International Journal of Energy
ISSN: 2957-9473 | Vol. 1, No. 1, 2022

Research on stratigraphic correlation method based on dynamic time bending distance algorithm

Zhenfei Li

School of Earth Sciences, Northeast Petroleum University, Daqing, Heilongjiang, China

Abstract: Stratigraphic division and correlation are the basis of oil and gas exploration. With the increasing degree of oilfield encryption, the traditional artificial comparison method is difficult to meet the actual needs of oilfield development, and the comparison method of different people is also subjective and different problems, it is difficult to form a more scientific quantitative method. In this paper, the dynamic time-bending distance algorithm of curve similarity algorithm is used for stratigraphic correlation, and two constraint methods based on beam constraint and parallelogram constraint are used to improve the dynamic time-bending distance algorithm. The application of dynamic time-bending distance algorithm in formation correlation is verified by using the real logging data of Nan8 area of Daqing Oilfield. The experimental results show that the dynamic time-bending distance algorithm improves the efficiency of formation correlation and achieves a good formation correlation effect on the real logging curve.

Keywords: Stratigraphic correlation; Dynamic time bending distance algorithm; Well logging curve.

1. Introduction

Formation correlation of drilling profile is a very important work in reservoir development and geological research. Formation correlation is mainly based on logging curves that reflect formation physical properties with depth and geological parameters that reflect formation structural properties. Log data record continuous logging values with depth and time. In order to understand the geological changes more intuitively and clearly, intuitive logging curves can be formed on the two-dimensional coordinate system. Curve similarity comparison of log curves is an important way of formation correlation. But with the increasing degree of field encryption, more and more new Wells are being drilled. Artificial reservoir correlation is difficult to meet the needs of oilfield development because of its high labor intensity and low efficiency. Moreover, the comparison methods of different people are subjective, and it is difficult to form a more scientific quantitative standard. Therefore, the use of computer for reservoir comparison has become a widely pursued and considered to be an effective method. In 1995, Geng Yaohui used the method of combining pattern recognition with the best matching of ordered elements in dynamic programming for comparison, which improved the accuracy of conventional stratigraphic correlation[1].In 2009, Wang Ping proposed a multi-well correlation algorithm based on the stratification results of well logs, using the common Kriging method to create a virtual well, using the virtual well to correlate the formation of the same interval in all Wells[2].In 2017, Gong Faming applied the dynamic string matching algorithm to stratigraphic correlation, overcoming the difficulty of incomparability of stratigraphic missing and stratum pinch-out[3].In 2020, Wang Wei proposed an automatic comparison method of small zones between multiple Wells based on quantum neural network, and constructed a network model by using logging curves and statistical characteristic data to realize automatic comparison of small zones based on QNN[4].

2. DTW algorithm principle

Suppose two time series Q and C whose length is m and n, respectively, as follows:

Q = q1, q2, q3， and..., qm

C = c1, c2, c3， and..., cn

First, a matrix with m rows and n columns is constructed, whose elements are the Euclidean distances of points between two sequence data objects

$$D(qi,cj)=|qi-cj| \quad (1)$$

This matrix is called the distance matrix D of the two sequences Q and Cm×n.

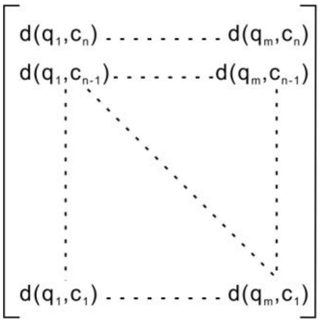

Figure 1. Distance matrix Dm×n

In order to calculate the dynamic time-bending distance DTW(Q,C) of Q and C, the optimal bending path W needs to be foundbest={w1, w2, w3...wK} minimize the cumulative distance between S and Q, wk. Represents the position of the curved path element in the distance matrix, i.e. wk= (i, j)kIs qi With cj And the matching relation between D(wi) = D(i, j)k. Generally, there are multiple bending paths, and an effective bending path generally meets the following conditions:

Boundedness: max (m, n) ≤K≤m+n-1;

Boundary conditions: the two ends of the diagonal of the distance matrix are the starting and ending elements of the curved path;

Continuity: Elements in a curved path are continuous with each other;

Monotonicity: curved path W before passing through the point (I, j) one point is only (I - 1, j), (j - I - 1, 1), (I, j - 1)

One of these three points, a point that has this characteristic, is monotonic on the timeline.

