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Curve Fitting And Interpolation Model Applied In Nonel Dosage Detection

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Abstract

The Curve Fitting and Interpolation Model are applied in Nonel dosage detection in this paper firstly, and the gray of continuous explosive in the Nonel has been forecasted. Although the traditional infrared equipment establishes the relationship of explosive dosage and light intensity, but the forecast accuracy is very low. Therefore, gray prediction models based on curve fitting and interpolation are framed separately, and the deviations from the different models are compared. Simultaneously, combining on the sample library features, the cubic polynomial fitting curve of the higher precision is used to predict grays, and 5mg-28mg Nonel gray values are calculated by MATLAB. Through the predictive values, the dosage detection operations are simplified, and the defect missing rate of the Nonel are reduced. Finally, the quality of Nonel is improved.

Keywords: *curve fitting, spline interpolation, dosage, gray*

1. Introduction

Nonel tube is constructed of the thin plastic tube and gunpowder, so the content of the gunpowder directly determines whether the booster can proceed smoothly. When excessive gunpowder accumulates in the certain plastic tube, the Nonel tube will be burnt through because of the external booster energy. However, if the gunpowder is not enough and even breaks in some area, the detonation wave will go out and result in the explosive fails. Therefore, it is necessary to detect the content of gunpowder in the Nonel.

The traditional detection methods are Standard Method and Analysis Method, but they cannot test the gunpowder instantaneously without destruction. In 1994, Wang Zhigang makes use of infrared to detect the amount of drugs in Beijing Institute of Technology, and the writer gives the mathematical models of the dose and light intensity. However, the test data are not analyzed carefully, so its detection accuracy is not high [1-2]. At the same time, the similar research is little abroad.

Since the types of Nonel are too many, it is difficult to test all the dosage of the Nonel with optical instruments. So curve fitting and interpolation are used to establish the models which shows the relations between Nonel gunpowder and gray values. With the limited sample data, the gunpowder of the random Nonel has been predicted from 5mg to 28mg.

2. The Principle of Numerical Analysis

2.1. The Interpolation Method

The simulative curve can pass all the given points justly through the interpolation method, which can forecast unknown data. Then, the simplest interpolation method is Piecewise Interpolation, with which the neighbor points are connected by the straight lines. Assuming that *f(x)* is the original function in [a, b], the construct interpolation function I(x) is given in the formula (1).

$$f(x) \approx I(x) = \sum_{i=0}^{n} y_i l_i(x) \tag{1}$$

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li(x) is the interpolation basis function, and its expression in (a, b) is as follow:

$$l_i(x) = \begin{cases} \dfrac{x - x_{i-1}}{x_i - x_{i-1}}, x \in [x_{i-1}, x_i] \\ \dfrac{x - x_{i+1}}{x_i - x_{i+1}}, x \in [x_i, x_{i+1}] \\ 0 \end{cases} \quad (2)$$

Meanwhile, the data in the engineering applications are mostly processed by the cubic spline interpolation, such as cam grinding, climate prediction, overland flow etc. It is defined as follows: [3-8]

A set of nodes in function f(x) in [a, b]: a=x0< x1< x2< … <xn=b and the function value in the nodes yi=f(xi). There is a function S(x) C2[a, b], and S(x) are cubic polynomials in the each cells of [xi, xi+1]. If S(xi)=yi, S(x) are the cubic spline interpolation function.

In order to guarantee the existence and uniqueness of S(x), any of the following three conditions should be fulfill:

(1) $S'(x_0)=f'_0$, $S'(x_n)=f'_n$
(2) $S''(x_0)=f''_0$, $S''(x_n)=f''_n$
(3) $S(x_0)= S(x_n)$, $S'(x_0)= S'(x_n)$, $S''(x_0)= S''(x_n)$

2.2. The Least Squares Method

The simple approximate functions are constructed with the data fitting method, which needn't pass the all the discrete data points justly, and the least squares method fits the data with the standard of the best square approximation. In the gunpowder detection, the residuals $t_i=f(x_i)-y_i$ of the fitting function *f(x)* in xi is assumed, and the least squares method chooses f(x), which minimize the squared sum of the residuals: Emin=min∑ti2.

