http://dx.doi.org/10.5755/j01.eee.19.5.2224 ELEKTRONIKA IR ELEKTROTECHNIKA, ISSN 1392-1215, VOL. 19, NO. 5, 2013

Fusing of Multi-Channel Sensors for Power Station Fault Diagnosis in Marine Power Systems

Chenxing Sheng[1,2], Zhihe Duan[1,2], Jun Cheng[2], Ting Xiong[1,2]
[1]*Key Laboratory of High Performance Ship Technology of Ministry of Education, Heping Road 1040, 430063 Wuhan, P. R. China,*
[2]*School of Energy and Power Engineering, Wuhan University of Technology, Heping Road 1040, 430063 Wuhan, P. R. China*
schxing@yeah.net

***Abstract*—Fault diagnosis of the marine power station is essential to ensure the normal electric supply for the whole ship. In this paper, a new faults diagnosis technique for the power station using the data fusion technique has been proposed. The vibration signals of the power station were recorded by the multi-channel sensors. The independent component analysis (ICA) was adopted as the data fusion approach to find the characteristic vibration signals of the power station faults. Then the wavelet packet was employed to extract the feature vector of the fused vibration signals. In addition, the oil particle features has been extracted using the oil analysis. Lastly, the least square support vector machines (LS-SVM) was used to recognize the fault patterns of the power station. Moreover, the improved particle swarm optimization (PSO) was employed to enhance the learning ability of the LS-SVM. The experimental tests were implemented in a real ship to evaluate the effectiveness of the proposed diagnosis approach. The diagnosis results have shown that distinguished fault features have been extracted and the fault identification accuracy is acceptable. In addition, the classification rate of the proposed method is superior to the traditional SVM based method.**

***Index Terms*—Marine safety, power system faults, fault diagnosis, signal processing algorithms.**

I. INTRODUCTION

The power station is one of the important electrical equipments in marine power systems. However, it may be damaged by failures. The over voltage and low voltage of the generation, the failures in the relay protect equipment and the frequency-power automatical control unit are the main fault types in the power stations, which account for a large proportion in general faults. In recent years, the health condition monitoring based on the vibration signals of the power stations has been put forward [1]. This technology can evaluate the situation of the power stations through the analysis of the vibration signal characteristics. Up to date, many methods have been proposed for the power station fault diagnosis based on vibration signal, such as wavelet transform [2], higher-order statistics [3], etc. These methods have been combined with artificial neural networks (ANNs) to provide accurate fault detection [4]. However, the problem is that due to the lack of the training samples, the networks easily fall into the local minimum [5]. This disadvantage restricts the ANNs in fault diagnosis. Li and Yan [6] adopted the support vector machine (SVM) for fault diagnosis of power transmission systems. The fault detection results suggested that the SVM could overcome the shortcomings of the neural networks. Hence, the use of improved SVM algorithm and its outcomes should be evaluated in the power station fault diagnosis.

In order to enhance the fault detection, a new approach is presented for the power station fault diagnosis in the marine power systems. The vibration signals were firstly fused by the independent component analysis (ICA) [1], [6], [7], then vibration features were extracted by wavelet packet. At the same time, the oil monitoring technique was adopted to obtain the oil characteristics of the power engine. Hence, the vibration features and the oil features were combined as the feature vector. Lastly, the particle swarm optimization (PSO) optimized LS-SVM detection model was employed to learn the fault feature vectors that matched with the corresponding fault patterns. Experiments were carried out in the power systems in a real ship to validate the effectiveness of the proposed method.

II. THE PROPOSED FAULT DIAGNOSIS METHOD

Before extracting the characteristics of the vibration signals of the power station under different working conditions, it is reasonable to fuse the multi-channel sensor's data into one useful signal that is close to the real vibration of the power station. For this reason, the ICA has been introduced to the data fusion of the multi-channel sensors. Then the wavelet packet is used to extract useful features of the fusion data, and the oil particle is calculated using the on-line oil particle counter. Lastly, the PSO optimized LS-SVM is proposed to identify the plant operation states. The workflow of the diagnosis is shown in Fig. 1. The theories of the ICA and SVM are not given in this paper. The detail can refer to [1], [6], [7].

Manuscript received August 18, 2012; accepted November 18, 2013.
This project is sponsored by the grants from National Natural Science Foundation of China (NSFC) (No. 51139005) and the National High Technology Research and Development Program 863 (No.2011AA110202).