Boundaryness is the starting point W that guarantees w1(1, 1) and the end point wK(m,n) in the lower left and upper right corner of the distance matrix Dm×n; Monotonicity and continuity are used to ensure that the next point of the curved path is above, to the right, or to the right of the current point, as in wk+1- w.k∈ {(1, 0),(1, 1), (0, 1)}.Among the many effective paths, the only optimal path can be found to minimize the cumulative distance, namely:

$$D(Q, C) = \min_{W}\left\{\frac{1}{K} \quad \sum_{k=1}^{K} D(w_k)\right\} \qquad (2)$$

The purpose of denominator K in Equation (2) is to obtain the same standard when comparing all curved paths of different lengths, which is similar to the standardization process. In order to solve equation (2), dynamic programming method is used to construct a cumulative distance matrix, in which each element can be obtained by the following formula:

$$\gamma(i, j) = D(i, j) + \min \begin{cases} \gamma(i-1, j-1); \\ \gamma(i-1, j); \\ \gamma(i, j-1). \end{cases} \qquad (3)$$

Where: i=1, 2...m, j=1,2...n, γ (0,0) = 0, γ (i, 0) = γ (0, j) = ∞. Formula (3) represents the cumulative distance of the current element as the current distance value plus the minimum cumulative distance value of the three adjacent elements in the lower left corner. γ(m,n) is the minimum cumulative cost of dynamic time-bending measures Q and C, namely DTW(Q,C) = γ(m,n).After the minimum cumulative cost is obtained, in order to obtain the optimal bending path, then inversely take wKTrace the path back for the starting point to find the curved path until i = j = 1 and wkWhen (i, j) = (1, 1), the search process ends and the complete bending path W is finally obtained.The following is an example to check the optimal dynamic time-bending path of two sequences and calculate the DTW distance. Suppose there are two sequences, A={3,5,5,7,4,9,10} and B={2,4,5,8,6,3,9,11}, the cumulative distance matrix is constructed according to the two sequences, and the above formula is used to calculate the results shown in Figure 2.

11	26	18	18	14	17	7	6
9	18	12	12	10	10	5	6
3	12	8	8	8	5	11	15
6	12	6	6	4	5	8	10
8	9	5	5	3	7	6	8
5	4	2	2	4	5	9	16
4	2	2	3	6	6	11	17
2	1	4	7	12	14	21	29
B/A	3	5	5	7	4	9	10

Figure 2. Cumulative distance matrix of sequence A and B

According to the cumulative distance matrix of sequence A and B, DTW (A, B) = 0.75. The red area in the figure is the optimal dynamic time-bending path of the two sequences A and B.

3. Improved algorithm of DTW

3.1. Global banded constraints

First of all, we need to define a constraint condition of the deformation path. In the actual calculation, in order to prevent some paths that do not meet the actual situation from being selected, we need to constrain each element w in the deformation path the common path constraints are divided into two types, one is the global ribbon constraint, the other is the parallelogram constraint. As shown in Figure 3-1, let the length of the two sequences Q and C be m and n respectively, and the global banded constraint should meet the following conditions:

$$\begin{cases} i \geq \frac{m}{n} \times (j-r) \\ i \leq \frac{m}{n} \times (j+r) \end{cases}$$

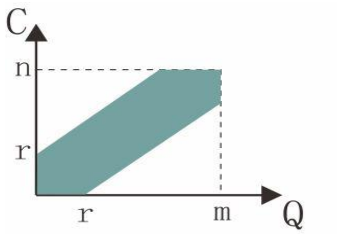

Figure 3. Banded constraints on the traceback path

Where r is defined as the reachable radius. In the cumulative distance matrix constructed by sequence Q and C, each frame of data in sequence Q does not need to be calculated with each frame of data in sequence C, but only the data within the global banded constraints can be calculated. By adopting such a method, part of the computation amount of the algorithm can be reduced.