The principle of the least squares method is as follow: for a set of data (x_i, y_i)($i=0,1,\ldots,m$), there are a number of functions $\Phi=corre(\varphi_0,\varphi_1,\ldots,\varphi_n)$ characterizing the relationship between independent variable *x* and dependent variable *y*, and the function $y=S^*(x)$ in Φ is found, which minimize the squared sum of deviation $\|\delta\|_2$.[9-12]

$$\|\delta\|_2^2 = \sum_{i=0}^{m} \delta_i = \sum_{i=0}^{m} [S^*(x) - y_i]^2 = \min_{s(x)\in\varphi} \sum_{i=0}^{m} [S(x_i) - y_i]^2 \quad (3)$$

$$S(x) = a_0\varphi_0(x) + a_1\varphi_1(x) + \ldots + a_n\varphi_n(x)(n < m) \quad (4)$$

3. The Source of Samples

3.1. Dose Detection Method

The uniformity of the Nonel filler depends on the stability of the production speed, and the Nonel powder detection method is used based on the CCD in the article. After acquiring Nonel gray values, the relationship between Dose and Gray is established. Obviously, the powder of the unknown Nonel can be calculated by the relationship, and the software will judge whether the productions are qualified.

In the experiment, take a section of qualified Nonel T_0 as the example. Firstly, the images are collected by the line scan camera, and the average gray value of each picture is calculated. Then, repeat the previous step for five to ten times, and take out the maximum value G_{0max}, the minimum value G_{0min} and the average value G_{0avg}.Secondly, the professional equipment is used to blow the powder of the Nonel tube T_0 into a container, and the powder quality M_0 in the Nonel T_0 is get by weighing the container. Obviously, G_{nmax}, G_{nmin}, G_{navg} and M_n from the different Nonel T_n can be get with the similar method. Then, the correspondence table between continuous dose values and the gray values is shown by the means of numerical analysis, so the gray qualified intervals of the different dose are draw up with the Dose-Gray relation table. Finally, the instantaneous grays and the average grays are detected by image recognition procedures constantly, which will judge whether they are in the quality intervals.

3.2. The Gray Detection of Standard Nonel

The gray detection of the standard Nonel is as follows:

(1) Read the image of fi(x, y), and acquire each pixel gray value Gray(s, t) in the target area;

(2) Calculate the average gray value Ei of each picture of Nonel;

$$E_i = \sum_{s \le X} \sum_{t \le Y} Gray(s,t) \Big/ XY \tag{5}$$

(3) Count the total frames F of the Nonel, the average gray value E, the maximum Emax and the minimum Emin;

$$E = \sum_{i \le F} E_i \Big/ F \tag{6}$$

Emax=Emax{E1,E2,…,EF} (7)

Emin=Emin{E1,E2,…,EF} (8)

(4) Record E, Emax, Emin and its dynamite M.

(5) The qualified Nonel of different doses are used to repeat step (1) to (4), such as 6mg, 9mg, 12mg, 15mg, 18mg, 21mg, 24mg and 27mg, and the results are as follow:

Table 1. Discrete Doses and Corresponding Grays

Num	Dose (mg)	Upper Gray	Lower Gray	Average Gray	Num	Dose (mg)	Upper Gray	Lower Gray	Average Gray
1	6	161	160	160	5	18	106	98	102
2	9	155	154	154	6	21	88	85	87
3	12	146	137	139	7	24	74	69	71
4	15	123	119	121	8	27	56	54	56

4. The Establishment of Dose-Gray Model

In the numerical analysis, mathematical models predicting data are mostly established by curve-fitting and spline function. Taking the mean gray as example, the interpolation method and least squares method are adopted to analyze the sample data in MATLAB.

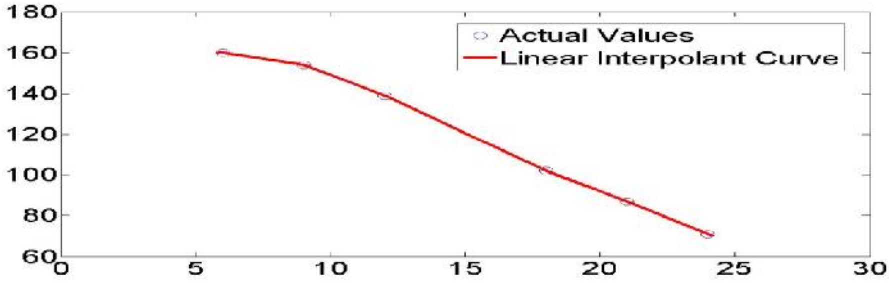
4.1 The Establishment of the Interpolation Model

Input the data of groups 1-3 and 5-7 in MATLAB, and draw linear and 3-spline interpolation curves respectively by interpolation orders, and the results are shown in the Figure1.

