Fault Diagnosis of Automotive Engine Cooling System Based on Support Vector Machine

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Abstract

In order to solve the fault diagnosis problem of automobile engine cooling system, a classification algorithm based on support vector machine(SVM) is proposed. Firstly, by analyzing the causes and types of cooling system faults, the variables needed for cooling system fault diagnosis are determined. Then the sample data of system variables are collected and normalized. Finally, a fault diagnosis algorithm for cooling system based on SVM is designed, and the algorithm is trained and tested with the processed sample data. The experimental results show that the fault diagnosis rate is 96.7%. The algorithm can identify various fault types efficiently and accurately.

Keywords

Engine cooling system, fault diagnosis, support vector machine.

1. Introduction

Fault diagnosis of engine cooling system is an important part of engine fault diagnosis. Whether the cooling system works properly or not has a great impact on the performance of automobile engine and other systems. Controlling the engine to work in the optimum temperature range can greatly reduce air pollution and fuel consumption. Reasonable cooling of the engine to keep the engine at the optimum working temperature is conducive to improving the efficiency of the engine, while reducing the occurrence of engine faults and improving the service life of the engine. Research shows that engine failure accounts for about 50% of vehicle failure, and cooling system failure accounts for about 50% of engine failure[1]. Engine cooling system plays an important role in vehicle reliability.

Several papers have done some research on fault diagnosis of cooling system. The fault diagnosis method of marine engine cooling system is designed by using BP neural network[2]. The fault model and cause analysis are given. The fault diagnosis system is trained and tested, and good diagnosis results are obtained. The fault diagnosis of marine diesel engine cooling system is realized by using improved BP neural network algorithm in the subject of [3]. Compared with the traditional BP neural network, the system has stronger self-learning and self-adaptive ability.Faults are divided into five categories: lack of coolant, pump fault, thermostat fault, fan fault and radiator clogging in [4]. Mathematical model of each component is established, judgment basis is given and fault diagnosis algorithm is designed.

In this paper, support vector machine is used to diagnose the fault of automobile cooling system. Support vector machine , proposed by Vapnik et al. in 1995, is a machine learning algorithm based on statistical analysis. SVM maps sample data from low-dimensional space to high-dimensional space by using kernel function transformation, which is beneficial to solving the problem of non-linear classification. Meanwhile, SVM has good learning ability and can effectively solve the problem of small sample pattern recognition [5]. In this paper, a fault diagnosis method for engine cooling system based on SVM is proposed to locate and diagnose the faults of the cooling system.

2. Vehicle Cooling System

2.1 Cooling System Structure

According to the different cooling medium, the cooling methods of automobile engine are mainly divided into air-cooled and water-cooled. Water-cooled engine cooling system is the main way, so this paper studies the water-cooled cooling system. The engine cooling system is mainly composed of radiator assembly, thermostat, cooling water pump, compensation water tank and other accessories[6]. The engine cooling system circuit is shown in figure 1.

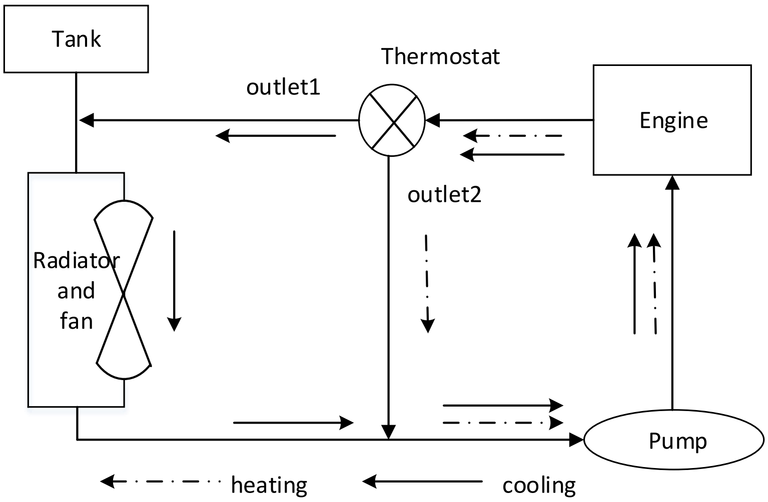

Fig. 1 Engine cooling system circuit

The thermostat has three ports, the inlet is connected with the engine outlet, and the outlet 1 and 2 are respectively connected with the cooling water pump inlet and the radiator assembly inlet. The thermostat controls the opening and closing state of its port according to the change of the temperature value of the coolant, thus changing the circulation route of the coolant. The radiator assembly is located on the front end bracket of the automobile engine, including the radiator core and cooling fan. Centrifugal electronic water pump provides stable cooling fluid circulation power for engine cooling system. The compensating water tank is connected with the water inlet of the radiator assembly to provide enough coolant for the cooling system.