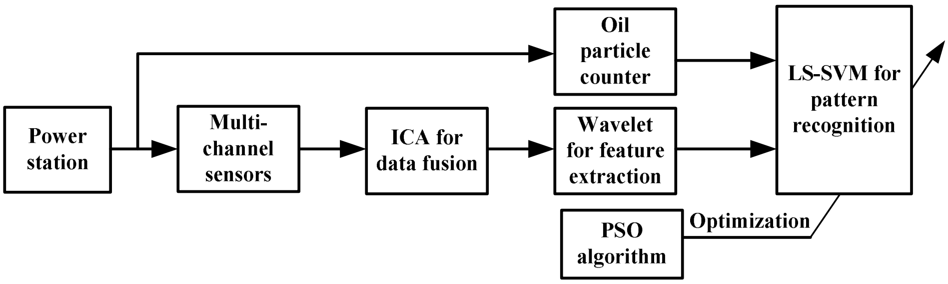


Fig. 1. The workflow of the proposed diagnosis procedure.

III. Experiments and Results

The experiments of the simulated faults have been carried out in the power system in a real ship. The power generators are two MAN made diesel engines with a rated power 680 kW. Four accelerometers have been used to record the engine vibrations. The vibration data is collected every other 5 minutes with 1000 rpm of the engine speed under five different conditions: pattern A — normal, pattern B — over voltage of the generation, pattern C — low voltage of the generation, pattern D — malfunction of the relay protect equipment, and pattern E — fault of the automatical control unit.

The vibration signal recorded under low voltage of the generation is taken as an example to evaluate the performance of the ICA based data fusion. Fig. 2 shows the fusion result of the vibration signals, where f_0 is the basic operation frequency of the diesel generator.

It can be seen from Fig. 2 that by the use of ICA fusion, sensitive frequency information is presented at the sidebands of the $4f_0$. In contrast to the original signal, the energy peaks about the basic operation frequency of the diesel generator is clearer in the fused vibration signal. That is to say, more reliable features of the fault signal can be capture. Hence, the wavelet packet transform is employed to decompose the fused vibration signal into four sub-wavelet bands and extract the statistical characteristics of each band. In this paper, the average value, variance, crest factor, skewness, and kurtosis are calculated as the input feature vector of the LS-SVM detection model.

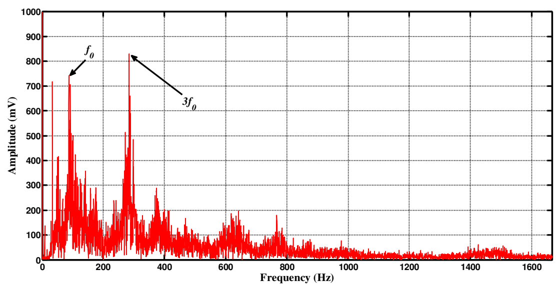
The on-line particle counter has been adopted for the diesel engines [8]. Fig. 3 shows the counted particles in normal and faulty conditions. It can be seen in Fig. 3 that the particles collected under faulty condition is evidently larger than normal ones.

The LS-SVM has been trained and tested using 100 samples of the four fault conditions. A portion of the fault diagnosis results for the power station is shown in table 1. The fault detection performance of different diagnosis approaches is given in table 2. In the fault pattern recognition, the ICA-PSO-LS-SVM, ICA-LS-SVM and LS-SVM have been compared with respect to the diagnosis performance. Table 2 also gives the comparison of the performance of the LS-SVM, back-propagation neural network (BP NN), RBF neural network (RBF NN).

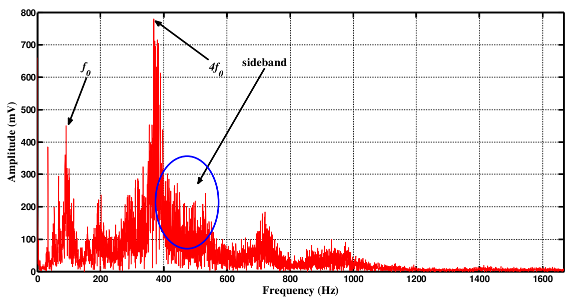
IV. Discussion

Table I and Table II show that the proposed method can enhance the fault detection precision. The use of the ICA and PSO can decrease the false and uncertain diagnosis results. It can be seen in table 2 that the SVM testing accuracy is increased significantly after the ICA fusion and PSO optimization. Moreover, the uncertain detections have been decreased by 1.6% when conduct the PSO processing, and the detection rate is 95.6% when conduct both ICA and PSO processing. Compared with the 84.4% of the LS-SVM and 90.8% of the ICA-LS-SVM, the proposed diagnosis method can increase the detection rate up to 4.4% at least.

