Morphological Diagnosis of High-speed Automaton Malfunction

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Abstract. The mathematical morphology was applied to high-speed automaton fault diagnosis in this paper, which a new method was proposed to diagnosis high-speed automaton fault based on mathematical morphology and the combination of fuzzy clustering. Take a high-speed automaton fault data in laboratory tests for example; various types were analyzed for the fault signal. The results demonstrated that the combination of mathematical morphology and fuzzy clustering applied on a high-speed automaton can effectively diagnose faults, providing a new way for high-speed automata fault diagnosis.

Introduction

High-speed automata is the core component of small caliber gun. It can be done automatically continuous shooting and constituted the cycle of shooting various institutions collectively. Whether it is operating normally will directly affect the performance of the entire system. So it has practical significance of condition monitoring and diagnostics for high-speed automata [1].

Condition monitoring and fault diagnosis of small caliber gun is a equipment modernization issue. Because of its special research areas, there are no much to do domestic work in this area. Morphological analysis is based on integral geometry and random set, which is different from the time domain and the frequency domain analysis method. Morphological analysis method depends only on the morphological characteristics of the signal to be processed through a complex morphological transformation will break down into different parts of the signal has a physical meaning, stripped of its context, at the same time to retain the shape of the main characteristics of the signal[2]. As the shape of the spectrum of multi-scale morphological transformation and morphological spectrum entropy can quantitatively describe the characteristic shape of the signal changes at different scales. In this paper, multi-scale morphological feature vectors and fuzzy clustering method based on a combination of high-speed automaton fault diagnosis in real time, to achieve a higher degree of accuracy.

Multi-scale Morphology

Morphological filtering theory is by the French mathematician G.Mathero and J.Sarran created in the early 1980s, it is according to the characteristics of the processing object, with its special structural elements for morphological transform in order to achieve the purpose of the analysis and processing.The four basic operations of mathematical morphology is corrosion, expansion, opening operation and closing operation [3]. Multi-scale operations are structural elements using different scales to the signal conversion, so as to realize the signal processing and analysis of structural elements at different scales, and the perception of such a multi-level mechanism to match the most important feature is the multi-scale method the advantage of a signal sequence if *f(x)* is the form of the operation *F(f)*, then the multi-scale morphological operation is defined as:

$$F_\lambda(f) = \lambda[F(f_\lambda(x)/\lambda)]_{1/\lambda} \tag{1}$$

After the structural elements *g (x)* by the scale parameter λ telescopic effect in *f (x)* obtained f_λ *(x)*: λ *(λ>0)* to F_λ *(f)* of the scale, according to equation (1) launched erosion, dilation, opening operation multi-scale computing and closing operation is:

$$(f \Theta g)_\lambda = f \Theta \lambda g_{1/\lambda} \tag{2}$$

$$(f \oplus g)_\lambda = f \oplus \lambda g_{1/\lambda} \tag{3}$$

$$(f \circ g)_\lambda = f \circ \lambda g_{1/\lambda} \tag{4}$$

$$(f \square g)_\lambda = f \square \lambda g_{1/\lambda} \tag{5}$$

As can be seen from the above formula, the multi-scale computing only need to replace structural elements g. If you take the structural elements of a convex function, with scale λ increases, the multi-scale operation will be greater changes filtered signal to form a signal of more simple.

Fault Feature Extraction

Form Spectral Entropy. Let $f(x)$ is a non-negative real number domain function, $g(x)$ is a convex function of the structure, the function $f(x)$ in the form of the spectrum is defined as:

$$PS_f(\lambda, g) = -dS(f \circ \lambda g)/d\lambda, \lambda \geq 0 \tag{6}$$

$$PS_f(\lambda, g) = -dS(f \circ (-\lambda)g)/d\lambda, \lambda < 0 \tag{7}$$

Where, represents the limited area defined domain; when the form is open computing spectrum, the spectrum of morphological closing operation [4].

