Research on PHM Technology for Special Vehicle Weapon Control System

Chunming Li[1], Haiping Song, Yang Lei, Jing Xu, Hong Du
Information & Control Technology Department
China North Vehicle Research Institute
Bejing, China
xjcat8912@163.com

***Abstract*—With the increasing complexity of modern special vehicle weapon control system, the traditional methods of regular maintenance and post-maintenance are far away from the actual combat needs. In this paper, the technology of fault prediction and health management is introduced into the special vehicle weapon control system to realize the requirement. The functional requirements of PHM for weapon control system are analyzed. Through the detailed functional design of the module, the 7-layer architectures are adopted. According to the principle of friendly man-machine interface, the related implementation and test are carried out. The basic functional requirements of weapon control system PHM are realized. The experimental results show that the system has the functions of fault diagnosis, fault prediction, data record and analysis, and plays an important role in the health management of weapon control system.**

Keywords-weapon control system; fault diagnosis; fault prediction; data record and analysis;7-layer architectures

I. INTRODUCTION

Regular service and breakdown maintenance are mostly adopted in fault diagnosis and maintenance of weapon control system for conventional tank & armored vehicles [1]. Through monitoring of main performance parameters of the system or equipment, all kinds of fault features extracted in practice shall be analyzed, reasoned and diagnosed methodically. As a matter of fact, the correctness of fault diagnosis depends on long-term experience and history fault patterns, lacking accuracy and reliability. The weapon control system of modern armored vehicles is characterized by many units, complicated principle and high level of software and intelligence, as also improves requirement for weapons & equipment [2]. Due to the rapid progress in sensor technology, bussing technology, testing technology and computer technology, the existing fault diagnosis & maintenance mode has already been failed to satisfy the requirement for new mode of modern & network centric warfare in a more economic and effective way. Therefore, it becomes a trend to introduce PHM (prognostic and health management) technology in the R & D of weapon and equipment.

As early as in the 1970s, the concept of integrated health management was put forward for the spacecraft firstly by the United States [3-5]. And in the 1990s, the US army introduced on-condition maintenance technology [6-8]. In China, the research on PHM is mainly carried out in universities or research institutes, focused on PHM theory, architecture and the prediction algorithm [9, 10]. Starting from the system's current state, the PHM technology can carry out prognostics based on state of completion of system function and diagnosis of the predictive information obtained, operating requirements and available maintenance resources so as to make a proper decision for the maintenance of products [11-14]. However, the application of PHM technology in the health management of weapon control system is still at the level of concept. Xu has made some theoretical researches in FCS design [15], but there is no description in details for weapon control system. Therefore, it is of great practical significance to explore a health management system that is supported by advanced theories, based on advance science and technology, and satisfy the development requirements for health management of weapon control system.

In this paper, the PHM functional requirements for weapon control system of special vehicles are analyzed. On this basis, PHM function module and system architecture for weapon control system is designed, followed by experimental verification of fault diagnosis and fault prediction and data acquisition and analysis of data recorder component.

II. FUNCTIONAL REQUIERMENTS OF PHM FOR WEAPON CONTROL SYSTEM

PHM system is the important part of weapon control system, featuring of independent, multi-functional, compatible and modularized system. Before the fault occurs, on-condition maintenance is expected to be realized through prediction of possible cause based on the various history information resource and provision of corresponding fault maintenance measures. Fig.1 shows PHM functions block diagram for weapon control system.

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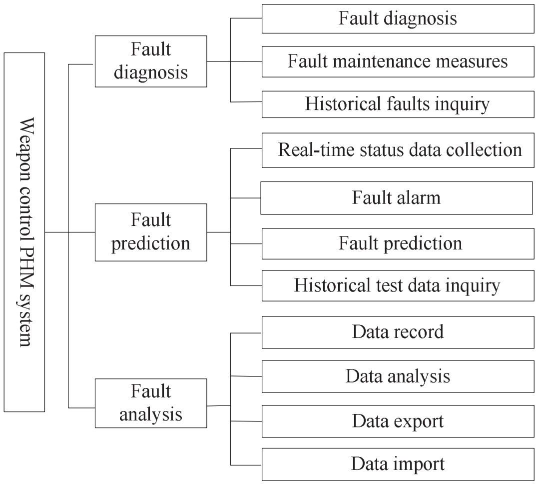


Figure1. PHM functions block diagram for weapon control system

A. Fault Diagnosis

Varieties of check and test methods are used to judge of the system running status and abnormal situations, checking if the system is faulty. When a fault occurs, type, location and cause of the fault shall be diagnosed by means of principle, experience and keyword search etc., and eventually a proper maintenance policy is given. At the same time, the historical fault message is provided for record and summary of those high-frequent faults, which might be prevented from being reoccurred.