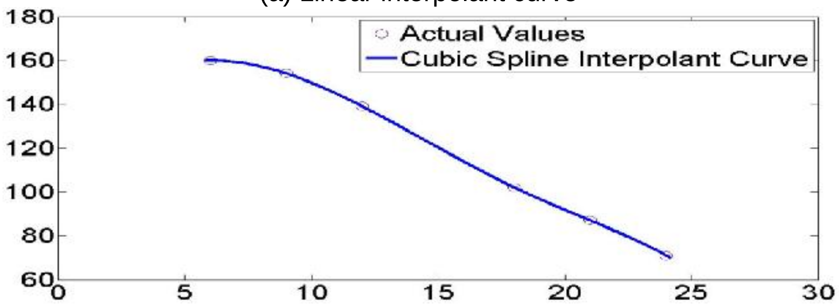
In the Figure 1, the smooth of piecewise linear interpolation is visibly poor in [5, 12] of the horizontal axis, so the volatility of its first derivative is large. Meanwhile, the two approximation effects in surplus areas are similar, so the Gray-Dose model is created by cubic spline interpolation. With the model, the grays of 15mg and 27mg are forecast in the Table 2. [13-15]

Table 2. The Comparison of the Actual Value and Prediction

Nonel Dose	Actual Gray	Prediction Gray	Deviation
15mg	121	120.19	-0.81
27mg	56	48.13	-7.87



(a) Linear interpolant curve



(b) Cubic Spline Interpolant Curve

Figure 1. Different Orders of the Interpolant Curves

4.2. The Establishment of Fitting Model

In the Table 1, *y* decreases as the increasing of *x*. The linear function, polynomial function, power function etc. are conformed to the given data relationship. Taking No.1-3, 5-7 sets of data in the Table 1 for curve fitting, the results are shown in Figure 2.

Calculate the deviations of each fitting function with MATLAB as Table 3. In Table 3, the greater polynomial is, the smaller deviation square sum is, which is better for the curve fitting degree.

Table 3. The Error of Curve Fitting

Fitting Function	Deviation Squared Sum
linear fitting	71.26
cube polynomial fitting	5.02
Power function fitting	37.41

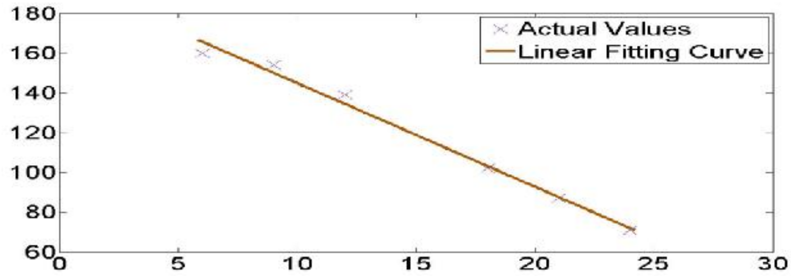
But the greater the orders are, the larger the amount of calculation is. Comparison of the three approximations, the deviation of cubic polynomial curve-fitting is the smallest. Considering the accuracy and real-time, cubic polynomial is used to make curve-fitting. Calculating the polynomial by MATLAB, the formula is as follows:

$$f(x)=0.01543x^3-0.7681x^2+6.441x+146.0612 \quad (9)$$

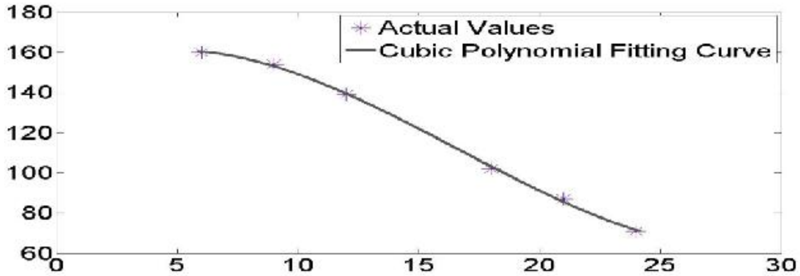
Calculate the gray values of 15mg and 27mg according to the formula (9), the results are as Table 4.

