Study on Diesel Engine Status Analysis and Fault Diagnosis Based on SAE J1939 Protocol

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Abstract—SAE J1939 is one of the most widely used application layer protocols in automotive industry based on CAN bus. SAE J1939 defines vehicle application layer to make us read the status of the vehicle easily. We propose an improved RBF neural network fault classification algorithm to classify diesel engine fault. Also we analyse the state of the vehicle from vehicle CAN bus and use they to train PSO-RBF neural network, the resulting effect is better than PSO neural network and we can use it to do a diesel engine fault diagnosis.

Keywords-SAE J1939; diesel engine; fault diagnosis; PSO-RBF neural network

I. INTRODUCTION

With the development of the automobile industry and electronic control technology, getting data of vehicle fault is no longer only rely on traditional method. Traditional methods such as extracting eigenvalues of the vibration signal, hydraulic waveforms to diagnosis engine fault. Due to it is analyzed by one data source, it has a high probability of misdiagnosis. Therefore, vehicle fault diagnosis based on various data sources has become a research focus.

SAE J1939 developed by the American Society of Automotive Engineers, is the vehicle bus recommended practice used for communication and diagnostics among vehicle components, originally by the car and heavy-duty truck industry in the United States [1]. SAE J1939 defines four layers in the seven-layer OSI network model: physical layer, data link layer, network layer, vehicle application layer, and the physical layer is based on CAN controller [2]. SAE J1939-71 developed for the application layer is to make the data provided by source node can be used by the other nodes [3].

Engine fault diagnosis is also largely dependent on human experience and traditional diagnostic methods currently, fault diagnosis based on SAE J1939 protocol is still in the development stage. We import the data which obtained in the operation of the vehicle into MATLAB. Analysis in MATLAB is effective that we can analyze the state of vehicle and diagnose whether the vehicle has a potential fault.

II. SAE J1939 PROTOCOL

Open System Interconnection Reference Model (OSI/RM) is a networking model proposed by International Organization for Standardization (IOS). OSI protocols stacks are split into seven layers. CAN protocol only defines physical layer and data link layer. SAE J1939 protocol is based on CAN2.0B, and defined network layer and application layer in addition.

A. Data Link Layer

Data link layer provides reliable data transmission between physical connections, including sending synchronization, sequence control, error control and flow control which is necessary for CAN data frame [4]. In the CAN standard, MAC ID has two standards: CAN2.0A, which is 11-bit, and CAN2.0B, which is 29-bit. The structure difference is mainly in arbitration field and control field [5]. J1939 uses CAN2.0B communication mechanism. The physical layer follows electrical characteristics, communication media, physical interface of CAN protocol. In data link layer, J1939 redefines 29-bit ID of arbitration field and 64-bit data of data field corresponding to vehicle information [6].

Protocol data unit consists of seven parts: priority, extended data page, data page, PDU format, PDU specific domain, source address and data fields. PDU is encapsulated in one or more CAN data frames to transmit to the other network devices through physical medium. Each CAN data frame has only one PDU. The PDU format is as Table 1.

<table>
<thead>
<tr>
<th>Name</th>
<th>Priority</th>
<th>Ext. Data Page</th>
<th>DAT Page</th>
<th>PDU Format</th>
<th>PDU Specific Domain</th>
<th>Source Address</th>
<th>Data Fields</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

B. Application Layer

Application layer of J1939 is stipulated by J1939-71. It provides a way to access the OSI environment and describes packet format, data range, transmission repetition rate, parameters naming and ISO Latin character through PGN (Parameter Group Number) and SPN (Special Parameter Number).
A set of parameters called "parameter group" (PG), PGN is its unique identification number. PGN serves as an index in the communication process. It shows the contents and purpose of the message, determines packet type and number of frames. Here is an example, PGN 61444: Default Priority is 011, Extended Data Page is 0, Data Page is 0, PDU Format is 1110000, PDU Specific is 0000100 and Data fields as follow:

<table>
<thead>
<tr>
<th>Start Position</th>
<th>Length</th>
<th>Parameter Name</th>
<th>SPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>4bit</td>
<td>Engine Torque Mode</td>
<td>899</td>
</tr>
<tr>
<td>2</td>
<td>1byte</td>
<td>Driver's Demand Engine - Percent Torque</td>
<td>512</td>
</tr>
<tr>
<td>3</td>
<td>1byte</td>
<td>Actual Engine - Percent Torque</td>
<td>513</td>
</tr>
<tr>
<td>4-5</td>
<td>2byte</td>
<td>Engine Speed</td>
<td>190</td>
</tr>
<tr>
<td>6</td>
<td>1byte</td>
<td>Source Address of Controlling Device for Engine Control</td>
<td>1483</td>
</tr>
<tr>
<td>7.1</td>
<td>4bit</td>
<td>Engine Starter Mode</td>
<td>1675</td>
</tr>
<tr>
<td>8</td>
<td>1byte</td>
<td>Engine Demand - Percent Torque</td>
<td>2432</td>
</tr>
</tbody>
</table>

Parameters of PGN 61444 represent electronic engine controller 1, which composed of seven specific parameters. For example in SPN190, SPN 190: data length is 4 bits, resolution is 16 states/4 bit and 0 offset, data range is 0 to 15, operational range is also 0 to 15, type is Measured. If we got the data of SPN 190 is 201B, it shows that the engine speed is 868rpm. The other data can be got as the same way.

