An Ontology Based Approach with Intelligent Decision for Off-Line Diagnosis of ECU

Xiaoci Huang [1,2,*], Lili Yin [3]

1. Shanghai University of Engineering Science, Shangha,i 201620, China
2. *Department of Mechanical Engineering*, East China University of Science and Technology, Shanghai, 200237, China
3. *Department of Automobile Engineering*, Beijing Modern Polytechnic College , Beijing, 101300 ,China

***Abstract* — In order to meet the urgent need for diagnosis of ECU (Electronic Control Unit) function, this paper proposed an simulation approach for ECU intelligent off-line diagnosis based on ontology. A simulation diagnostic system for ECU was established based on this approach. In this system, the minimum numbers of input and output signals to maintain the normal operation of ECU was provided. With the knowledge model constructed in OWL ontology language, the system can simulate the operation environment of ECU and reason the best next operation step. On this basis, the input signals were intelligent regulated. We validated the proposed approach. Proposed approach could help diagnosis engineer to fast diagnose the fault of ECU, and provide valuable reference to development and test of the control strategy of ECU.**

Keywords - ECU; ontology; diagnosis; simulation

I. INTRODUCTION

With the development of the vehicle technology, the electronic control function is increasingly intelligent, complex and integrated. Modern vehicles often use ECU which is an integrated control system to control the whole electronic control functions of a vehicle. With more and more functions has the electronic control system, the degree of automation is increasing. Therefore, it is more difficult to diagnose the electronic fault of the modern vehicle. The electronic control system of vehicle composes of sensors, actuators and ECU. The actuator fails to work or working in a wrong state is the normal fault symptom of the electronic control system, such as injector unable to work or inject less oil. Diagnosis engineer often use diagnostic equipment to detect fault. Nowadays, there are two main types of diagnostic equipment [1]. One is self-diagnostic system in vehicle, another is detecting instrument (external vehicle diagnostic equipment). The diagnostic equipment can read fault codes and data streams of ECU. But sometimes, there are some faults such as sensors fault or ECU logic fault cannot detect by diagnostic equipment. This make difficulty to diagnostic engineer. These faults may durative fault occurs in every working conditions or temporary fault occurs in definite working condition. Traditional diagnostic equipment which is an on-line tester can monitors the data stream of ECU when vehicle is running. It is unsuitable for long time full working station test, and neither can neither simulates particular faults of electronic control system nor makes diagnosis decision. Therefore, we need to develop a simulation approach for ECU off-line diagnosis, which can simulate every working conditions of ECU and can simulates some electronic faults of electronic control system. This off-line diagnosis approach not only saves more cost than traditional on-line method, but also overcomes the difficult of set faults to electronic control system manually when on-line diagnose.

In order to intelligent simulates the working condition of ECU, a method which can makes the knowledge of electronic control system conceptualization, easy to share and be suitable to pervasive computing is needed. Ontology is a conceptual model of abstract concepts related to some phenomena in the objective world. It can make clear and definite description to shared concept system [2]. Using ontology makes to easily get the set of generalized concept about domain while heterogeneous agents and services interact with each other. It can make various logic-reasoning mechanisms because it expresses based on description-logic about knowledge of human. It is reusability of knowledge and information [3, 4]. A. Bernaras had proposed an ontology for fault diagnosis in electrical networks, which used for locate and alarm the fault of electric element [5]. Weishan Zhang had present a semantic, state machine based diagnosis approach for a web-service based middleware. They used OWL ontologies and SWRL to develop both diagnosis and monitoring rules, based on state changes and also invocation relationships [6]. Sungdo Park had proposed the model using ontology for Monitoring-Control system and showed the process of suitable monitoring and control by context awareness [3].

Based on ontology, this paper proposes an intelligent simulation approach for ECU working condition. A simulation diagnostic system for ECU is established based on this method. The system can used for fault diagnosis an also can serves as a pervasive platform of development and debug for ECU. The rest of the paper is structured as follows: Section 2 presents an overview of the simulation diagnostic system. In section 3, the ontology based simulation approach for working condition of ECU is presented. Section 4 details hardware and software design of the system. Section 5 evaluates our work with the case study. Conclusions and future work end the paper.