In this method, the choice of r is the focus. If the choice of r is infinite, then it becomes unconstrained, and then the constraint becomes meaningless. If the selection of r is too small, it will make the selection of matching path become harsh in the path backtracking process, which may filter out the best matching point and fail to get the desired result. Generally, the bandwidth length is set between 5% and 10%, which can not only effectively match, but also reduce the amount of computation and save time.

3.2. Parallelogram constraint

Let the length of the sequence Q and C be m and n respectively, and the four vertices of the flat quadrilateral are (1,1) and (Xa,2Xa-1), (Xb,(Xb+1)/2), (m,n), dynamic bending is calculated in three sections, which are: (1,Xa), (Xa+1,Xb), (Xb+1, m). Among them

$$\begin{cases} Xa = \frac{2 \times n - m}{3} \\ Xb = \frac{2 \times (2 \times m - n)}{3} \end{cases}$$

Xa, Xb Are rounded nearest to each other, from which the constraints on m and n can be obtained:

$$\begin{cases} 2 \times n - m \geq 3 \\ 2 \times m - n \geq 2 \end{cases}$$

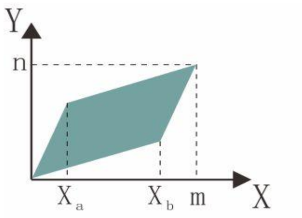

Figure 4. Parallelogram constraint diagram of the backtracking path

If the above conditions are not met, it is considered that the length gap between the two sequences is too large for dynamic bending matching.

When the parallelogram constraint is adopted, the data of each frame on the X-axis sequence no longer needs to be calculated and compared with each frame on the Y-axis sequence, but only with the data on the Y-axis [ymin, ymax] frames between sequences are computed and compared, where, ymin and ymax is calculated as follows:

$$y_{min} = \begin{cases} \frac{1}{2}x \quad (0 \le x \le X_b) \\ 2x + (n - 2m) \quad (X_b < x \le m) \end{cases}$$

$$y_{max} = \begin{cases} 2x \quad (0 \le x \le X_a) \\ \frac{1}{2}x + (n - \frac{1}{2}m) \quad (X_a < x \le m) \end{cases}$$

In addition to the above, X may also occura>Xb in this case, the three segments matched by dynamic bending are: (1, Xb), (Xb+1, Xa), (Xa+ 1, m).

4. Experimental verification

According to the above principles and methods, this paper selects six Wells in the eighth south area of Daqing to form a block profile for stratigraphic correlation experiment. According to the logging response characteristics, according to the standard layer selection criteria: 1, stable distribution throughout the area, moderate thickness, 2, lithology, physical property is basically stable, 3, good borehole effect, reliable logging data. S25, S37, P14, P26 and G111 are selected as the standard layer. According to the selection criteria of standard Wells: 1, complete logging series, superior logging conditions, 2, located in the favorable position of the structure, far away from the fracture zone, deeper drilling, 3, representative range distribution, vertical well is appropriate. Two Wells n8-31-p2036 and n8-31-p2043 were selected as standard Wells.

According to the characteristics of the marker formation, well n8-31-p2034 selected 932.4m~1195m as the contrast well interval, a total of 58 small intervals, well n8-31-p2036 selected 943.1m~1207.8m as the contrast well interval. A total of 58 small formations and Wells n8-31-p2038 were selected 955.8m~1221.5m as the contrast interval, and a total of 58 small formations and Wells n8-31-p2039 were selected 957.5m~1224m as the contrast interval. A total of 58 small formations, n8-31-p2040 well 963.3m~1233.4m as the contrast interval, a total of 58 small formations, n8-31-p2041 well 966.8m~1236.4m as the contrast interval. A total of 58 zones and Wells n8-31-p2043 were selected 965m~1222.9m as the contrast interval, and 58 zones and Wells n8-31-p2044 were selected 969.5m~1223.6m as the contrast interval, a total of 58 zones. Based on the response characteristics and correlation analysis of logging curves, RMN logging curves are selected and DTW curve similarity algorithm is used for formation correlation. According to the standard layer, two curve similarity algorithms based on DTW are adopted, namely, DTW algorithm based on beam constraint and DTW algorithm based on parallelogram constraint. The absolute difference between the top of the contrast layer and the middle top of the original stratified data is the error standard. The error ratio and comparison time of the two algorithms are respectively counted, as shown in the Table 1.