B. Fault Prediction

With the help of those universal interfaces such as CAN bus, FlexRay bus, serial port and video signal. Data information is collected from the single unit. Then the fault prediction is carried out according to fault prediction model and fault evaluation criteria for single unit. Realize alarm of the possible abnormal states and save the collected data into database for inquiry.

C. Data Analysis

Its main functions include data recording, analyzing and database exporting. According to protocol specifications, record all data transmitted by FCS communication bus and save them in database; analyze those data which are saved in database and provide the analyzed data for fault prediction module. According to the user's protocol specifications, export the database periodically every 15 days or 30 days for fear of data loss due to insufficient storage space.

III. Design of System Function Module

A. General Design

The system hardware design adopts high-performance ARM-LINUX +TI c2000 DSP embedded platform, provided with varieties of data transmission & interaction means such as network interface, CAN communication interface, serial port, AD acquisition channel and video capture etc., compatible for different interfaces between equipment and modules, so it has relatively high adaptability. The software design adopts cross-platform & component programming, being full featured and easy understood, completely realizing the friendly operation interface of PHM system for weapon control. As shown in Fig.2.

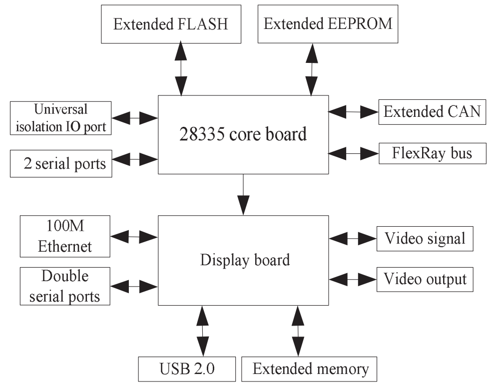


Figure2. Block diagram of system overall design

The core chip adopts TI 28335 chip with processing capacity as high as 150MHz and 32-bit FPU, composed of universal isolation IO port, 4-channel CAN bus, 2 serial ports, FlexRay bus, extended FLASH and extended EEPROM. The display board is based on the ARM-LINUX architecture, able to collect 1-channel PAL black/ white analog video signal, with 768 × 576 interlaced scanning, field frequency of 50, and frame cycles of 25. Video compression format H.264 guarantees the quality of video signal with proper compression ratio. It is configured with analog output display interface of 25 frames per second and 100M Ethernet interface communication, with double-serial ports capable of sending the data package which is synchronized with video information, the concerned command package, system time synchronization package and time stamp package. It is also provided with USB2.0 host interface used for extending storage device & data unloading capacity, and internal memory possible to save data and video data for more than 24 hours.

B. Function Design

1) Fault diagnosis

The fault diagnosis means that, in case of system being faulty, PHM system will locate the fault by means of principle diagnosis, experience diagnosis, keywords search and integrated query etc., and then find out the source of fault and give the corresponding solution. Once the fault of system is detected or monitored, sound or light alarm will be available in real time, which gives feedback on the fault location and the maintenance solution. Fig. 3 shows overall structure of the fault diagnosis. The performance requirements of the fault diagnosis are as follows.