II. THE SIMULATION DIAGNOSTIC SYSTEM

The simulation diagnostic system composed of context aware reasoning engine, electronic control system and diagnostic engine, as shown in Fig. 1. In electronic control system, some basic signals which could maintain the normal operation of ECU are input to ECU. ECU sends commands to actuators after calculation. Actuators perform the commands. This part is construct by simulate the real working environment of ECU. The input signals which simulate the real signals of sensors compose voltage signals, switch signals and resistance signals. The actuators mainly are ignition signal receivers and injection signal receivers. There are some indicator lights to indicate the working sate of actuators. As a close Loop control, some signals such as oxygen sensor signal, rotating speed signal and accelerate paddle position signal are needed to continuously regulate by the electronic control system. These signals will feedback to ECU for decision of the working condition of the electronic control system. When ECU enters a new working condition, these signals would be regulated to match it. Therefore, a context-aware reasoning engine is proposed based on ontology. It reasoning the work condition of ECU through receives the feedbacks from electronic control system, and then regulates the input signals to maintain the operation of ECU. The diagnostic engine monitors the working state of the electronic control system and judges if the function of ECU is normal.

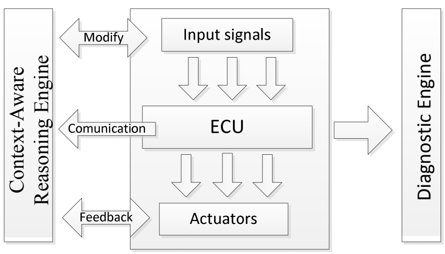

Fig.1 The Composition of the Simulation Diagnostic System

III. THE ONTOLOGY BASED SIMULATION APPROACH FOR WORKING CONDITION OF ECU

The most important step of off-line diagnosis is performs the intelligent simulation on working condition of ECU. Because the control strategy of ECU is very complicated and different in each type of vehicles, therefore it is very difficult to fully simulate the working environment of ECU. A simple and pervasive simulation environment is needed. We provide minimum numbers of input signals which can maintain the normal operation of ECU. This paper constructs a context-aware reasoning engine with OWL ontology language and SWRL rule, which can simulate the operation environment of ECU and reason the best next operation step. In this section, we express knowledge, fault, state, and action by ontology for simulation of ECU working condition.

A. *Expression of Knowledge*

Knowledge expresses objective facts. We divide the knowledge into structure knowledge and function knowledge.

The structure knowledge expresses components of electronic system. Physical entities are basis of this expression. The physical entities mainly composed of sensors such as water temperature sensor and intake air manifold pressure sensor, actuators such as injector and spark, and ECU.

The function knowledge expresses the control function of ECU, such as ignition control, inject control and emission control. There are some relations between structure and function, for example, inject control is related to injector signal, throttle position signal and accelerator pedal position signal, as shown in Fig. 2.

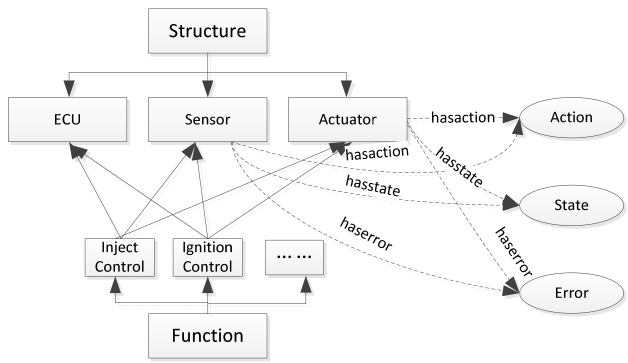

Fig.2 The Structure of the Proposed Ontology

B. *Fault Expression*

Fault expresses the event indicated by fault code which is detected by self-diagnosis of ECU. As the KWP2000 protocol is the common diagnostic protocol at present, the fault code form from different type vehicles is consistent. The fault event often points to some components of structure knowledge. These components have an abnormal state. In our expression, "N" expresses there is no fault; "H" expresses the fault event is too high, such as the concentration of mixture is too high; "L" expresses the fault event is too low, such as the concentration of mixture is too

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low; "F" expresses the fault event is failure. There is "haserror" relation between fault and component, as shown in Fig. 2.

