish different water bodies, but it's not ideal for subsidence basin water[6].The existing researches show that it is also difficult to distinguish different water bodies apart by multi-spectral remote sensing image directly. Hyper-spectral remote sensing image has wide range spectrum, high sensitivity and spectral resolution, which can distinguish the different water apart from the responding curves of different pixels in theory [7, 8].The popular ways in literatures is to construct indexes from the curve's characteristic absorption valleys and characteristic reflection peaks [9] to identify different ground objects, however, if the component content difference of ground objects is too small, the characters of spectral curves in responding to the objects will disappear [7].

Fractal model is demonstrated as an excellent tool for exploring non-linear complex system. The fractal value, being an important characteristics and measurement of complex system, can be taken to describe the complex objects as a stable feature [10].Hyper-spectrum response curve is the synthesized attribute of physical, chemical and environmental characteristics of objects, therefore, the fractal value of spectral curves may be related to object types. In this paper, a method of employing the fractal value of spectral curve to distinguish between subsidence water and natural water is introduced; the method interpolates the unequal interval curve to equal interval curve, and calculate the fractal value of curve by a new "full fractal value" way, which is effective in distinguishing between the subsidence basin water bodies and natural water without any ground investigation.

Ⅱ. DATA SOURCE AND PREPROCESSING

The hyper-spectrum curves are extracted from HYPERION remote sensing image of EO-1 satellite by ENVI software, the acquisition date of image is December 02, and 2009.The image is of L1G level, the satellite orbit is 121-037, with less cloud covering. The range of spectrum is from 350nm to 2500nm, and the spectrum resolution is about 10nm but not equal interval. The spatial resolution is

30m.According to the parameters of satellite images, some invalid, repeated bands are removed [13].There are only 176 valid bands left at last. The reflectance of each band is calculated by this formula:

$$r = \frac{c \times L_{\lambda} \times D^2}{ESUN_{\lambda} \times \cos\theta_s} \qquad (1)$$

r is reflectance. L_{λ} is sensor brightness. D is sun-earth distance (astronomical unit), and it's 0.9870 by interpolating the image acquisition date according to julian day (which means the image acquisition date is 336 in julian day). $ESUN_{\lambda}$ is average solar radiation intensity above aerosphere, and it can be queried from many channels. θ_s is solar zenith angle=90°-31.461063° (sun elevation angle) =58.538937°.

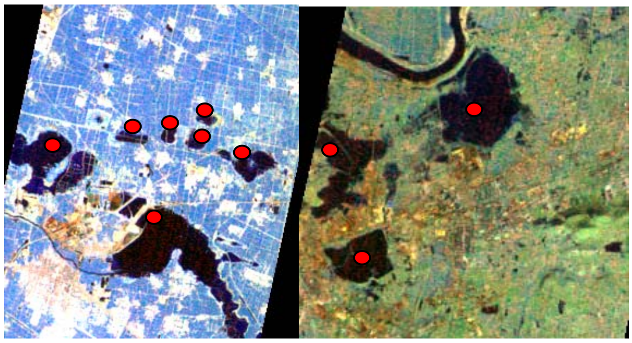
After image mosaic and coordinate correction, adding subsidence area and water system to images. The water bodies are divided into two types as natural water bodies and subsidence basin water bodies, then extracting spectral curves at each water body center (Fig. 1).Eleven subsidence basin water curves and six natural water spectral curves are extracted (TABLE Ⅰ).Image processing software in the study is mainly ENVI and IDL, and the images satisfies the experiment requirement because there are little cloud on them.

The samples for study are collected at the centre of water bodies, because the spectrum of sampling points near the bank may be influenced plants and organic matters, the image space resolution of 30m is detailed enough to extract the spectral curve.

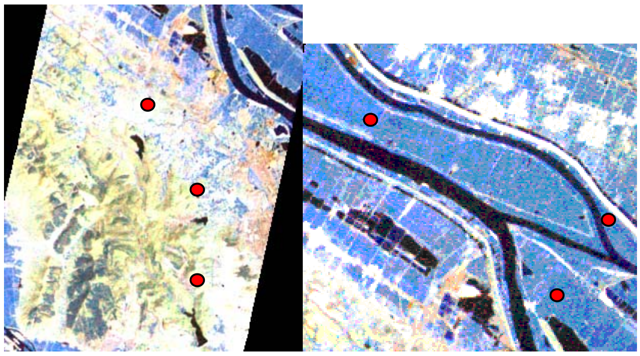
The subsidence basins come into being since 1992[5], and they are still in the process of subsiding, so the images near 2010 can be used to distinguish two types of water.