For the one-dimensional discrete signal transform form a continuous scale only take integer values, morphological structure function takes the flat element, spectral shape can be simplified as:

$$PS_f(\lambda, g) = S[f \circ \lambda g - f \circ (\lambda+1)g]; 0 \leq \lambda \leq \lambda_{max} \tag{8}$$

$$PS_f(\lambda, g) = S[f \circ (-\lambda)g - f \circ (-\lambda+1)g]; \lambda_{min} \leq \lambda < 0 \tag{9}$$

Morphological spectrum entropy value reflects the degree of spectral shape sparse, that the shape of the probability distribution of different forms of signals having the degree sequence, shape spectral entropy is defined as:

$$PSE(f/g) = -\sum_{\lambda=\lambda_{min}}^{\lambda_{max}} q(\lambda) \lg q(\lambda) \tag{10}$$

Where, $q(\lambda) = PS_f(\lambda, g)/S(f)$, will $PSE(f/g)$ divided by $\lg(\lambda_{max} - \lambda_{min} + 1)$ which get normalized spectral entropy [5].

Principles of Fuzzy Clustering. Let the set of samples to be classified as follows: where n is the number of samples to be classified. Each sample Ui can be set m feature indicators, i.e. represents the i-th sample to be classified corresponding to the j-th feature parameter value.

Here uses the absolute calibration subtractive method, which is defined as:

$$r_{st} = \begin{cases} 1, s = t; \\ 1 - c \sum_{i=1}^{m} |U_{sj} - U_{tj}|, s \neq t. \end{cases} \tag{11}$$

Where, r_{st} of similarity coefficient, which means that kinship between samples U_s and U_t, c is the coefficient should be properly selected so that $0 \leqslant r_{st} \leqslant 1$.

For the domain U with n samples with classification, you can get a $n \times n$ represents the relationship between the two samples of any similarity coefficient, and constitute $n \times n$ order matrix:

$$R = \begin{vmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{vmatrix} \tag{12}$$

R, the fuzzy similarity matrix, reflects the relation of n-domain samples to be classified U [6].

Experimental Analysis. Vibration response data measured during a test site collected shot automaton shown in Fig.1, are given in figure 3 kinds of conditions of the time domain response

curves, corresponding to the normal automaton, fault 1 (the rotational angle of the nicks), failure 2 (the lockout hit fillet nicks), the sampling frequency was 51.2kHz.
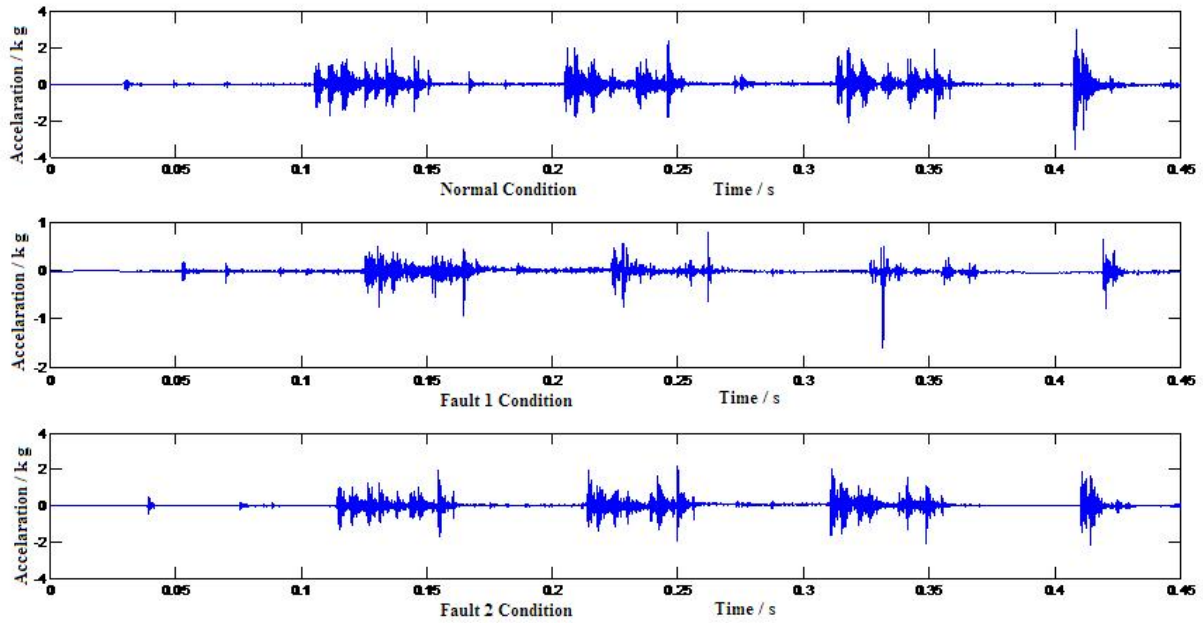

