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Research Article

The application of wavelet bilinear interpolation algorithm in research of well log similarity

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Abstract: Well log is a data manifestation of geographical, chemical, physical and other information detected in different geological environment and formation condition by means of different well log methods. Aiming at the noise existing in well log signal and the property of its morphological characteristics and combining and analyzing bilinear interpolation algorithm and the theory of wavelet transform of well log, the paper proposes the application of a modified wavelet bilinear interpolation algorithm in well log similarity. In addition to eliminating noise in well log signals, the modified wavelet bilinear interpolation algorithm reserves detailed information of well log and lays a good pretreatment foundation for comparing the similarity of well log. The detailed feature information of well log received after modifying wavelet bilinear interpolation is analyzed and judged by means of slope distance metric method to identify the similarity of well log. As experiment shows, this method is well applied in comparing the similarity of well log.
Keywords: Bilinear interpolation algorithm; Wavelet transform; Well log; Similarity comparison

INTRODUCTION

Well log is a data manifestation of geographical, chemical, physical and other information detected in different geological environment and formation condition by means of different well log methods, which is sampled by discrete data used to measure the change of physical quantity according to its depth and showed by the synthetic and continuous well log. However, noise widely exists in original well log data, and well log is important in studying the property of oil gas reservoir stratum and evaluating production capacity. The morphological characteristics of well log are major criteria for geological experts and well log analysts to study geological comparison and sequence stratigraphy. Therefore, it is definitely necessary to filter and deburr well log before analyzing and using it.

Block, jaggy and other phenomena are available to appear when managing well log by means of interpolation algorithm. To eliminate such phenomena, a new correlation method of wavelet transform and bilinear interpolation applied in the similarity of well log is proposed by making use of the multiscale analysis of wavelet transform and the similarity of each subband after wavelet transform is decomposed. As for the shortcomings of the combination of wavelet transform and interpolation, the low-frequency component of bilinear interpolation algorithm [1] should be used to overcome these shortcomings. The results obtained by using interpolation and combining wavelet transform and interpolation should be blended and matched according to some matching requirement. As the experiment shows, this method is simple and convenient, which can improve the quality of well log and efficiently manage the similarity of well log in later application [2].

The judgment of similarity is widely applied in managing and analyzing well log such as relative depth correction of perforation, the comparison of the contrast layer of malmstone and the curve judge judgment of the acceptance of logging information [3]. The depth correction of perforation means that the logging company makes Natural Gamma-Ray (GR) curve as the depth control curve and chooses marker bed in standard GR curve to search for and compare deeply the similar layers of the GR curve [4]. Due to the different sampling interval and collecting environment between the original data of well log to standard GR data and that of standard GR data to standard GR data, making searching for the contrast section of similar curve, the paper presents the measure method of similarity of well log which is based on the modified wavelet bilinear interpolation algorithm. Depending on the deformation of GR curve in corresponding position of reservoir and the features of well log and making a piece of GR in the same well as its standard, standard GR curve and contrast GR curve are managed by means of modified wavelet bilinear interpolation algorithm when partial curve is obtained from contrast curve. Then the similarity of detailed information of well log's features received by modified wavelet bilinear interpolation is judged by judging and analyzing by means of slope distance measure method [5]. Finally, amore ideal effect is received through the experiment of the practical well log data.

THE THEORY OF BILINEAR INTERPOLATION ALGORITHM

Continuous function is inserted in discrete data to make all the data points on the continuous curve, which is the theoretical basis of bilinear interpolation algorithm.

Define: Let assume the real-valued function of closed interval [a, b], which there are *n+1* different values of $x_0, x_1, \cdots, x_n$, and the corresponding values are $f(x_0), f(x_1), \cdots, f(x_n)$. Calculate the value of $f(x)$ when it is some point in the closed interval [a, b].

Find $p(x)$ satisfying conditions in chosen function class $\Phi(c_0, c_1, \cdots, c_n)$ which has *n+1* parameters $c_0, c_1, \cdots, c_n$.

$$p(x_i) = f(x_i), \quad (i = 0, 1, \cdots n) \tag{1}$$

$p(x)$ is the estimated value of $f(x)$.The function in $\Phi(c_0, c_1, \cdots, c_n)$ satisfying above formulas is interpolation function.

$$R(x) = f(x) - p(x) \tag{2}$$

$R(x)$ is the remainder of interpolation. Among that, if estimation point is involved in the minimum closed interval which includes $x_0, x_1, \cdots, x_n$, it is called interpolated value, on the contrary it is called extrapolation.