2.2 Working Principle of Cooling System

In cold regions with lower temperatures, when the car starts, because the coolant temperature is much lower than the set cooling temperature, the outlet 1 of the thermostat is completely closed, and the coolant flows in a small cycle consisting of cooling water pump, engine water jacket and thermostat. The heat generated by the engine is used to heat itself to realize the fast preheating function of cold start. When the engine temperature is higher than the set cooling temperature, the outlet 1 of the thermostat gradually opens, and the coolant flows in a large cycle consisting of compensation water tank, engine water jacket, thermostat, cooling water pump and radiator assembly. In the large cycle, the coolant exchanges the heat generated by engine operation with the radiator core, and the electronic fan set at the back end of the radiator core runs to increase the air flow rate, rapidly distribute the heat to the air, and then reduce the temperature of the coolant. When the engine temperature continues to increase, the rotational speed of the cooling water pump and the cooling fan correspondingly increases, the volume flow of the cooling fluid increases, and the heat exchange rate between the cooling fluid and the environment increases, so as to improve the cooling efficiency and realize the effective control of the engine outlet temperature.

2.3 Fault Types of Cooling System

The main manifestation of engine cooling system failure is that the cooling liquid temperature of engine outlet is too low or too high. Engine cooling system failure may be caused by many factors.

The main types of failure can be divided into radiator clogging, fan mechanical failure, pump mechanical failure, thermostat failure and coolant leakage [38]. The corresponding fault codes for the cooling system are shown in the table 1.

Table 1 Fault coding of cooling system

Fault Types	Binary Coding				
	y_5	y_2	y_3	y_4	y_5
normal system	0	0	0	0	0
radiator clogging	1	0	0	0	0
fan mechanical failure	0	1	0	0	0
pump mechanical failure	0	0	1	0	0
thermostat failure	0	0	0	1	0
coolant leakage	0	0	0	0	1

3. Data Acquisition and Processing

The 11 variables of cooling system are collected as the basis of fault diagnosis. T_1, T_2, T_3 respectively represent engine outlet temperature, engine inlet temperature and radiator inlet temperature; M_1, M_2 respectively represent engine outlet flow rate and thermostat port 2 flow rate; P_1, P_2, P_3, P_4 respectively represent engine outlet pressure, thermostat port 2 pressure, radiator outlet pressure and pump outlet pressure; V represents vehicle speed and T represents ambient temperature. Under the driving condition of NEDC, the sampling time is set to 30 seconds. Under the ambient temperature of -7℃, 20℃ and 40℃, 50 sets of sample data are collected under normal working conditions, and 50 sets for each of the five failure conditions, which are merged into a sample set. Some sample data in the sample set are shown in table 2.

Table 2 Sample data of cooling system

Num	T_1	T_2	T_3	M_1	M_2	P_1	P_2	P_3	P_4	V	T_{amb}
1	26.26	25.22	20.00	0.64	0	1.43	1.02	1.02	1.75	3.79	-7
2	56.22	55.10	20.00	0.63	0	1.53	1.13	1.13	1.84	1.81	-7
3	89.33	75.39	79.04	0.62	0.15	1.65	1.25	1.25	1.95	11.05	-7
4	91.59	87.00	91.33	0.62	0.11	1.74	1.34	1.35	2.04	2.59	-7
5	94.84	88.42	94.24	0.61	0.44	1.77	1.40	1.36	2.06	8.89	-7
⋮											
296	96.53	92.48	96.54	0.86	0.81	2.33	1.58	1.11	2.91	19.46	40
297	103.69	98.14	103.47	0.84	0.84	2.37	1.64	1.13	2.93	25.12	40
298	105.79	100.75	105.09	0.84	0.84	2.43	1.70	1.20	2.99	19.45	40
299	102.77	99.06	103.04	0.84	0.84	2.39	1.66	1.15	2.95	14.13	40
300	96.68	92.59	96.68	0.86	0.82	2.33	1.58	1.11	2.91	7.45	40