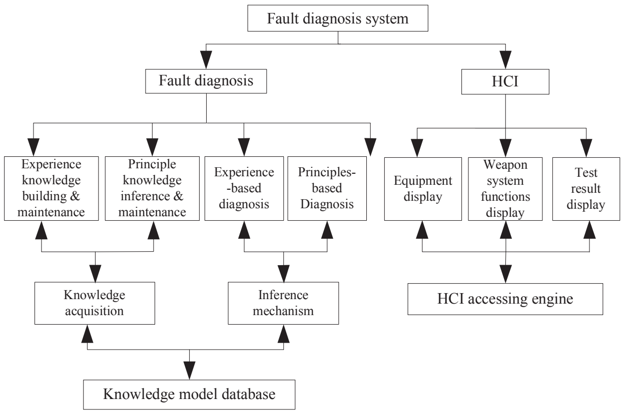


Figure3. Overall structure diagram of the fault diagnosis

a) Timeliness of fault diagnosis. The fault is required to be detected at earliest as it occurs.

b) Capability of fault isolation. System is required of capability in distinguishing different faults and isolating them lay by layer.

c) Accuracy of fault knowledge. The domain expert knowledge stored in the system is required to be detailed, comprehensive and accurate.

2) Fault prediction

The fault prediction is to set the current service state of the equipment as the start point of prediction, take the structural characteristics, functional parameters, environmental conditions and historical running conditions as the basis of prediction, make full use of the existing knowledge in the domain knowledge base and adopt proper solution, so as to predict the possible failure and its time, cause and location of occurrence in the certain period of future. Consequently, it is possible to make an effective forecast, diagnosis and maintenance and ultimately improve the operational performance & service efficiency of weapons and equipment.

The fault prediction of this system is designed for predicting the fault occurs at the level of component and key location. The flow chart of FP is shown in Fig. 4.

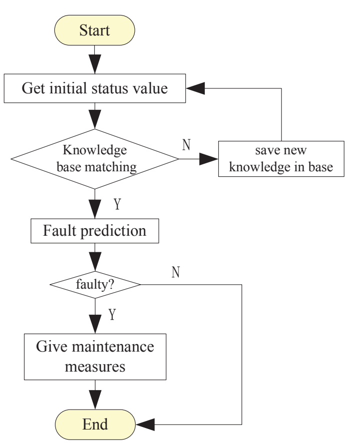


Figure4. Flow chart of fault prediction

3) Data recorder analysis

Main functions of the data recorder include data acquisition, data recording, data storage and data analysis. When there is any data communication in CAN bus, Ethernet or FlaxRay bus, PHM system will record these data in real-time and store them in database for convenience of being analyzed and called by other modules. At the same time, the data are generally stored in database in the format specified by the communication protocol and these messages are defined by the designers in the industry. Before they are used by others, these data messages must be analyzed into the messages which are understood both in and outside the industry, and displayed with dialogue box in the interface.

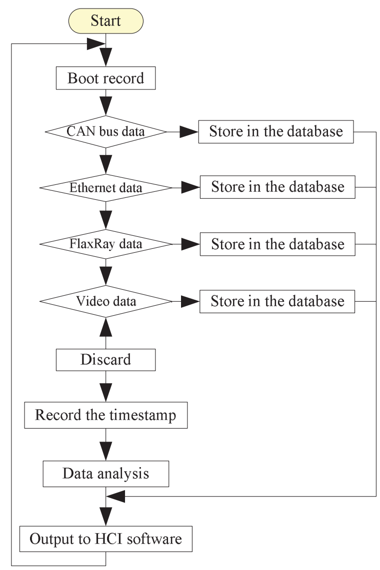


Figure5. Process of analysis for data recorder

C. Architecture Design

In accordance with the induction and conclusion on PHM system composition by OSA-CBM (Open System Architect-Condition Based Maintenance), system architecture is composed of 7 layers: data acquisition layer, data processing layer, state monitoring layer, diagnosis & processing layer, prediction & processing layer, decision support layer and expression layer [14, 16], which are shown in Fig. 6.