III. HYPER-SPECTRUM CURVE CIRCLE SPECTRUM FRACTAL VALUE

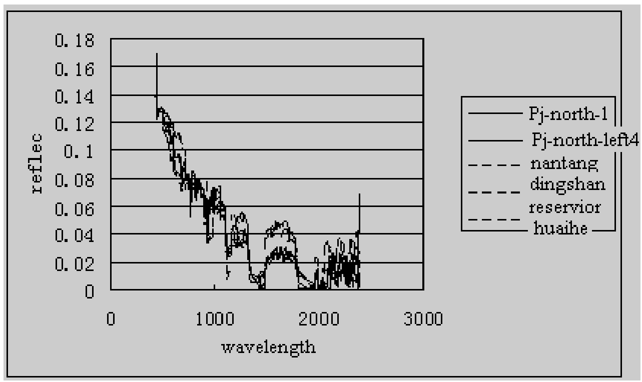
The valuable features extraction from Hyper-spectrum is an important research point of hyper-spectrum image processing, such as principal component analysis(PCA),spectral angle method(ICA),projection addressing(PP),minimum noise separation transformation(MNF) and the method of multi-fracture[11,12].



a.The Sample Points of Subsidence Water



b.The Sample Points of Rivers and Lakes



c.The Spectrum Compare Between Subsidence and Lake(river) Water(dot line is lake or river)

Figure 1.The Distribution of Samples and the Spectrum Comparison

But these algorithms are complex, leaving too much output to recalculate [7]. If we can describe response spectrum curve by an integrated value and can distinguish targets apart by the value effectively [11], the process and result will be applicable. Richardson [14] believes that any

TABLE 1. DIFFERENT WATER SPECTRAL CURVE FRACTAL VALUE STATISTICAL TABLE

Sample point	D value	δ	α
Subsidence water			
Pj-north-1	0.312085	0.001493	standard
Pj-north-left1	0.342382	0.001543	0.976929
PJ-north-left2	0.336849	0.0016	0.981199
PJ-north-left-3*	0.384603	0.001665	0.98635
Pj-north-left4	0.29865	0.001404	0.978673
PJ-north-left5	0.296314	0.00169	0.977551
PJ-north-lef-tdown	0.336115	0.000885	0.97094
laobietang	0.314218	0.000978	0.92935
shijianhu*	0.349504	0.000973	0.955991
xinzhuangzi*	0.362203	0.00096	0.990238
erdaohe*	0.365322	0.001844	0.978011
mean	0.336204		
Natural water			
Nantang reservoir	0.421659	0.001084	standard
Dingshan reservoir	0.419106	0.001036	0.971945
Wolong lake	0.398186	0.00102	0.979315
Wabu lake	0.375138	0.002073	0.952704
Nihe river	0.409329	0.001182	0.941434
Huaihe pingyu	0.426308	0.001535	0.944729
mean	0.408288		

Explanation: in the table, D is fractal value. δ is the spectra curve variance. α represents the relationship between this and the first spectral curve.

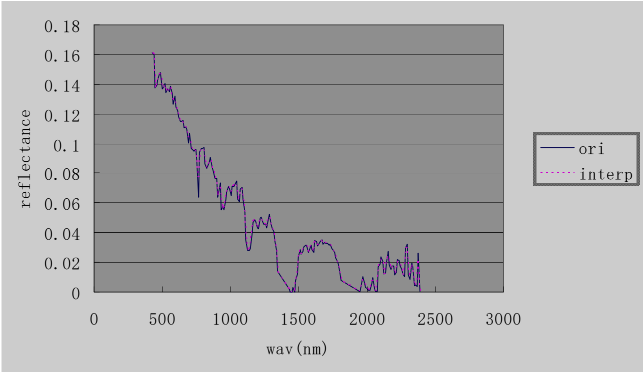


Figure 2.The Curve Comparion Between Original Spectral cCurve and Resampling

complex curve satisfies the formula: $L(d)=kd^b$, d is measurement length, $L(d)$ is curve length measured by step d , k is a constant, b is a negative number. If b keeps steady within a certain scale, then d =1-b is called the fractal value of the curve. It has been proved that the spectrum curves have fractal characteristics.