On the other hand, from the diagnostic results in table 2, one can be noticed that the LS-SVM detection model can effectively identify different fault patterns. In contrast to BP NN and RBF NN, the LS-SVM adopts structural risk minimization principle to enhance the pattern recognition ability. The learning precision and speed are better than the ANNs. Therefore, it is proved that the proposed fault diagnosis method has good classification precision and is considered to be an effective method for the power station fault diagnosis for the marine power system.

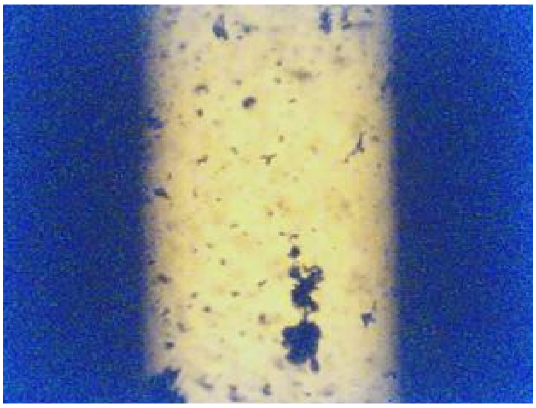


(a)

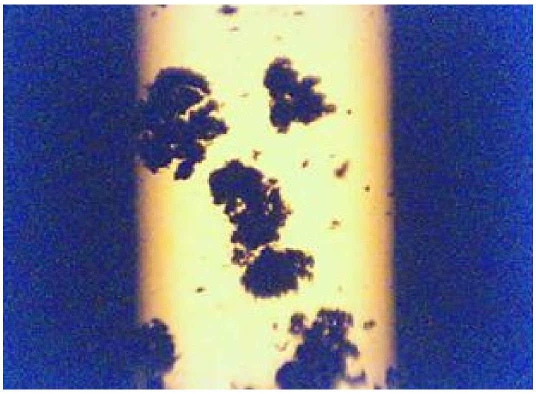


(b)

Fig. 2. The engine vibration signals: (a) the original vibration signal and (b) the fused vibration signal using ICA.



(a)



(b)

Fig. 3. The engine wear particles: (a) particles in normal condition and (b) particles in faulty condition.

TABLE I. A PORTION OF THE FAULT DETECTION RESULTS.

Test number	Diagnostic approach	Diagnosis output			Desired output	Detection result	Desired result
1	LS-SVM	0.0563	0.0363	0.0082	[0 0 0]	Pattern A	Pattern A
	ICA-LSSVM	0.0125	0.0127	0.0143	[0 0 0]	Pattern A	Pattern A
	ICA-PSO-LSSVM	0.0083	0.0036	0.0065	[0 0 0]	Pattern A	Pattern A
2	LS-SVM	1.0053	0.6402	2.2124	[0 0 1]	*Uncertain*	Pattern B
	ICA-LSSVM	0.4809	0.5033	1.6476	[0 0 1]	Pattern B	Pattern B
	ICA-PSO-LSSVM	0.3812	0.4061	1.1481	[0 0 1]	Pattern B	Pattern B
3	LS-SVM	0.5003	1.2150	0.4866	[0 1 0]	Pattern C	Pattern C
	ICA-LSSVM	0.5443	1.2404	0.8545	[0 1 0]	*Uncertain*	Pattern C
	ICA-PSO-LSSVM	0.5686	1.1266	0.3007	[0 1 0]	Pattern C	Pattern C
4	LS-SVM	1.4990	0.1251	0.8435	[1 0 0]	*Pattern E*	Pattern D
	ICA-LSSVM	1.3591	1.3089	0.3313	[1 0 0]	*Uncertain*	Pattern D
	ICA-PSO-LSSVM	1.4828	0.1607	0.2195	[1 0 0]	Pattern D	Pattern D
5	LS-SVM	1.4429	0.1154	0.2124	[1 0 1]	*Pattern D*	Pattern E
	ICA-LSSVM	0.3802	0.4342	1.3009	[1 0 1]	*Pattern B*	Pattern E
	ICA-PSO-LSSVM	1.4150	0.1399	1.4653	[1 0 1]	Pattern E	Pattern E

TABLE II. THE FAULT DETECTION PERFORMANCE OF DIFFERENT DIAGNOSIS APPROACHES.