THE THEORY OF WAVELET TRANSFORM

Essentially, wavelet transform is the projection relationship of wavelet basis function.

If basic wavelet function $\Phi(t) \in L^2(R)$ satisfies $\int_{-\infty}^{\infty} \Phi(t)dt = 0$, then the function cluster $\Phi_{a,b}(t) = \frac{1}{\sqrt{|a|}}\Phi\left(\frac{t-b}{a}\right)$ generated by basic wavelet by means of translating and stretching is called continuous wavelet. The wavelet transform of function $f(x) \in L^2(R)$ is:

$$W_f(a,b) = \langle f, \Phi_{a,b} \rangle = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} f(x)\Phi\left(\frac{x-b}{a}\right)dx \tag{3}$$

$$W_s f(x) = f(x) \times \Phi_s(x) = \frac{1}{s}\int_{-\infty}^{\infty} f(t)\Phi(\frac{x-t}{s})dt \tag{4}$$

In which, $\Phi_s(x) = \frac{1}{s}\Phi\left(\frac{x}{s}\right)$, *s* is scale parameter.

If the Fourier transform $\Phi(w)$ of function $\Phi(t)$ satisfies the permissibility condition $C_\Phi = \int_{-\infty}^{\infty} |\Phi_{(w)}|^2 |w|^{-1} dw < \infty$, then wavelet transform is reversible. The reconstructed form of formula (4) is:

$$f(x) = \frac{1}{C_\Phi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} W_s f(t)\Phi_s(x-t)\frac{1}{s}dsdt \tag{5}$$

In the practical application, it is unnecessary to continuously get the value of scale parameter of wavelet transform. On the contrary, discretization management is made to continuous wavelet and its transform by means of certain method. Get $s = 2^j, j \in Z$, then the wavelet transform of $f(x)$ under scale parameter is 2^j:

$$W_{2^j} f(x) = f(x) * \Phi_{2^j}(x) = \frac{1}{2^j}\int_{-\infty}^{\infty} f(t)\Phi\left(\frac{x-t}{2^j}\right)dt \tag{6}$$

$$f(x) = \sum_{j=-\infty}^{\infty}\int_{-\infty}^{\infty} W_{2^{-j}} f(t)\left\{2^j X[2^j(x-t)]\right\}dt \tag{7}$$

Decompose and reconstruct the wavelet of $f(x)$ according to Mallat Pyramid algorithm.

$$S_{2^j} f(x) = f \times \phi_{2^j}(x) = \sum_{l \in Z} h_l S_{2^{j-1}} f\left(x - 2^j l\right)$$

$$W_{2^j} f(x) = f \times \phi_{2^j}(x) = \sum_{l \in Z} h_l S_{2^{j-1}} f\left(x - 2^j l\right) \tag{8}$$

$$S_{2^{j-1}} f(x) = \sum_{l \in Z} h_{l-1} S_{2^j} f\left(x - 2^{j-1} l\right) + \sum_{l \in Z} k_l W_{2^j} f(x - 2^{j-1} l) \tag{9}$$

In that case, the filter coefficient of wavelet function, scaling function and reconstructed wavelet function are respectively $\{g_l\}$, $\{h_l\}$ and $\{k_l\}$.

Well log data are a group of discrete data signal with limited length, so they have limited energy which is presented as $\{d_i\}_{i\in Z} \in l^2$. If the sampling density is 1, then there is a function $f(x) \in L^2$ which makes:

$$d_i = f(x)\times\varphi(i) = S_1 f(i) \tag{10}$$

THE APPLICATION OF THE ALGORITHM IN SIMILARITY IDENTIFICATION

In order to present how the wavelet bilinear interpolation algorithm improve the accuracy in identifying well-logging similarity and for the purpose of objective assessment, this paper used actual well log data taken from several wells for the similarity comparison experiment. Firstly, separate curved sections can be acquired from GR datum curve and GR correlation curve. Then gathering the bilinear interpolation on datum curve section, and using wavelet transform preprocessing on datum and correlation curve sections. Thirdly, employing slope distance metric method to search for the most similar curve sections.