Fig.1 Response date of automatic machine vibration

Figure 1 is a high-speed automaton during normal and fault 1,2, time domain waveform under these three states, we can see from the figure, the time-domain waveform automaton vibration acceleration signal having three state comparison significant differences. After making high-speed automaton kinematics analysis, time-domain signal obtained were the EMD (Empirical Mode Decomposition), through EMD decomposition will get several IMF component and a margin, as described in Fig.2 and 3 are a high-speed automaton running on EMD obtained the results.
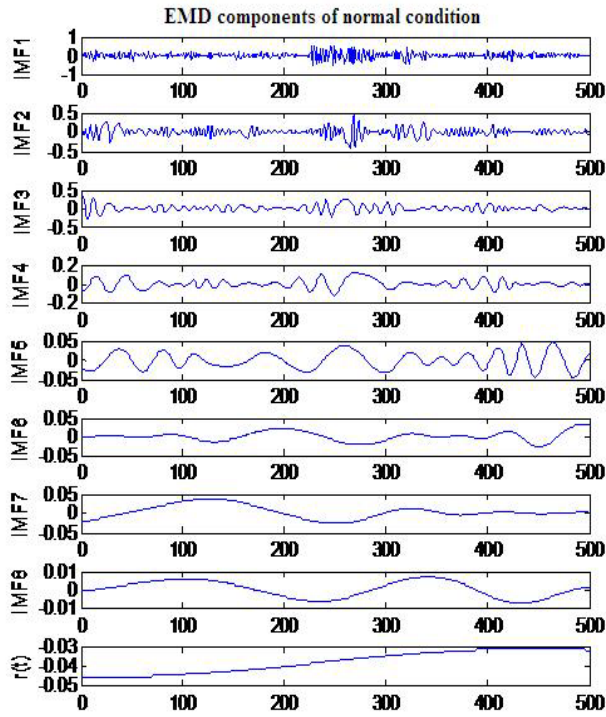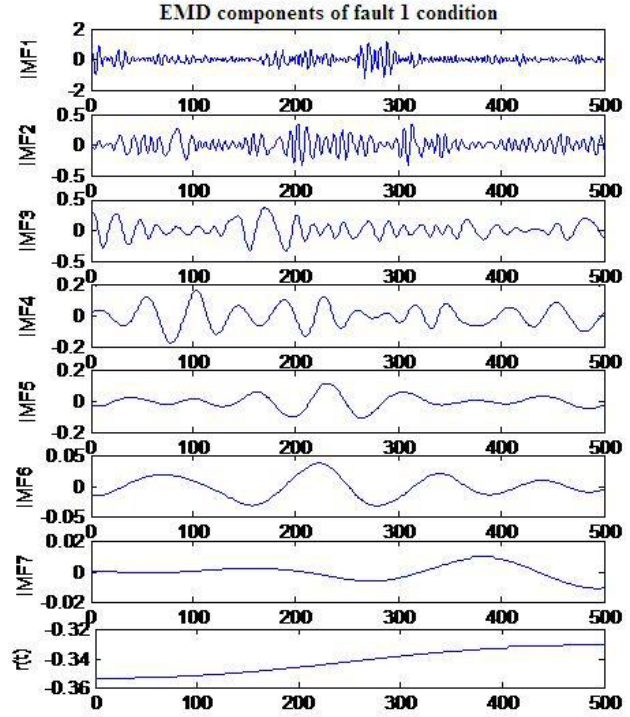