Method	Diagnosis performance		
	Detection rate	Uncertain decision	Time consumption
LS-SVM	84.4%	5.6%	0.41 s
ICA-LS-SVM	90.8%	2.8%	0.40 s
ICA-PSO-LS-SVM	95.6%	1.2%	0.36 s
ICA-PSO-BP NN	93.4%	2.0%	0.53 s
ICA-PSO-RBF NN	94.2%	1.8%	0.47 s

V. CONCLUSIONS

The power station in the marine power system provides the electricity supply for the whole ship. Any failures may lead to great losses of the trip. Therefore, it is crucial to detect the early faults and protect the operation security of the power stations. In order to improve the fault detection accuracy, a new detection method based on ICA-PSO-LS-SVM is proposed in this paper. Innovation points are that the new method adopts the ICA algorithm to fuse multiply sensors into one optimal signal that represents the fault characteristics. Moreover, the improved PSO is employed to optimize the LS-SVM parameters. Hence, satisfactory LS-SVM structure can be obtained. Experimental results have validated the effectiveness of this new method. The optimized LS-SVM has high accuracy of classification and diagnoses speed, and its performance is superior to the traditional SVM models and the ANN models. Hence, the proposed method is feasible for the fault diagnosis of the power station.

ACKNOWLEDGMENT

The authors will thank the Editors and the reviewers for their kind and constructive comments on this paper.

REFERENCES

[1] Z. Li, X. Yan, Z. Guo, P. Liu, C. Yuan, and Z Peng, "A new intelligent fusion method of multi-dimensional sensors and its application to tribo-system fault diagnosis of marine diesel engines", Tribology Letters, vol. 47, pp. 1–15, 2012. [Online]. Available: http://dx.doi.org/10.1007/s11249-012-9948-1

[2] Z. Li, X. Yan, C. Yuan, Z. Peng, L. Li, "Virtual prototype and experimental research on gear multi-faults diagnosis using wavelet-autoregressive model and principal component analysis method", Mechanical Systems and Signal Processing, vol. 25, pp. 2589–2607, 2011. [Online]. Available: http://dx.doi.org/10.1016/j.ymssp.2011.02.017

[3] Z. Li, X. Yan, C. Yuan, J. Zhao, and Z. Peng, "Fault detection and diagnosis of the gearbox in marine propulsion system based on bispectrum analysis and artificial neural networks", Journal of Marine Science and Application, vol. 10, pp. 17–24, 2011. [Online]. Available: http://dx.doi.org/10.1007/s11804-011-1036-7

[4] B. Sokouti, M. Sokouti, S. Haghipour, "A Non-Linear System's Response Identification using Artificial Neural Networks", *Elektronika ir Elektrotechnika (Electronics and Electrical Engineering*), no. 7, pp. 63–66, 2007.

[5] N. Pamuk and Y. Uyaroglu, "Modeling of Fault Diagnosis in Power Systems using Petri Nets", *Elektronika ir Elektrotechnika (Electronics and Electrical Engineering*), no. 2, pp. 63–66, 2012.

[6] Z. Li and X. Yan, "Independent component analysis and manifold learning with applications to fault diagnosis of VSC-HVDC systems", Journal of Xi'an Jiaotong University, vol. 45, pp. 44–48, 2011.

[7] Z. Li, X. Yan, C. Yuan, and Z. Peng, "Intelligent fault diagnosis method for marine diesel engines using instantaneous angular speed", Journal of Mechanical Science and Technology, vol. 26, pp. 1–11, 2012. [Online]. Available: http://dx.doi.org/10.1007/s12206-012-0621-2

[8] J. Zhao, H. Yin, J. Wang, C. Sheng, X. Yan, "Design of an on-board software for inland waterway tenders remote monitoring", *Journal of Transportation Information and Safety,* vol. 30, pp. 114–117, 2012.