Interval Prediction and Stability Analysis of Time Series (Part Ⅱ: Experiment)

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Abstract. The interval prediction and stability analysis model of time series are verified by the manufacturing system and friction torque experiments of rolling bearings in this paper. According to the dynamic characteristics of the surface roundness error of outer ring, the stability situation of outer ring groove grinder of rolling bearings is assessed; via the current signal of friction torque, the performance trend of bearings is analyzed during their operation. The two experiment cases of time series are collected 50 sample data. Based on the grey bootstrap method, the intervals of above two time series are predicted by using the former 6 data to forecast analysis and the latter 44 data to verify this model, and the prediction results show that the prediction interval contains almost all the experiment value with a small rate of misinformation and high precision. Then based on the fuzzy-set theory, the stability of time series is analyzed, and the study shows that products have a good stability during their operation.

Introduction

The nonlinear time series generally exist in the fields of society, economy, national defense, industry and agriculture, which often imply deterministic rules of a certain attribute [1-3]. Only exploring and discovering the rules, can the accurate prediction and stability analysis of time series of nonlinear dynamic system be realized, and it is also the direction of the experts and scholars to study recent years. At present the researches of this problem are more and more, but the engineering application is less, so we always don't know what to do when facing these problems of irregular poor information. If the interval prediction and stability analysis can be achieved, the uncertainty factor of time series will be effectively described, and the dynamic self-diagnosis be real-time completed and dynamic characteristics of product be recognized during its operation [4-6].

Based on the groove surface roundness error and friction torque of time series of rolling bearings, the grey bootstrap distribution can be established by an equiprobable sampling with replacement and data generated using the grey bootstrap method [7-8]. The interval is estimated under the condition that the given confidence level is 100%, and results show that the rate of misinformation is extremely low, so this model can be used in the engineering practice effectively. Based on the fuzzy-set theory [9-10], the fuzzy equivalence relation can be obtained by preprocessing the segmented data, and the stability analysis is realized via the given threshold value of 0.5 level with results showing that both of the research objects have a good state during their work.

Experimental Research

Case 1: The time series research of manufacturing system of rolling bearings

The experiment instrument is an outer ring groove grinder of rolling bearings, which grinds the bearing type of 6208. The experiment purpose is to forecast the roundness error of groove surface and analyze the stability of the manufacturing system, and verify that the interval prediction of grey bootstrap method and the stability analysis of fuzzy equivalence relation are reasonable and feasible.

50 outer rings is grinded in the grinder, generating a sequence A with 50 data (unit: μm).

A = [0.58 0.67 0.53 0.51 0.50 0.45 0.42 0.42 0.63 0.54 0.35 0.54 0.50 0.58 0.39 0.48 0.36 0.38 0.57 0.50 0.48 0.49 0.54 0.41 0.60 0.52 0.56 0.72 0.46 0.60 0.69 0.80 0.46 0.56 0.58 0.56 0.50 0.56 0.68 0.96 0.55 0.57 0.67 0.75 0.38 0.43 0.64 0.43 0.60 0.80]

Case 2: The time series research of friction torque of rolling bearings

The research object is steady current of bearings friction torque under the condition that room temperature is 20 ~ 25℃ and relative humidity is more than 55%. The control box of reaction outputs voltage on command to drive the rolling bearing in vacuum experiment device, and the current signal is obtained after the feedback device sampling and transforming. According to the current signal of steady state, the time series of friction torque of rolling bearings are indirectly obtained. The bearing friction torque is equal-interval measured 50 times, acquiring a sequence B with 50 data (unit: mA).

B = [350 346 344 339 331 341 342 335 331 333 339 335 332 335 337 340 342 341 344 341 347 345 339 333 332 336 334 338 338 335 340 340 339 340 336 336 340 340 342 335 340 341 342 339 333 340 338 336 338 337]

Interval Prediction. The performance interval range of time series is forecast by taking the former n=6 data and using the grey bootstrap method, and the reliability of the static prediction is verified by the rest of 50-n=44 data. The biggest feature of grey bootstrap method is suitable for poor information problems, whose probability distribution and the trend chang are unknown. Suppose the confidence level P=100%, B=10000, N = 6, the prediction results are shown in Table 1.

Table 1 The prediction results of time series A and B

Time series	A	B
Prediction interval	[0.302, 0.805]	[317.3, 359.5]
The number of exceeding interval	1	0
The rate of misinformation /%	2.27	0

Through the experiment study of time series A and B, we can find that the grey bootstrap method can really forecast overall fluctuation characteristics of product performance parameters under the condition there is no any information of probability distribution and the number of data is extremely small. Under the confidence level P=100%, the difference between upper and lower limit is smaller, and the difference of A is 0.503μm and B is 42.2mA, viz. the forecast precision is higher. What's more, two time series showing significant uncertainty and the interval prediction very complex, so the results of interval prediction are satisfactory.