C. *State Expression*

State expresses the current state of some components. For example, injector is injecting oil now, or the opening of the throttle vale is increasing or decreasing. In our expression, "T" expresses a components is in working state; "F" expresses a components is in not working state, "I" expresses the current state of a components is increasing, "D" expresses the current state of a components is decreasing. State relates components with "hasstate" relation, as shown in Fig. 1.

D. *Action Expression*

Action expresses the normal action of the vehicle, such as accelerate action. Current action is expressed by change of state. For example, the action of acceleration is expressed by increasing state (The state is "I") of accelerate pedal signal. Action relates components with "hasaction" relation, as shown in Fig. 1.

E. *Context-Awareness*

Because the ontology itself does not have reasoning function, we should adopt some reasoning rules to realize the context-awareness of working condition. Combine with ontology, the SWRL rule is used to realize the context-awareness.

SWRL is an expressive OWL-based rule language, which can be used to write rules to reason about OWL individuals and to infer new knowledge about those individuals. In SWRL rules, the symbol "^" represents conjunction, "?x" represents a variable, and "!" represents implication. If there is no "?" in the variable, then it is an individual [7].

An example of the reasoning rules is shown below:

Rule1:Accelerator_pedal(?s1)^hasaction(?s1,a1)^Action(?sa1,I)^Accelerator_pedal(?s2)^hasaction(?s2,I)^hasaction(?s2,a2)^Action(?a2,I)^Throttle_valve(?s3)^hasstate (?s3,sa1)→State(?sa1,I)

Rule2:Throttle_valve(?s1)^hasstate(?s1,sa1)^State(?sa1,I)^Throttle_valve(?s2)^hasstate(?s2,sa2)^State(?sa2,I)^Maniford_presure(?s3)^hasstate(?s3,sa3)^State(?sa3,I)^Maniford_presure(?s4)^hasstate(?s4,sa4) ^ State(?sa4,I)^Injector(?ij1)^hasstate(?ij1,sa5)^Error(?e1)^Error_state (?e1,N)→state(?sa1, I)

The first rule expresses that when the sensors (s1 and s2) of the accelerator pedal have an action (hasaction) of increasing (I), then the state of the throttle valve is reasoned as increasing (I). The second rule expresses that when the sensors (s1 and s2) of the throttle valve and the sensors (s3 and s4) of the intake air manifold pressure have a state of (hasstate) of increasing (I) respectively, and the state of error code（Error_state）is none (N), then the state of the injector is reasoned as increasing (I).

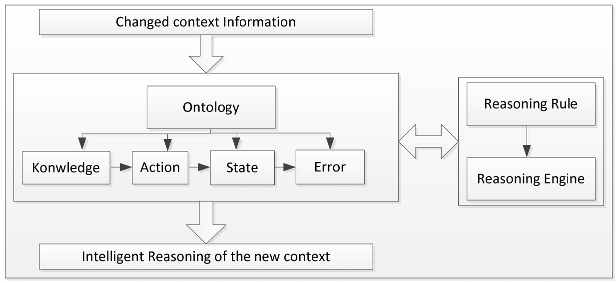

Fig.3 The Main Structure of the Context-Aware Reasoning Engine

The main structure of the context-aware reasoning engine is shown as in Fig. 3. The reasoning rule extract the classes and relations from ontology to form a reasoning engine. When the context information changes, the knowledge in ontology is modified according to the modeling for state and action of acquired context through ontology and reasoning Engine. Then a new context is intelligent reasoned.

IV. HARDWARE AND SOFTWARE DESIGN OF THE SYSTEM

A. *Hardware Design of the System*

The hardware structure of the system is shown in Fig. 4. In order to take a rapid and effective test on the function and the performance of ECU, and to quickly locate the fault position, this system adopts two ways to generate input signals for ECU. One way is the signals from actual sensors and another way is the analog signals from digital simulation. This method makes the simulation of many kinds of working conditions of vehicle more easy and precise.