Represent the sample set as $X=(x_1,x_2,\cdots,x_k)^T (X\in R^{k\times h})$, $k=11$, $h=300$, $x_1,x_2,\cdots,x_{11}$ corresponds to 11 variables of coolant temperature, flow rate, pressure, vehicle speed and ambient temperature in Table 2. Normalize the sample data:

$$x'_{ij}=\frac{x_{ij}-\min(x_{ij})}{\max(x_i)-\min(x_i)} \tag{1}$$

Where, x_{ij} ——source data, x'_{ij} ——processed data, i ——row, j ——column, $i=1,2,\cdots,k$, $j=1,2,\cdots h$.

4. Fault Diagnosis Design of Cooling System Based on SVM

4.1 The Design of SVM

SVM was initially applied to solve the binary classification problem, but there are five types of fault in engine cooling system, which are multi-classification problems. Therefore, in the design of SVM-based fault diagnosis method, it is necessary to extend the SVM binary classification method to multi-classification method.

The main methods of constructing SVM multi-classifier are: one-to-one method, one-to-many method and DAGSVM (Directed Acyclic Graph SVM) [7]. Because of the large amount of fault diagnosis data, many types of faults and unpredictable occurrence of faults, it is not suitable to use one-to-one method and DAGSVM method. In this paper, a multi-class SVM fault diagnosis model with six binary classifiers is designed by one-to-many method. The diagnosis results of each binary classifier correspond to the normal state of the system and five fault types respectively.

There are six state types in engine cooling system, so it is necessary to design six binary classifiers using one-to-many method. Each binary classifier can distinguish one state type from the other five state types. The normalized sample data is used as input for each binary classifier. Sample set is marked by system state: if the sample is identical with the corresponding binary classifier classification state, it is marked as 1, otherwise it is marked as -1. A Two-Classifier for fault diagnosis of cooling system is designed. The minimum value of formula (3) is obtained when formula (2) is satisfied.

$$y_i[(w\cdot x_i)+b]\ge 1-\xi_i,\qquad i=1,\cdots,h \tag{2}$$

$$\phi(w)=\frac{1}{2}\|w\|^2+C\sum_{i=1}^{h}\xi_i \tag{3}$$

Where, w ——weight vector, b ——bias, ξ ——relaxation factor, C ——penalty factor.

The following Lagrange functions are designed to solve constrained optimization problems:

$$L(w,b,a)=\frac{1}{2}\|w\|^2+C\sum_{i=1}^{h}\xi_i-\sum_{i=1}^{h}a_i[y_i(w\cdot x_i+b)-1+\xi_i] \tag{4}$$

For w , b , a_i respectively, partial differential is calculated to solve the minimum value of Lagrange function. Radial basis function[8] transform is introduced to map sample data from low-dimensional space to high-dimensional space. Finally, the discriminant function is obtained as follows:

$$f(x)=\mathrm{sgn}\{\sum_{i=1}^{h}a_i^* y_i K(x_i,x_j)+b^*\} \tag{5}$$

Where, a_i^* ——optimum solution, b^* ——classification threshold, $\mathrm{sgn}()$ ——sign function.

4.2 Analysis of Fault Diagnosis Results

Under the same working conditions, 60 sets of data samples under normal and five failure states of cooling system were collected to form test set samples, and the trained SVM are tested.The output of SVM is a one-dimensional array containing six values, each of which is the diagnostic output of six binary classifiers. The fault type corresponding to the maximum value of the array is the final diagnostic result of SVM, and the diagnostic result is transformed into fault code for output. Some diagnostic results are shown in table 3.