There are a lot of fractal value calculation methods [10, 11]. This paper takes the following steps to calculate spectral curve fractal value. A spectral curve is described as:

$$\Omega=(x_1,r_1;...;x_i,r_i;...;x_n,r_n) \tag{2}$$

x_i is band center. r_i is the reflectance of corresponding wavelengths. Because Hyperion image spectrum intervals are not fixed, the value of $x_{i+1}-x_i$ changes. So the Ω is mapped into Ω' by the linear interpolation method for fractal value calculating effectively:

$$\Omega' = (y_1,r_1;...;y_i,r_i;...;y_n,r_n) \tag{3}$$

$\forall y_{i+1}-y_i$ =10nm , $y \in [427nm,2387nm]$ .Fig. 2 is the spectral curve after re-sampling.

The curve length is measured under different steps as 10nm, 20nm, 40nm, 80nm, 160nm, 320mn, 640nm, 1280nm:

$$len = \sum sqrt((x_k - x_i)^2 + (r_k + r_i)^2) k = i + step \tag{4}$$

This method can measure different curve length under different step theoretically; the measurement by formula (4) is more convenient in $\Omega^{/}$ than in Ω. But the full curve length is not integer times for each step in practice, some data at the end of curve will be discarded [10, 11] in fact. In this paper, a new method is proposed: when the last step is out of the curve rang, using $r_{k+1} = r_k \%2386$ to change the curve to a ring to compensate insufficient data reasonably and it also can highlight the shortwave spectrum. This method is called circle spectrum fractal value (CSFV).

Finally, in the double logarithm coordinate system, using the least square regression model to fit $\ln(step)$ and $\ln(len)$, and then getting the spectral curve fractal value $D=-b$ (b is the slope of fitting straight line).

Ⅳ. Results and Analysis

The forms, shapes and curvatures of spectral curves from different water bodies differ a little or very much, they are synthetically response to the environment, component of ground objects, yet they are not just related to one or a few characteristic parameters of the objects. In fact, it is hard to find out these quantitative parameters. However the fractal value can represent the complexity of the hyper-spectrum curves from the ground, the measurement f the curve by fractal value can provide us with relevant structure and potential knowledge of the ground objects not just the forms, the shapes and the curvatures etc. The spectral curve analysis based on fractal theory has a good effect on target recognition [11].

The samples from Huainan subsidence field (Fig. 1 a, b) in table 1 are divided into two categories. Their spectral curves are extracted at accurate pixels from the hyper-spectrum image. The curves correlations of each type are of big value mostly more than 0.95. It's hard to distinguish two types of water by spectral curves themselves (Fig. 1 c). Two kinds of curve fractal values are discrepant but there is a cross section, but the fractal values of subsidence water in the left column of table 1 are commonly bigger than that of natural water list in the right column of table 1. For example, the fractal value of some samples with * in the left column is bigger than others, it is because that although the sample of PJ-north-left3 belongs to subsidence basin water, but it also is an original natural lake (Fig. 3) when comparing it to early the remote sensing image of 2004.This is why the fractal value of the area is bigger. The sample of the Shijianhu* is although in coal mining subsidence area, but it irrigate from Huaihe River as well as the xinzhuangzi sample. The fractal value of the erdaohe River is also bigger although it is a river yet which is influenced by subsidence.

The water samples are clustered by the spectral curve and their fractal value through system cluster method respectively, the result diagram is showing in Fig. 4, which indicates that it's more effectively to identify subsidence basin water by fractal value than by the spectrum itself, when the class number is set to 2, only the Wabuhu Lake is mis-classified. The reason may be that the lake water source is from Dabie Mountain area while the other lakes are from Huaihe River. The mis-classification is high when using the original spectral curve as classification index. This study implies that the fractal value of spectral curve is more effective than the spectral curve itself in distinguishing between the two types of water.

The reason why the fractal values of subsidence basin water are lower than of natural water may be that subsidence water accumulation time is short, the weak mineralization results in reducing absorption and reflection intensity, so the curve's complexity and fractal value decreases. The quantitative relationship between the element of the water and fractal value needs further study.

