The Study on the Intelligent Fault Diagnosis Based on the Immune Algorithm

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Abstract: This paper studies the new method of fault diagnosis in the absence of failure apriori knowledge and feature information. The immune algorithm is applied to fault diagnosis of mechantronic system. It discusses the negative selection principles based on the principle of immunity, and puts forward the improved immune algorithm and its match rules as well as algorithm process, and applies the improved immune diagnosing method to fault diagnosis of mechantronic system. The process of diagnosis by immune algorithm is divided into two phases: Immune system establishment and immune function implementation phases. The principle verification and tests have been performed on the rotor test rig, and the verification by the examples has also been performed. The results show that the basic functions are realized.

Keywords: Immune Algorithm Fault Diagnosis

1 Introduction

With the development of modern science & technology and industrial production, mechantronic system has been widely used in every fields of the national economy. The failure of the system usually affects the normal operation of the system, resulting in the damage of industrial production, great economic losses, and even fatal accidents such as injure and death, environmental pollution. The development of testing, computer, and artificial intelligence technologies promotes continuous development and advancement of system failure monitoring diagnosis technology. At present, various failure monitoring diagnosis technologies developed by domestic and foreign research institutes have achieved the automation and intelligence to some extent. However, the common point of these technologies is that a complete failure database is required as the basis. The same is for even an intelligent diagnosis system. For example, an expert system requires it as the judgment basis of monitoring diagnosis; a neural network system requires it as training and learning samples. Because the complexity of mechantronic system is higher and higher, and the types and models are more and more, the types of signals that need to be monitored become more and more. Meanwhile, the scale of the system is generally big, thus it is difficulty to acquire complete failure information database. Therefore, the failure mechanism analysis and failure information acquisition become the bottleneck of the development and applications of failure monitoring and diagnosis technology.

Relative to the actuality of failure monitoring and diagnosis technologies of artificial systems such as mechantronic system, the biological systems in the nature such as animals, human individuals are more successful in the aspect of maintaining normal operations of life process, recognition of abnormal conditions and allo-invasion, rejection on the allo-and auto-repair. This is because that there is more complex, subtle and effective immune system in the organism than failure monitoring diagnosis system. Besides immune system has attracted the attention of the scientists in the biology and medicine fields, it also attracts the attention of the researchers in the engineering technology fields. It is realized that the inherent mechanism of immune system doesn't only help the development of biology and medicine, but also has important apocalypse for artificial intelligence technology and its related technologies in the engineering technology fields. It enlightens us that we can research the method how to perform the diagnosis in the absence of failure apriori knowledge based on the animal's immune mechanism.

The immunology is a subject that researches tissue structure and physiological functions of immune system. The important physiological function of immune system is recognition and response to the self and non-self antigens. Under normal immune functions, the immune system can produce rejection effect on the nonself antigen, and take the immune protection action. The immune system is an important functional system of the organism. It acts as immune defense, monitoring and self-stable functions. With self demarcation and defense, the immune system makes the life possible. One of key substances that help immune system to take on the challenge from the disease is antibody. The biological immune systems that are formed through hundreds million years of evolvementa are the most subtle, complex known defense systems. The knowledge about immune system gives us illumination. The system can properly identify countless viruses, bacterium and other foreign matters that threat the health of the organism in absence of apriori knowledge. This can help us to implement the fault diagnosis in absence of failure apriori knowledge and characteristic information.

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fields, it also attracts the attention of the researchers in the engineering technology fields. It is realized that the inherent mechanism of immune system doesn't only help the development of biology and medicine, but also gives important apocalypse for artificial intelligence technology and its related technologies in the engineering technology fields. The apocalypse to us is that we can research the method how to perform the diagnosis in case of lacking failure apriori knowledge based on the animal's immune mechanism.

This paper aims to the problem how to perform fault diagnosis in absence of failure apriori knowledge and characteristic information, and researches to apply immune algorithm into mechantronic system.

2 Immune algorithm principles

For the researchers who concern the safety problem of artificial systems, it is an important and significant apocalypse that immune system is capable of taking on the unknown virus and bacterium that threat the health. The immune system achieves the recognition for unknown foreign invasion by means of negative selection. That is, first produce a great deal of antibodies, and then eliminate the invasion that matches the auto. These break through the technical bottleneck mentioned above. To simulate the basic principles of immune system using mathematical and computer programs, and to achieve basic functions of immune system, the researchers put forward artificial immune algorithms. The most important one in these algorithms is immune algorithm based on the negative selection principles [1,2]. Its basic principles are as follows:

1) Define that the set *U* of the variables that are required to be monitored by the system is feature space. Define the *S* as auto factor set. The *U* indicates the state space of all features of the system. The *S* is a subspace of the *U*, and is the feature set indicating that the system is in the normal conditions. The *S* can be obtained with apriori knowledge or learning process.