Table 4. Predicted Results of Cube Polynomial Fitting

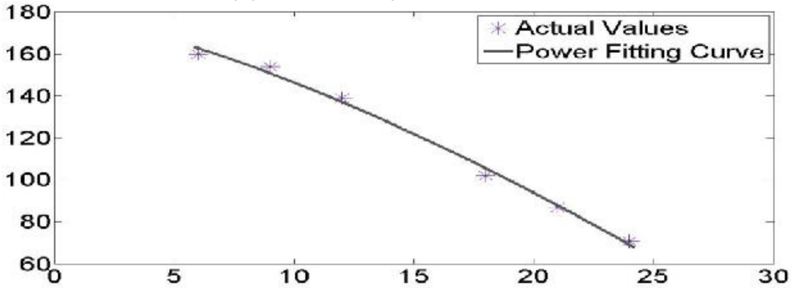
Nonel Dose	Actual Gray	Prediction Gray	Deviation
15mg	121	121.93	0.93
27mg	56	63.75	7.75



(a) Linear Fitting Curve



(b) Cubic Polynomial Curve



(c) Power Fitting Curve

Figure 2. The Predictions by Curve Fitting

5. The Comparison of Two Forecasting Results

Through the prediction results from two models, it is found that extrapolation deviations and the squared sum of the residuals caused by the cubic curve fitting is slightly less than cubic spline interpolation, but the inner precision by the three times spline interpolation is higher. The comparisons are shown in table 5:

Table 5. The Prediction Deviations by Two Models

Nonel Dose	Actual Gray	Prediction Deviation by Cubic Spline Curve	Prediction Deviation by Least Squares Method
15mg	121	-0.81	0.93
27mg	56	-7.87	7.75
Residual Squares Sum	-	62.593	61.238

Though MATLAB, the discrete grays from 5mg-28mg are speculated with the two models, and the results are in Table 6 and Table 7. It is normal that the gray decreases as the dose increase in two tables, but it is abnormal that 5mg gray is smaller than 6mg gray in table 6. Therefore, the cubic polynomial fitting is adopted in this article at last, whose continuous prediction values are drawn in Figure 3.

Table 6. Discrete Prediction Results in Grams from 5mg to 28mg by Cubic Spline Interpolation

Dose	Gray	Dose	Gray
5	159.07	17	107.73
6	160.00	18	102.00
7	159.33	19	96.75
8	157.27	20	91.82
9	154.00	21	87.00
10	149.73	22	82.07
11	144.67	23	76.81
12	139.00	24	71.00
13	132.92	25	64.43
14	126.60	26	56.88
15	120.19	27	48.13
16	113.85	28	37.96

Table 7. Discrete Prediction Results in Grams from 5mg to 28mg by Cubic Polynomial Fitting

Dose	Gray	Dose	Gray
5	161.00	17	109.39
6	160.39	18	103.12
7	158.80	19	97.00
8	156.33	20	91.08
9	153.06	21	85.49
10	149.09	22	80.31
11	144.51	23	75.62
12	139.41	24	71.53
13	133.88	25	68.13
14	128.03	26	65.50
15	121.93	27	63.75
16	115.68	28	62.95