Table 3 Test results of SVM fault diagnosis

Test number	Actual output value	Actual output	Desired output	Result

5	[-0.0733 -0.8711 -1.7810 -0.7963 -0.7445 -0.8451]	[0 0 0 0 0]	[0 0 0 0 0]	Ture
10	[1.1243 -1.5264 -1.8182 -0.7970 -2.2708 -0.9470]	[0 0 0 0 0]	[0 0 0 0 0]	Ture
15	[-0.5394 1.1770 -1.4344 -2.4197 -1.7035 -0.6677]	[1 0 0 0 0]	[1 0 0 0 0]	Ture
20	[-0.6239 1.2831 -2.6070 -1.3636 -2.9854 -1.0746]	[1 0 0 0 0]	[1 0 0 0 0]	Ture
25	[-0.6251 -1.5371 0.9514 1.6580 -4.1476 -2.3821]	[0 0 1 0 0]	[0 1 0 0 0]	false
30	[-0.6042 -1.6611 2.3161 -1.2574 -3.9082 -2.6788]	[0 1 0 0 0]	[0 1 0 0 0]	Ture
35	[-0.5499 -1.9564 -1.0728 1.1372 -1.6234 -0.2803]	[0 0 1 0 0]	[0 0 1 0 0]	Ture
40	[-0.4317 -1.0753 -1.9758 0.5091 -2.5154 -0.5256]	[0 0 1 0 0]	[0 0 1 0 0]	Ture
45	[-0.3503 -1.0953 -2.1227 -0.8441 0.4193 -1.3963]	[0 0 0 1 0]	[0 0 0 1 0]	Ture
50	[-0.5802 -0.9506 -2.5060 -1.7420 1.2482 -1.4526]	[0 0 0 1 0]	[0 0 0 1 0]	Ture
55	[-0.5500 -1.9450 -0.8636 -1.4133 -0.6925 1.6298]	[0 0 0 0 1]	[0 0 0 0 1]	Ture
60	[-0.5925 -2.0114 -0.2191 -1.5710 -0.7475 0.8031]	[0 0 0 0 1]	[0 0 0 0 1]	Ture

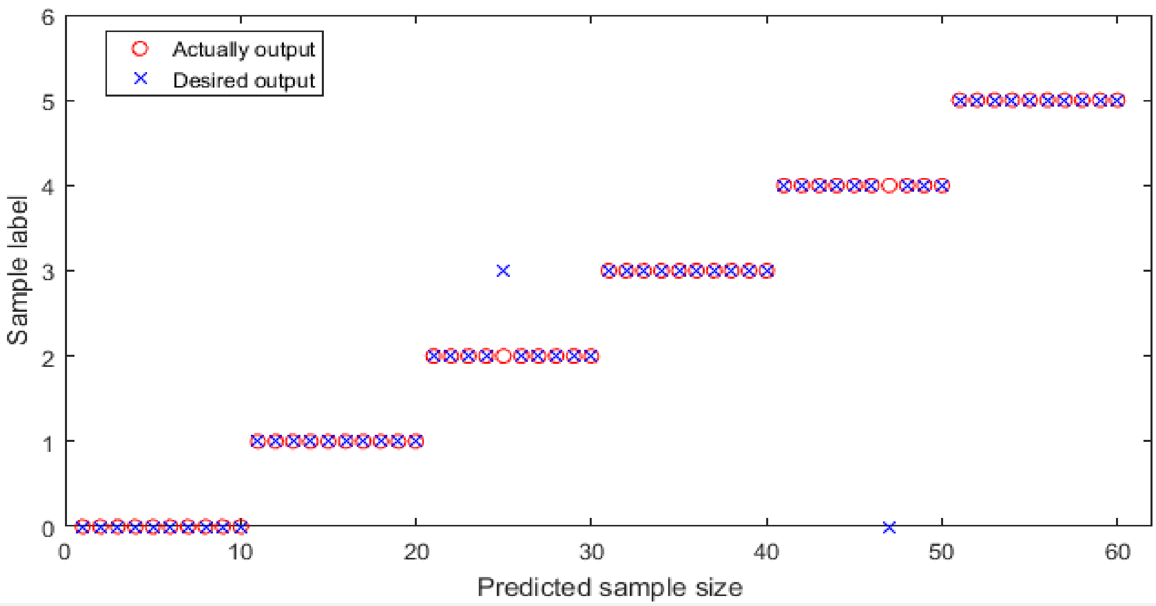

Fig. 2 SVM Fault Diagnosis Results

The correct rate of fault diagnosis is 96.7%, and the running time is 1.1350s. From the result of SVM fault diagnosis in figure 2, it can be seen that there are two classification errors in 60 fault diagnosis, which are predicting fan mechanical fault as pump mechanical fault and predicting thermostat fault as normal system.

5. Conclusion

This study designs a fault diagnosis method for engine cooling system based on SVM. The collected cooling system data are normalized, and then the designed SVM algorithm is used for fault diagnosis. The diagnosis results show that the SVM algorithm can identify the fault types efficiently and accurately.

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