2) Define the *F* as monitoring factor set. Any element of the *F* shall not match with any element of the *S*. By simulating the process that immune system produces the antibodies, you can obtain the *F*, (i.e., monitoring factor produced randomly), and reject the monitoring factors that match with the elements in the auto set. The rest is the *F*. This is a negative selection process. $U = S \bigcup F$, $S = \bigcup S_i$, $F = \bigcup F_i$, the *Si* is auto factor, and the *Fi* is monitoring factor.

3) For the state variables of the system, continuous monitoring will be performed using monitoring factor, i.e., performing match operation. When the condition matching with the auto element appears, it means that the system is in some normal condition; when the condition matches with the monitoring element, it means that the system is in some abnormal condition, thus the diagnosis results are obtained.

3 Immune algorithm for fault diagnosis

The information that is processed by the diagnosis system comes from the mechantronic system as diagnosis object, various sensors and instruments test the mechantronic system, the computer perform the signal analysis of test signals. For analysis result, further data processing shall be performed so that the characteristic information reflecting operation conditions of mechantronic system can be obtained. The artificial immune system performs the immune calculation for characteristic information so that the fault diagnosis can be achieved.

The process that immune algorithm achieves fault diagnosis is divided into two phases: immune system establishment and immune function implementation phases. In the establishment phase, firstly determine the auto set *S* in the feature space *U*. This requires confirming the normal operation conditions of mechantronic system according to apriori knowledge and domain expert's experiences; then the computer randomly produces a great deal of antibodies that can cover the *U*, i.e., monitoring set *F*, and performs maturation processing for the *F*, that is, eliminates the factors that match with the *S*. According to the tests, simulation results and domain expert's experience and knowledge, parts of monitoring factors can correspond to exact failure causes. The factors that don't correspond to the causes can be listed as unknown failure. This makes it possible for immune system to perform the diagnosis of failure classification and causes. In this phase, domain experts play an important role, become an important link of establishing the immune diagnosis system, this also means that immune diagnosis system can contain the knowledge of domain expert, and play the function of expert system [3,4].

In the implementation phase of immune function, immune diagnosis system will perform the match calculation for characteristic information of operation conditions of mechantronic system that is obtained from the tests, signal analysis and data processing. The system performs the diagnosis according to the match results, and determines whether the system is in normal operation conditions. For the characteristic information that doesn't match with them, it can be judged as abnormal conditions. The match calculation with the *F* can be performed further to judge its failure classification. The domain expert can also perform randomly the check for diagnosis results. For unknown failures, based on domain expert's experience and post diagnosis results, its failure classification determine so that it becomes known failure. Therefore, the effect of the diagnosis is improved. Algorithm flow charts corresponding to two phases are shown in Figures 1 and 2.

4 Algorithm description and match rules

In the above data processing, related processing methods include distance calculation, match judgment, etc. Their processing methods are as follows: using the Minkowski distance (*D)*, measure the distance between two points in the feature space.

$$D=\left\|F_i - S_i\right\| = (\sum_k (f_{ik} - s_{ik})^{\lambda})^{1/\lambda} \qquad (1)$$

When λ= 2, Minkowski distance is changed into Euclidean distance. Using the match degree (α), judge the match is OK or not. When

$$\left\|F_i - S_i\right\| < \alpha \qquad (2)$$

, you can judge that candidate monitoring factor Fi matches with the Si. Otherwise, it is judged unmatched. Match degree (α) expresses the fine degree of the diagnosis, implies domain radius of auto and monitoring factors in the feature space, i.e., influence range of auto and monitoring factors. For determining feature space and auto set as well as judging whether one monitoring factor can be identified as known failure, specific conditions of the object under the diagnosis shall be considered. This also reflects the action of domain expert. Termination condition of loop process established by immune diagnosis system is that monitoring factor covers monitoring space. To make the results of data processing more comparable, the data of feature space shall be subject to the normalization preconditioning before the processing.