Table 1. The error ratio and comparison time of the two algorithms

	Value of error (x)	Proportion of error	Time of comparison
DTW algorithm based on bundle constraints	0≤x≤0.2m	74.1%	141.36s
	0.2m<x≤0.4m	20.7%	
	0.4m<x≤0.5m	1.7%	
	x≥0.5m	3.5%	
DTW algorithm based on parallelogram constraint	0≤x≤0.2m	77.5%	108.42s
	0.2m<x≤0.4m	13.8%	
	0.4m<x≤0.5m	5.1%	
	x≥0.5m	3.6%	

As can be seen from the table, the error rate of the DTW algorithm based on the beam constraint is not much different from that based on the parallelogram constraint. However, the DTW algorithm based on the parallelogram constraint is more efficient and faster than that based on the beam constraint. Therefore, it is more reasonable to adopt the DTW algorithm based on the parallelogram constraint. Therefore, the DTW algorithm based on parallelogram constraint is adopted to conduct stratigraphic correlation from well n8-31-p2034 to well n8-31-p2044 profile, and the results are shown in figure 5.

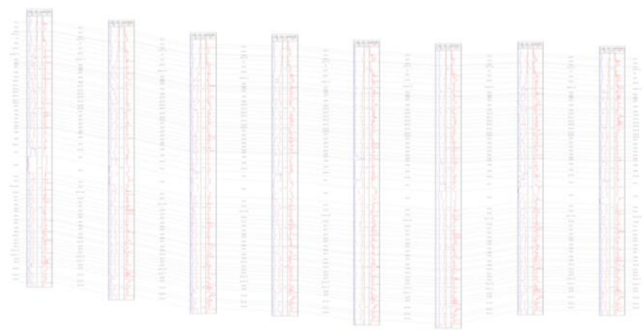

Figure 5. Formation correlation from well n8-31-p2034 to well n8-31-p2044

5. Conclusion

(1) A large number of data from the Nan8 block of Daqing oilfield were analyzed by using this method for stratigraphic correlation, and compared with the artificial stratification results. The comparison results of this method are accurate and meet the requirements of correlation.

(2) The experiment proves that it is feasible and effective to use the dynamic time-bending distance algorithm to make curve similarity comparison for stratigraphic correlation. For the fine correlation of small layers, the traditional manual method is difficult to carry out the follow-up work efficiently and quickly due to its strong subjectivity and heavy workload.

With the rapid development of computer technology in the future, the research on the automatic correlation of strata based on curve similarity algorithm will certainly play a more and more important role.

References

[1] Geng Yaohui, Xu Shaohua, Liu Honglin. Application of pattern recognition in formation correlation of well logging curve [J]. Journal of Daqing Petroleum Institute,1995(04):34-37.

[2] Wang Ping, Tang Lianwei, Ma Nan, ZANG Yuwei. A stratigraphic correlation method based on virtual well and multizone correlation [J]. Journal of Tianjin University, 2009, 42(08):744-751.

[3] Gong Faming, Chen Tong, GONG Wenjuan, DOU Ruihua, ZHANG Xuena. Dynamic string matching algorithm in the application of stratigraphic correlation [J]. Journal of logging technology, 2017, 9 (01): 114-119. The DOI: 10.16489 / j.i SSN. 1004-1338.2017.01.020.

[4] Wang Wei, Zhao Ya, Li Panchi. Study on stratigraphic correlation based on quantum neural network [J]. Journal of Guangdong University of Petrochemical Technology, 20, 30 (04): 32-36.