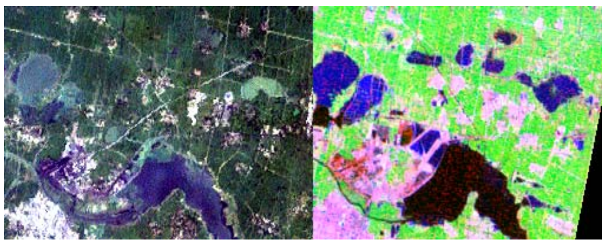


Figure 3. Subsidence Comparison Between 2004(left)-2010(right)

Ⅴ. Conclusions and Acknowledgements

Through field survey, this study extracts spectrum information from satellite image; seventeen spectral curves of water bodies from subsidence basins and natural water are measured to demonstrate they full fractal values based on statistical principle. The seventeen samples are clustered by original curves and their fractal value respectively. The result shows that the hyper-spectrum fractal value can be more accurately and effectively to distinguish coal mining subsidence basin water and natural water than original spectral curve. The study believes that the fractal values of spectral curves from subsidence basin water are lower than from the natural water on condition that they are in the similar water system and environment.

Any more, the methods to measure the fractal value are only introduced in the form of formula and principle in the literatures; there are not a little problems in practice, especially when the curve length is not the integral times of steps, the left end of curve is often discarded, which will leads to information distorted. The proposed method of full fractal value utilizes the curve fully to construct the fractal value, which is excellent than the old way theoretically.

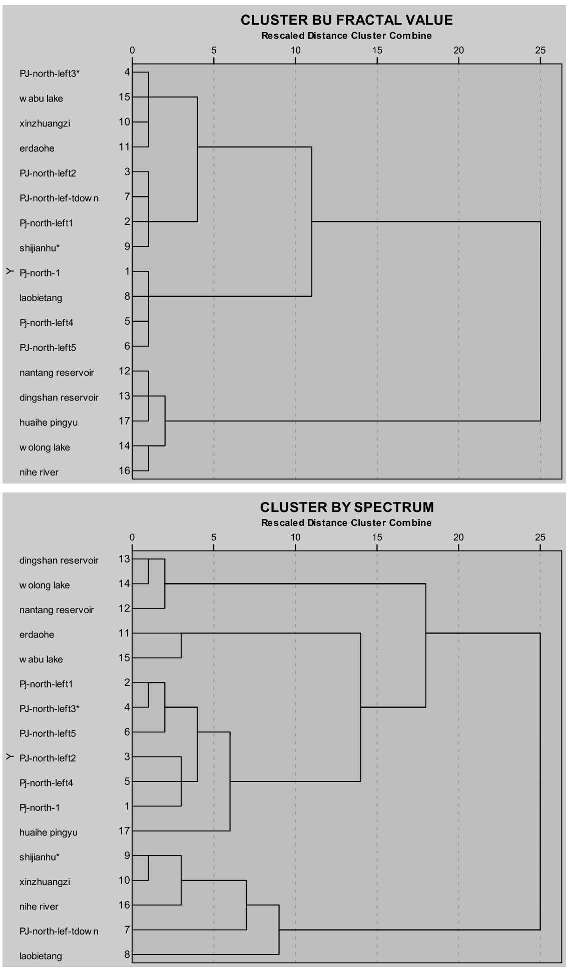


Figure 4. The Sample Clustering Diagram Based on Original Spectral Curve and Corresponding Fractal Value

The subsidence basins are mostly in closed system in Huainan area [15], the seeper is from the surface water and rain but not from existing rivers, which may be populated by chemical fertilizer, coal gangue and algae plants[16]. So the chemical components of the subsidence seeper are mainly organic matters; the time for metallic element accumulation is too short. But natural water we often called lakes or rivers are in open system, the water is from mountain and has a long migration route, the eutrophication of the water is weak, but the beneficial trace elements and minerals are complete and rich, such as carbon, hydrogen, oxygen, nitrogen, calcium, phosphor, kalium, sulfur, sodium, chlorine, magnesium, and iron, copper, zinc, manganese, iodine, cobalt, molybdenum, selenium, fluorin, barium, they are in the form of ions. The content of each element can be measured by equipments of course, but it is not an appropriate way for wide rapid monitor, the hyper-spectrum image can provide a cheap way.

It should be explained that the samples in this study are in one water system except for one sample named “Wabu lake” is in another water system, the fractal values of spectral curves may be incomparable if they are collected from different water system because the chemical components and evolution process of them are discrepant. “Wabu Lake” is that sample which has a bigger fractal value than the others values.

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