We can get a variety of vehicle status data based on SAE J1939 protocol. It is convenient for us to have a comprehensive understanding of the performance of vehicle. But the data is too scattered and inconvenient to understand, we need an analytical tool to analyze the data.

III. DATA ANALYSIS OF SAE J1939-71 IN MATLAB

The most important in J1939 protocol is PGN and SPN. We create two new cell type: PGN{}, SPN{}. PGN{} include: Name, Transmission Repetition Rate, Data Length, Extended Data Page, Data Page, PDU Format or mat, PDU Specific, Default Priority, SPNNUM, SPN{}. SPN{} include: Name, Data Length, Resolution, Data Range, Type.

After acquiring CAN data, we import the data into MATLAB as cell type. Flow diagram of J1939 data conversion is as Figure 1.

SPN{}.Out M() is the output of the SPN at the moment.

We get Diesel Exhaust Fluid injection unit input pipe failure data of Cummins 6B diesel engine, imported into MATLAB for analysis. Take SPN(190) and SPN(110) for example, the output shown in Figure 2. It shows the situation within this period of time the engine speed and the engine coolant temperature.

IV. DIESEL ENGINE FAULT DIAGNOSIS BASED ON IMPROVED RBF NEURAL NETWORK

A. RBF Neural Network

RBF neural network is two forward lays network with a single hidden layer. The input layer consists of source node. The number of hidden layer units depend on the fixed problem. Transformation from the input space to the hidden layer space is nonlinear, and from the hidden layer to the output layer space transform is linear. Hidden layer node consist of functions like Gaussian function. Output layer node is typically a simple linear function. The topology structure shown in Figure 3.
Transformation function for hidden node is radial basis function. It takes Gaussian function normally:

$$\Phi_j = \exp\left[-\frac{\|x - c_j\|^2}{2\delta_j^2}\right] \quad j = 1, 2, \ldots, q$$  \hspace{1cm} (1)

$i$-th output of the network is:

$$y_i = \sum_{j=1}^{q} \omega_{ij} \Phi(x, c_j, \delta_j) \quad i = 1, 2, \ldots, m$$  \hspace{1cm} (2)

$x$ is the input vector, $c_j$ is center of the hidden layer unit, $\delta_j$ is width, $\omega_{ij}$ is the connection weights. Because the value of $c_j$, $\delta_j$, $\omega_{ij}$, has a great influence on the learning and training effectiveness, for how to determine $c_j$, $\delta_j$, $\omega_{ij}$, we use PSO to optimize these three parameters.

Particle swarm optimization (PSO) algorithm deemed individuals to particles in N-dimensional search space. Each particle follow current best individual and change their speed and position through sharing information and find the optimal solution through continuous iteration eventually. The algorithm first randomly generated particle swarm, each particle has a speed in the N-dimensional solution space. Speed and position are adjusting by their own condition and the experience of other particles. Finally, reaching the maximum number of iterations or PSO searched the optimal fitness value [7].

PSO-RBF algorithm is as follows:

Each particle consist of $c_j$, $\delta_j$, $\omega_{ij}$, random initial its speed and position.

$$f = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{y_i - \hat{y}_i}{\hat{y}_i} \right|$$

Set as a fitness function to determine the best individual particles $P_{best}$ and global optimization $R_{best}$. $\hat{y}_i$ is the actual value and $\hat{y}_i$ is output value.

Compare the fitness value of each particle with best individual particles and global optimum. If $f(P) > f(P_{best})$, then $P_{best}=P$. If $f(P) > f(R_{best})$, then $R_{best}=P$.

Each particle update their speed and position.

If it does not met the termination condition, then return (2), otherwise, stop.

### B. Engine Fault Diagnosis Based on Improved RBF Neural Network

We got 84 sets of data of seven kinds of faults which are got from CAN bus of Cummins 6B diesel engine in a truck. A: Diesel Exhaust Fluid injection input unit has problem, B: fuel rail pressure of injector is below the normal operating range, C: Diesel Exhaust Fluid reservoir level is below the normal operating range, D: power losing when the ignition switch is turned on, E: engine control module calibration memory damages, F: speed is unstable, intermittent or error which based on the number of revolutions of the wheel, G: sensor of nitrogen oxides exporting updates rate abnormally. After MATLAB analysis, some of the data as follows:

![FIGURE III. THE TOPOLOGY STRUCTURE DIAGRAM OF RBF NEURAL NETWORK](image)

![FIGURE IV. THE CONVERGENCE CURVE LINES OF PSO-RBF AND RBF ALGORITHMS](image)
shorter training time.

**TABLE IV. THE DIAGNOSTIC RESULTS AND TRAINING TIME**

<table>
<thead>
<tr>
<th></th>
<th>PSO-RBF</th>
<th>RBF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>89.3%</td>
<td>78%</td>
</tr>
<tr>
<td>Time</td>
<td>1.636 s</td>
<td>5.785 s</td>
</tr>
</tbody>
</table>

V. SUMMARY

Rely on powerful data processing capability and convenient language compiler environment of MATLAB, data processing base on J1939 has a unique position. We are able to process and analyze a variety of data to have comprehensive and accurate understanding of information on the vehicle. This can be an efficient analysis tool for vehicle detection and repairing. After analyze the data, we use PSO-RBF neural network algorithm to diagnose vehicle fault with a high accuracy. The algorithm can be improved in the future to make the accuracy to 100% and a shorter time.

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REFERENCES