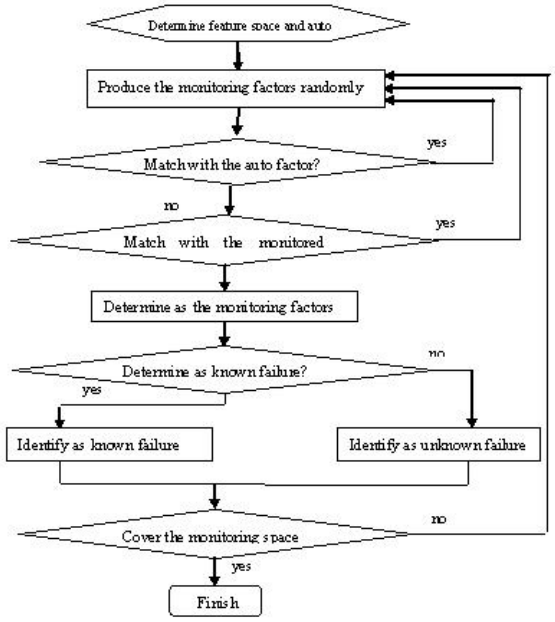

Figure 1 Flow chart of establishment phase of immune system algorithm

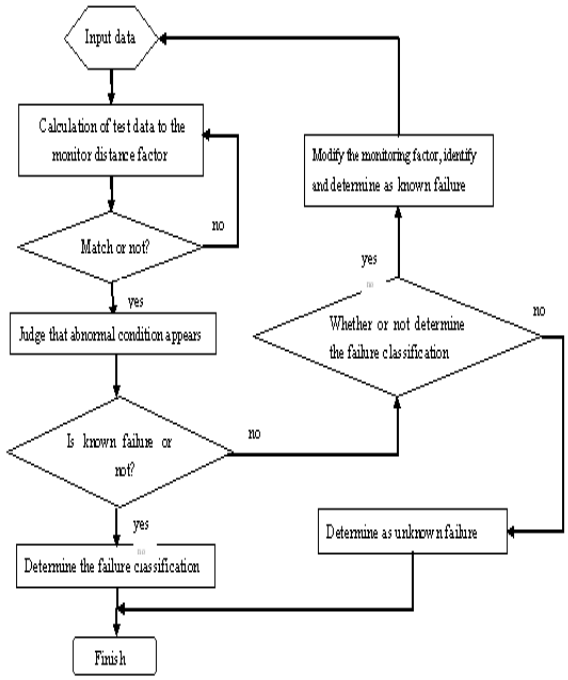

Figure 2 Flow chart of implementation phase of immune system algorithm

5 The test on the rotor test rig

Perform the principles verification and test on the rotor test rig. Select basic characteristic parameters that can reflect system operation conditions as feature space *U*.

$$U=\{ y_{rms}, f_0, A(f_0), A(0.42f_0), A(2f_0), T\} \qquad (3)$$

Where: y_{rms} is effective value of structural vibration speed, i.e., vibration intensity, which can reflect maximum damage energy on the equipment; f_0 is spindle rotation frequency, $A(f_0)$, $A(0.42f_0)$ and $A(2f_0)$ are frequency spectrum components at the $0.42f_0$, f_0, $2f_0$ respectively, the change of $A(f_0)$ reflects the unbalance of the spindle, the change of $A(2f_0)$, $A(f_0)$ reflects the spindle misalignment, the change of $A(0.42f0)$ reflects the oil-film oscillation. The change of *T* is reflected in the respects of spindle misalignment, oil-film oscillation. Parts of auto factor are shown in Table 1, parts of monitoring factor are shown in Table 2, and parts of diagnosis results are shown in Figure 3. The data are subject to the normalization processing, let λ= 2, α=0. 01.

Table 1 Auto factors

Feature space U		y_{rms}	f_0	$A(f_0)$	$A(0.42f_0)$	$A(2f_0)$	T
auto space	S1	0.20	0.30	0.45	0.02	0.21	0.40
	S2	0.25	0.30	0.43	0.01	0.20	0.40
	S3	0.24	0.50	0.56	0.00	0.25	0.43
	S4	0.31	0.50	0.55	0.03	0.26	0.42
	S5	0.35	0.70	0.61	0.10	0.34	0.45
	S6	0.39	0.70	0.58	0.10	0.29	0.46

Table 2 Monitoring factors

Feature space U		y_{rms}	f_0	$A(f_0)$	$A(0.42f_0)$	$A(2f_0)$	T
Monitoring space	F1	0.60	0.30	0.44	0.22	0.20	0.72
	F2	0.25	0.30	0.73	0.01	0.63	0.43
	F3	0.54	0.50	0.86	0.03	0.43	0.45
	F4	0.33	0.50	0.55	0.07	0.54	0.54
	F5	0.67	0.70	0.76	0.11	0.38	0.48
	F6	0.58	0.70	0.68	0.08	0.33	0.55

Table 3 Diagnosis results

Feature space U		y_{rms}	f_0	$A(f_0)$	$A(0.42f_0)$	$A(2f_0)$	T	Diagnosis result
Testing sample	d1	0.61	0.31	0.40	0.25	0.22	0.70	Oil-film oscillation
	d2	0.55	0.30	0.77	0.01	0.33	0.45	Spindle eccentricity
	d3	0.65	0.48	0.68	0.05	0.56	0.55	Spindle misalignment
	d4	0.68	0.33	0.35	0.02	0.24	0.45	Unknown failure
	d5	0.78	0.54	0.58	0.03	0.34	0.50	Unknown failure

6 Conclusions

We introduce the biological immunity principles, research new method performing fault diagnosis in the absence of failure apriori knowledge and characteristic information, discuss negative selection principles based on the biological immunity principles, put forward the improved immune algorithm and its match rules and algorithm process; we apply the improved immune fault diagnosis method to fault diagnosis of mechantronic system, and perform the verification by the examples.

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