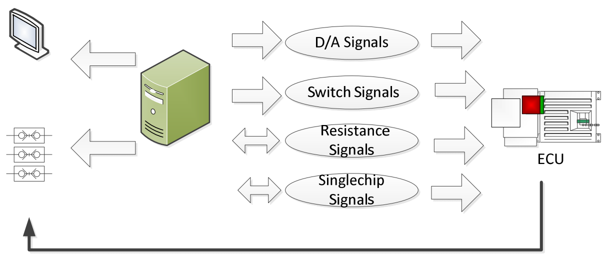

Fig.4 Hardware Structure of System

According to the requirements of the test, the simulated signals include: analog signals, digital signals, switching signals, resistance signal and CAN (Controller Area Network) bus signals etc.

The analog voltage signals are generated by the DA data acquisition card. Engineers can configure the signal value through a friendly man-machine dialogue program designed, as shown in Fig. 6. The main function of analog voltage signals are to simulate the signals of throttle position sensor, accelerator pedal position sensor, air flow sensor and oxygen sensor, etc. [8].

The resistance signals include water temperature sensor and intake air temperature sensor signal etc.

These kinds of signals are variable resistor values which cannot be directly generated by the DA data acquisition card. In order to easily adjust the resistance value and realize programmable configuration, the system adopts digital potentiometers which can be controlled by voltage signals which are outputted by the DA data acquisition card. The basic circuit schematic diagram of the controlled digital potentiometer is shown in Fig. 5.

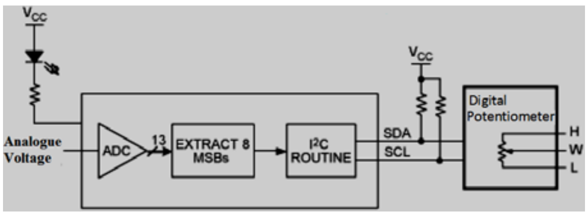

Fig.5 The Basic Circuit Schematic Diagram Of The Controlled Digital Potentiometer

The digital pulse signals include crankshaft speed signal and camshaft speed signal. Because of the high frequency of these signals, it is impossible to be generated by data acquisition card. Therefore, we have to use a SCM (single chip computer) to complete this function. A circuit system with SCM which can generates high precision continuous pulse signal by the capture/compare functional module is designed. The amplified digital pulse signal are inputted to the tested ECU terminal via an amplification circuit. The SCM communicates with IPC (Industrial Personal Computer) through the RS232 serial ports. The functions of signal triggering and waveform edit can be realized by IPC.

The switching signals of electrical equipment include many vehicle operating switch signals (such as air conditioning switch, power steering switch, etc.) and status switch signals (such as cruise control switch, clutch switch, air conditioning pressure switch, etc.). This function is achieved by I/O data acquisition card.

The CAN bus signal, whose main function is to achieve the ECU communication aforementioned is generated by the SCM. The SCM adopts a UART serial to achieve the function of the communication between ECU and RS232 serial port. Because the protocols of the physical layer, the data link layer and the application layer have been programed in SCM, the SCM can automatically achieves initialization process before communication and generates all the corresponding periodic signals. Therefore we only need to write the standard protocol of the application layer of OBD□ which is ISO15031-5 communication command text to the PC control program [9,10].

In addition, the system has some receiver to simulate the actuators which can receive some command signals such as the ignition signal and the injection signal from ECU. Also some indicator light is connected in circuit to indicate the working state. Because the injection pulse width signal is an important parameter of the ECU state, it is calculated by the SCM and then be sent to IPC through RS232 serial ports.

B. Communication and Software Design of the System

This system adopts the KWP2000 (Keyword Protocol 2000) diagnostic protocol standard which is widely used in the European automotive field. KWP2000 is a kind of diagnostic protocol which is based on K-line and CAN bus [9]. Among them, the protocol standard based on K-line mainly includes the ISO/WD14230-1~14230-4. The protocol standard based on CAN bus is ISO15765. As the K-line's physical layer and data link layer have limitations of not regarding network management and communication speed, so the K-line cannot meet the requirements of more and more complex on-board diagnosis networks. CAN communication has gained overwhelming success in the automotive network field, because it has a non-destructive network mediation mechanism, and a higher communication rate (up to 1 Mbps). It is a flexible and reliable measure of communication.

There are 9 main types of service modes (mode 1-9) which can be realized by application protocol [10].