In the process of similarity comparison, the experiment compared three experimental methods: the modified wavelet bilinear interpolation algorithm put forward by this paper, bilinear algorithm and wavelet interpolation, so as to provide visual judgment reference for different results. Artificial recognition was also included in determining similarity. The experiment, based on the similarity comparison done on 100 datum well sections of 15 wells, gathered compatible results of well sections similar in well log and well sections similar in artificial recognition. The experiment shows that the method proposed in this paper are more accurate than the other two. Adding evaluation index of curve sections image into image entropy and use it as another identification standard. The following are the experiment procedures.

In the experiment, the primitive curve is partial section of a well's log. For comparing the effectiveness of wavelet bilinear interpolation algorithm in determining well log similarity, the experiment compared results of bilinear algorithm, wavelet interpolation and modified wavelet bilinear interpolation algorithm. As shown in table 1, the Peak signal-to-noise ratio and entropy correspond to the results of the three algorithms. The PSNR and entropy of bilinear algorithm and wavelet interpolation are lower than that of wavelet bilinear interpolation algorithm. Therefore, the modified wavelet bilinear interpolation algorithm is obviously advantageous in enhanced PSNR and entropy and improving detailed information of images, which sufficiently laid the foundation for further similarity identification.

Table 1. Experimental results of image interpolation

Method	PSNR/dB	Entropy /bits
Bilinear interpolation	20.413	13.624
Wavelet interpolation	24.147	13.678
Wavelet bilinear interpolation	27.457	13.845

Using slope distance and slope presenting method proposed in literature [6] to indentify the similarity of well log curve under modified wavelet bilinear interpolation algorithm.

The piecewise linear representation as basis, sequence block slope represents time series, k as the line slope of section i, and t_i as finish time of each section. Then equation (11) represents the slope of time series:

$$S = \{(k_1,t_1),(k_2,t_2),\cdots(k_i,t_i),\cdots,(k_n,t_n)\} \tag{11}$$

Slope as the basis of lope distance of time series, as shown in equation (12):

$$D_k(S',S'') = \left|\sum_{i=1}^{n} \Delta t_i \left(k_i^{'} - k_i^{''}\right) / t_n\right|, i = 1,2\cdots n \tag{12}$$

In which, $\Delta t_i = t_i - t_{i-1}$, the slope distance with clear physical significance, highlighted the diversity of two sequential tendency and with fewer distance in calculating complexity comparing to other methods.

As shown in table 2, for each datum curve section, three corresponding depth ranges of correlation curve section, curves of images, and comparison results of three algorithms were listed. Experimental data shows: for the same datum curve section, employing the modified wavelet bilinear interpolation algorithm and the slope distance method for similarity contrast calculation, the slope distance is much shorter than that of bilinear algorithm and wavelet interpolation. Seeing from the distance results, the shorter the distance between correlation and datum curve section, the similar they are. What's more, the results of artificial recognition are also more obvious. Therefore the result of similarity identification is more reasonable and better for artificial and computer recognition.

Table-2: Identification results of three method

Datum depth	Comparison depth	Bilinear interpolation	Wavelet interpolation	Wavelet bilinear interpolation	Recognition result
1025.10-1028.70	1013.59-1017.50	18.14	17.65	12.46	Dissimilarity
	1025.04-1028.68	17.60	16.30	6.75	Similarity
	1127.13-1130.36	18.39	15.46	10.22	Dissimilarity
1236.05-1238.85	1105.77-1107.50	16.12	11.69	10.24	Dissimilarity
	1205.03-1207.22	16.09	12.88	11.04	Dissimilarity
	1235.79-1238.83	14.52	10.45	5.42	Similarity
1178.15-1181.50	1008.57-1012.06	19.31	9.76	8.24	Dissimilarity
	1174.43-1177.01	21.24	11.47	11.64	Dissimilarity
	1178.63-1182.05	18.72	10.11	6.20	Similarity

CONCLUSION

The experiment results suggests: the modified wavelet bilinear interpolation algorithm applied to well log similarity identification not only can well maintain primitive well log information, improve spatial resolution of well log and reach optimum value of well log's PSNR, but also can improve high frequency information and entropy of well log. The well log under interpolation algorithm and wavelet transform processing is beneficial to human eyes' observation. With more detailed information and clarity, distortion became rare. The experimental results proved that the modified wavelet bilinear interpolation algorithm is an effective method for improving well log similarity identification.

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