In addition, in the process of model validation by using the latter 44 data, the number of exceeding prediction interval of the two time series is quite small with A is 1 and B is 0, viz. the prediction results is reliable and this model can be used to online analysis in the engineering practice; The highest rate of misinformation is 2.27% and the lowest is 0%, viz. the prediction reliability of time series is 97.73-100%, so the forecast accuracy and reliability of time series is ideal. At the same time, there is a good consistency between the latter 44 data and the former 6 data with no obvious evolution and a good stability state.

Stability Analysis. Case 1: The number of samples is m=10, and the sample size of each sample is n=5.

$\hat{Z}$ = [Z_1, Z_2, Z_3, Z_4, Z_5, Z_6, Z_7, Z_8, Z_9, Z_{10}]

The matrix of fuzzy equivalence relation can be obtained as follows

1.000 0.550 0.508 0.550 0.617 0.617 0.688 0.556 0.583 0.556
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0.550 0.689 0.508 1.000 0.550 0.550 0.550 0.550 0.550 0.550
0.617 0.550 0.508 0.550 1.000 0.694 0.617 0.556 0.583 0.556
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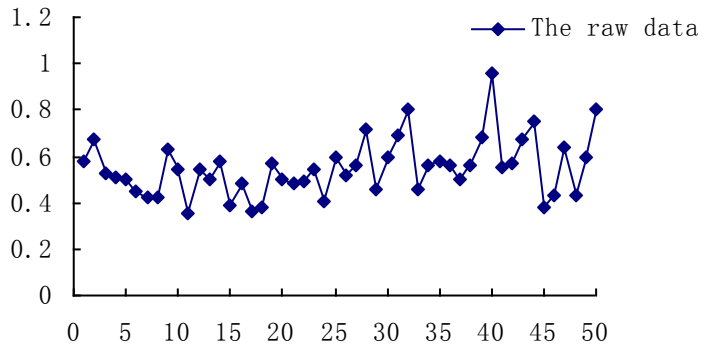
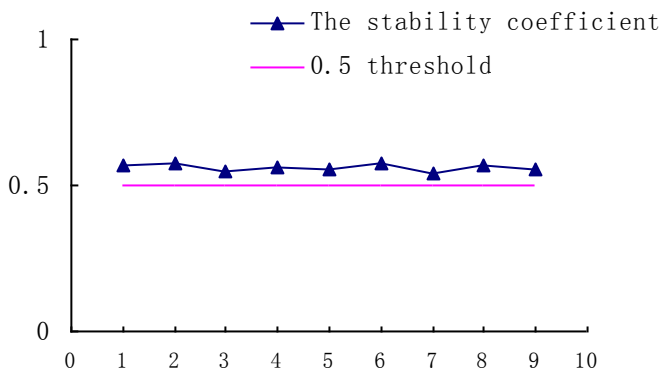
0.556 0.550 0.508 0.550 0.556 0.556 0.556 0.612 0.556 1.000

The set of stability coefficients is given by

U = [0.566 0.578 0.550 0.561 0.556 0.574 0.538 0.566 0.556]



(a) Time series of the roundness error



(b) The stability coefficients of time series of the roundness error

Figure 1. The case of manufacturing system of rolling bearings

Fig. 1 (a) is the raw data, and the general rule of the original data can be obtained from the figure. Among them, the fluctuation of the former 30 data is a bit small and the latter 20 data is a bit large, showing that the latter data relative to the former data have taken place a smaller change, which is the evolution rule of time series about the roundness error. Fig. 1 (b) describes the relationship between the stability coefficient u_j and the time parameter j, and the mean of the former 6 stability coefficients is 0.564 and the latter 3 is 0.553, showing that the stability of time series A is slightly decreasing. At the same time, it also verifies the consistency with direct analysis according to the raw data. In summary, the change of u_j is little along with the change of j, and the minu_j = 0.538>λ=0.5. The minimum stability coefficient is caused by the sudden increase of 0.96 in the seventh group data. To sum up, there is no stability variation of each group sample about time series with maintaining a good running state.

Case 2: The number of samples is m=10, and the sample size of each sample is n = 5.