Mode1: requests current powertrain data;

Mode2: requests freeze frame data;

Mode3: requests emission related trouble code about powertrain diagnostic;

Mode4: clear / reset the diagnostic information about emission;

Mode5: requests the information from the oxygen sensor;

Mode6: requests the information from the discontinuous monitoring system of the OBD;

Mode7: requests the information from the continuous monitoring system of OBD;

Mode8: requests control the vehicle system;

Mode9: reads the identification number of calibration in vehicle.

Each mode is followed by a PID (parameter identification) which represents what the following parameter is. During the Application, the user only needs to send the corresponding mode number and PID to the vehicle, then the corresponding data can be obtained. For example: if the instruction of “0105” is send to the vehicle, then we can receive data “>0105 4105 7B”, where “41” represents Mode 01, “05” represents PID05, “7B” is the water temperature and its decimal number is 80. So it indicates that the current water temperature is 80 degrees.

The software of the system is the communication interface between the user and the system. The software design adopts the principles of software engineering, and using the method of structured and modularized program design. The theory of the relational database is integrated with software design. The functions of the serial communication, data acquisition, data analysis and the database query are realized.

The software is developed with the LabVIEW graphical programming language. Local variables, global variables and shift registers is used to achieve multi-threaded programming. The executing procedure of each thread is independent and orderly running through using Queue multi-thread programming technology. In order to ensure the security of the program, some detection are designed as follows:

Step 1: Set up or close the dynamic communication channel;

Step 2: Set up or close the static communication channel;

Step 3: Confirmation of the sent message;

Step 4: The communication of the massive data.

The software consists of a main control module, a user interface module, a serial communication module, a data analysis module and a user management module. The main control interface is shown in Fig. 6. Several running modes of ECU which can automatic switched by system have already been saved in the program. Users also can manually set the parameters of running mode.

Fig.6 Main Interface of Diagnosis Program

The interface of communication setting and part results of diagnosis is shown in Fig. 7. In this interface, users can compare the test values with standard values. The diagnostic results can be generated as EXCEL files, so as to be printed or saved easily.

Fig.7 Communication Settings and Part Diagnostic Results Interface

In addition, a digital pulse signal editing module is designed for different types of vehicles. A variety of sensor pulse waveform signals which can directly selected by users have been saved in system. Users also can manually edit the waveform according to the crankshaft sensor signals and camshaft speed sensor signals of different engine.

V. CASE STUDY

An unlocked ECU from a Zhonghua car is selected as the diagnostic object. We running the simulation diagnostic system. Ignition switch is opened first. The rotate speed of the crankshaft is increase gradually. The parameters of intake air manifold pressure and water temperature etc. are auto regulated through the reasoning of the context-aware reasoning engine. ECU begin to running normally. Ignition and inject signal appear. After this, the signal of accelerator pedal sensor is manually regulated by us. Other input signal of ECU are varied automatically. We simulate a throttle valve fault which is too low of the value of sensor signal. A fault code about oxygen sensor is detected by system immediately. The reasoning engine inspect each running parameters and finally reasons that the signal from throttle valve is abnormal. The diagnostic result shows that the simulation diagnostic system can effectively simulates the working condition of ECU and makes correct judgment on fault.

VI. CONCLUSIONS

This paper proposed an intelligent simulation approach for ECU off-line diagnosis based on ontology. The characters of conceptualization of the knowledge, expandability and logical reasoning possible of ontology make it easy to realize a simulation of pervasive working environment of ECU. The constructed simulation diagnostic system for ECU based on this approach simulated the real working condition of ECU in an off-line environment. It maintained the normal operation of ECU. We validated the proposed approach which could help diagnosis engineer to fast diagnose the fault of ECU and provide valuable reference to the development and test of the control strategy of ECU. The system not only completes the diagnosis function of common OBD tester, but also can simulates many input signals of electrical control systems and diagnose the function of the ECU. This off-line diagnosis approach saves more cost than traditional on-line method, and overcomes the difficult of set faults to electronic control system manually when on-line diagnose. Case study verified the propose approach. The approach has universality and expandability.

In the future, we would proceed further evaluation and verification for serviceability and validity of proposed approach. The simulation on the multi working conditions of ECU will be performed in off-line simulation environment.

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CONFLICT OF INTEREST

The authors confirm that this article content has no conflicts of interest.

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