Fig.2 The EMD during normal condition

Fig.3 The EMD during fault 1 condition

Since the characteristics of high-speed automaton fault a fault signal is modulated to a high frequency normally while the natural frequency of the locking tab is usually around 10kHz. Therefore, a signal of its generalized fractal dimension mathematical morphology estimates, we can characterize the type of fault its high-speed automaton, and thus subject to extract the high frequency components of the object as a follow-up study.

Morphological spectrum curve is continuously varying signal in the scale of its morphological characteristics reflect changing circumstances, the greater the value of the spectrum, then the more the signal contains the same scale structural elements characteristic information, smaller spectral values, then the signal in the less-scale structure with the corresponding component elements, so the morphological characteristics of the signal spectral distribution curve of different components can be inferred characteristics. According to the formula (10) are calculated under different scales of normalized pattern spectrum value. Fig. 4, 5 and 6, respectively is automaton normal, fault 1 and 2 form spectrum curves under three states.
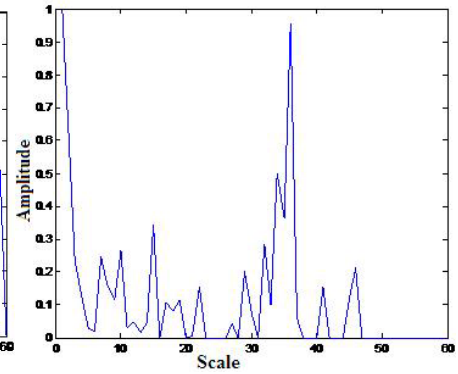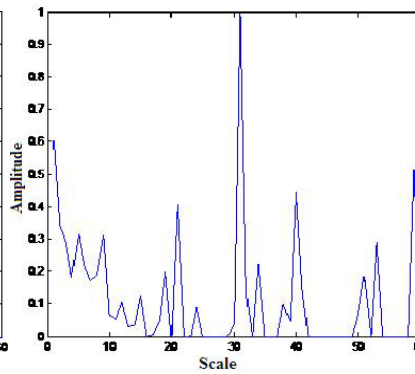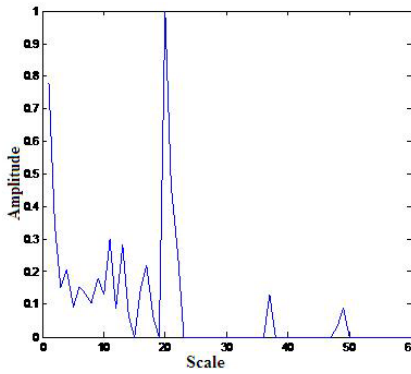

Fig.4 Normal form spectrum curve Fig.5 Fault 1 form spectrum curve Fig.6 Fault 2 form spectrum curve

Signal spectrum curve shape under the continuous change of the scale of the changes of its morphological characteristics, the spectral value, the greater the shows and the scale structure elements contained in the signal of the same characteristics more information;Spectrum value is smaller, the description of the signal with the scale and structure elements corresponding composition is less, so, through morphological spectrum curve can be concluded that signal the distribution characteristics of different characteristics in the composition. From three figure can see, the three automaton state under not scale structural elements, it is the shape of the spectral curve of distribution difference is obvious, this is due to the impact of the distribution of different ingredients.

Summary

As the first time applied mathematical morphology to automaton fault diagnosis, a new method based on mathematical morphology and fuzzy clustering combination was proposed to diagnosis fault of high-speed automaton. Experimental data show that the method based on a combination of mathematical morphology and fuzzy clustering is able to diagnose faults of high-speed automaton effectively, providing a new way for the new field.

Acknowledgements

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