$\hat{Z}$ = [Z_1, Z_2, Z_3, Z_4, Z_5, Z_6, Z_7, Z_8, Z_9, Z_{10}]

The matrix of fuzzy equivalence relation can be obtained as follows

1.000 0.619 0.667 0.667 0.714 0.667 0.667 0.667 0.667 0.667
0.619 1.000 0.619 0.619 0.619 0.619 0.619 0.619 0.619 0.619
0.667 0.619 1.000 0.676 0.667 0.676 0.676 0.676 0.676 0.676
0.667 0.619 0.676 1.000 0.667 0.684 0.755 0.755 0.755 0.755
0.714 0.619 0.667 0.667 1.000 0.667 0.667 0.667 0.667 0.667

0.667 0.619 0.676 0.684 0.667 1.000 0.684 0.684 0.684 0.684
0.667 0.619 0.676 0.755 0.667 0.684 1.000 0.814 0.818 0.805
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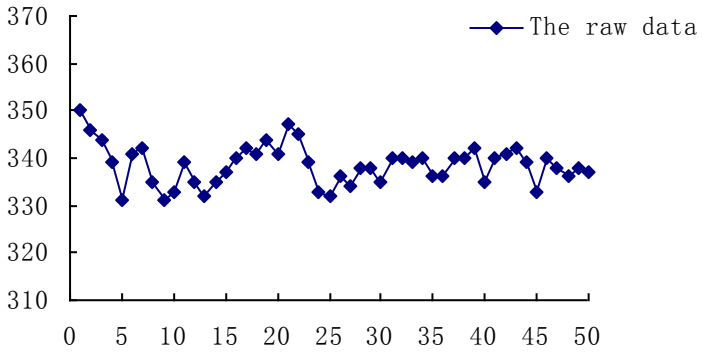
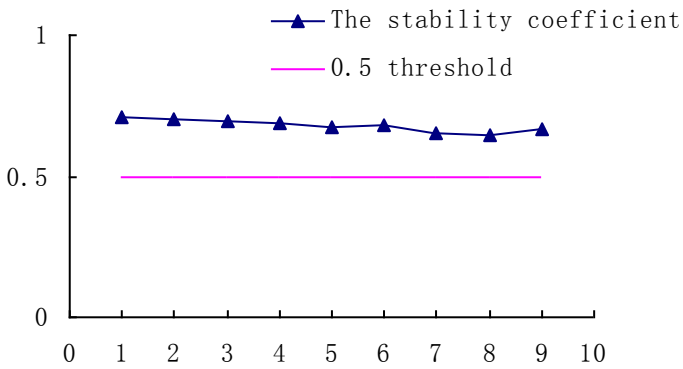
0.667 0.619 0.676 0.755 0.667 0.684 0.818 0.814 1.000 0.805
0.667 0.619 0.676 0.755 0.667 0.684 0.805 0.805 0.805 1.000

The set of stability coefficients is given by

U = [0.707 0.701 0.696 0.686 0.677 0.679 0.654 0.643 0.667]



(a) Time series of the friction torque



(b) The stability coefficients of time series of the friction torque

Figure 2. The case of friction torque of rolling bearings

Fig. 2 (a) is the raw data, and the general rule of the original data can be obtained from the figure. Among them, the fluctuation of the former 25 data is a bit small, and the others 25 data is a bit large with a bit downtrend of mean value, which shows that the change trend of stability should be from large to small. Fig. 2 (b) describes the relationship between the stability coefficient u_j and the time parameter j, and the mean of the former 5 stability coefficients is 0.693 and the latter 4 is 0.661. Although the change signs of raw data are not obvious, the stability coefficient can accurately identify its evolution. At the same time, it also verifies the consistency with direct analysis according to the raw data. In summary, the change of u_j is also little along with the change of j, and the minu_j = 0.643>λ=0.5. Therefore, there is no stability variation of each group sample about time series with maintaining a better running state.

In conclusion, the interval prediction of time series is accurate and reliable with a low rate of misinformation, which can better reflect the fluctuation of time series. In addition, the stability coefficient of two sets of time series can effectively identify its performance evolution rules. Therefore the proposed model method can effectively predict the interval range of time series, and the stability coefficient of fuzzy relation can accurately monitor the evolution situation of time series.

Summary

(1) The misinformation rate of prediction interval about time series A is 2.27%, showing the model can real-time predict the range changes; The minu_j = 0.538>λ = 0.5, which indicates that the outer ring groove grinder of rolling bearings keep a good running state during its work. The stability coefficient is gradually decreasing when comparing analysis the former 30 and the latter 20 data, viz. the stability decrease slightly.

(2) The misinformation rate of prediction interval about time series B is 0%, showing this model reliability is quite ideal. The minu_j = 0.643>λ=0.5, which indicates that the rolling bearing keep a good running state during its work. Analyzing the 1-25 and 25-50 two pieces of data, their means of the stability coefficient are 0.693 and 0.661 respectively, showing that the stability of the friction torque changes from high to low.

(3) Two experiment cases effectively prove the correctness of the proposed models, which can be used to the engineering practice with high security.

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