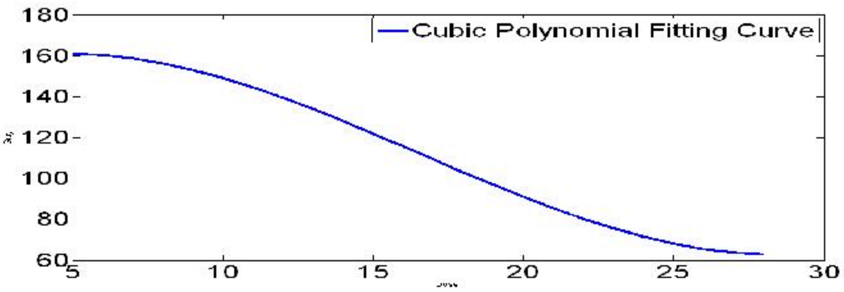


Figure 3. The Prediction Curve by Cubic Polynomial Fitting Curve

6. Summary

It is difficult to detect the dose of Nonel powder in the Nonel Quality Detection System, but the spline interpolation models and curve fitting models characterizing the relationship between doses and grays are separately established firstly, which depends on the limited Nonel samples caught by CCD. In this paper, considering the smoothness and stability, try to use three times spline interpolation function for the prediction of the Gray. Meanwhile, in order to simplify the prediction function and reduce the calculations, the cubic curve fitting is chose to predict Nonel gray by the least squares method. However, the extrapolation of three times spline interpolation resistances to the actual regular, so the cubic polynomial fitting is adopt according to the similar precision finally. Based on the continuous prediction curve, the discrete gray values between 5mg-28mg and the continuous curve are given. Therefore, the recognition accuracy of the powder defects in the Nonel is improved greatly, and the hidden dangers caused by the quality of products are eliminated largely.

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References

[1] Wang ZG, Li GX. The study on the infrared nondestructive testing technology of the Nonel tube. *Pyrotechnics*. 1996; 23-25.
[2] GUO JQ, Li GX, Zhang HP. Research on Photoelectric and Inspecting Methods and Its Effected Factors of the Explosive Content of Nonel Tube. *Science Press*. 2003; 5: 282-287.
[3] Estela BD, Pierre AC. Temporal Distribution, Interpolation and Extrapolation. *Lecture Notes in Statistics*. 2006; 186: 159-191.
[4] Zhang DQ, Han YB, Tang XY. Nonlinear/non-gaussian time series prediction based on RBF-HMM-GMM model. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 10(6): 1214-1226.
[5] Paul S. Recent Progress on Univariate and Multivariate Polynomial and Spline Quasi-interpolants. *International Series of Numerical Mathematics*. 2005; 151: 229-245.
[6] Sun XC, Luan YZ, Yan SY, Gui WZ, Huang XY, Wang YG. Application of curve fitting and interpolation model in deformation forecast of a mining area. *Non-ferrous metals*. 2012; 64(1): 66-68.
[7] Lu JG, You J, Yang QM. Nonlinear model predictive controller design for identified nonlinear parameter varying model. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2012; 10(3): 514-523.
[8] Detlef M, József S, Marcel de B. Trends and Applications in Constructive Approximation. *International Series of Numerical Mathematics*. 2005; 151.
[9] Cunha, José B. *Curve fitting: Fitting functions to agricultural and biological data*. Computers in Agriculture and Natural Resources - Proceedings of the 4th World Congress. 2006; 618-623.
[10] Michael C, Peter KK. Fitting Data Under Omnidirectional Noise: A Probabilistic Method for Inferring Petrophysical and Hydrologic Relations. *Math Geosci*. 2010; 42: 877–909.
[11] Li GD, Shiro M, Wang CH, Daisuke Y, Masatake N. *The hybrid grey-based model for cumulative curve prediction in manufacturing system*. Proceedings of the 2004 International Symposium on Safety Science and Technology. 2004; 4: 962-966.
[12] MJ Sablik, FJG Landgraf, R Magnabosco, M Fukuhara, MF de Campos, R Machado, FP Missell. Fitting the flow curve of a plastically deformed silicon steel for the prediction of magnetic properties. *Journal of Magnetism and Magnetic Materials*. 2006; 304: 155-158.
[13] Wang YF, Liu LL, Wen HY. Application of the Least Square in Deformation Monitoring. *Geospatal Information*. 2007; 5(3): 109-110.
[14] Noor FA, Iskandar F, Abdullah M, Khairurrija X. Numerical simulation of tunneling current in an anisotropic metal-oxide-semiconductor capacitor. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 10(3): 477-485.
[15] Pathak B, Abu-Farsakh M, Yu XB, Alshibli K. Interpretation of lateral load test of batter pile group using high order polynomials curve fitting. *Geotechnical Special Publication*. 2011; 211:152-161.