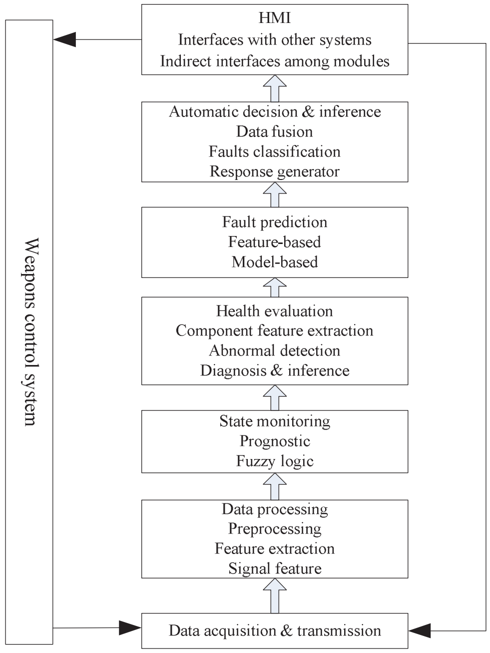


Figure6. Architecture diagram

1) Data acquisition layer

Data acquisition layer is the information source of the PHM system, realizing the functions of data acquisition, conversion and transmission. As the storage module of system source data, it mainly collects data from the equipment's sensors and the system data bus. The real-time data are collected on line or off line from the site equipment and the health characteristic parameters obtained from FCS, which provide FCS with the content of prognostics and other modules with the site data information. If FCS in course of operation, the data obtained through on-line structure condition monitoring is on-line collection whereas FCS in maintenance state, the data obtained through structure health monitoring or NDT is off-line collection.

2) Data processing layer

The collected data will be collated & sorted, analyzed and processed in data processing layer. According to the characteristics of data, they are categorized as follows: periodic data and aperiodic data, discrete data and continuous data, finite time domain data and finite frequency domain data, frequency data and energy data, etc. Generally, the data processing methods are as follows: filtering method, averaging method, statistical analysis method and spectral analysis method, etc. The data, after being processed, are converted into a unified format as required by local database or system design so that characteristic parameters are obtained which can reflect the health state of the system. Data processing methods vary with data characteristics so as to extract data parameters & state parameters related to system prognostics.Deletion: Delete the author and affiliation lines for the second affiliation.

3) State monitoring layer

After the data from sensors and control systems have been processed in data processing layer, they are input in the state monitoring layer, where the characteristics of components, subsystems and system are tested, analyzed and reported, and then the state of components, subsystems and system will be output. In PHM system, the state monitoring layer will carry out a further processing of the data which have already been processed in data processing. With the aid of a certain intelligent inference algorithm, simple fault state of the components, subsystems and system can be pre-disposed of so that basic status of FCS be determined. Generally, the threshold value is set as measure if system is running normally, that is, when system state parameters exceed the threshold value, the system is determined to be abnormal, and then diagnosed if the fault occurs. The threshold value of system is finally obtained by analysis of the results from stress test & fatigue test and the data from modelling. And meanwhile in system architecture design, factors of system load limit and fatigue limit should be taken into consideration in order to follow a proper design approach.

4) Health evaluation layer

The basic function of health evaluation layer is to monitor the health status degradation of components, subsystems and system. Once system is found to be abnormal during the monitoring process, the abnormal condition is required to be further diagnosed and analyzed so as to determine in which state of the life cycle the system is. Fault diagnosis are mainly divided into two types: data-based and model-based. The data-based diagnosis is intended to locate fault and recover system based on system data by use of algorithms such as expert system, pattern recognition and neural network. For the model-based diagnosis, the first priority is to build the accurate model of system, followed by difference operation between system state information & data from the monitoring and the built model, and finally to carry out fault diagnosis, judge the fault type and provide maintenance measures.

5) Fault prediction layer

The fault prediction layer takes the current state of system as the starting point, analyzes reliability of system, subsystems and components, and then predicts its remaining service life to be used. Use expert system knowledge, data acquired by sensors and system model for fault prediction while use status monitoring parameters for evaluation of system running status in the past, present and future. Based on the current working state & service condition of system, the system's remaining service life may be predicted by simulation of running process in the past and reference to historical faults.

6) Decision support layer

The decision support layer is mainly served for arrangement of maintenance and repair work for system, providing system with logistic support. In PHM system, health status reports will be generated by system status monitoring, health evaluation and fault prediction, which will accordingly help decide the arrangement of next testing time, maintenance personnel and maintenance measures etc.

7) Expression layer

The expression layer is the information interface between PHM system and users, and also acts the terminal display of system's PHM results, including HMI, data record, fault alarm & location, etc.

IV. SYSTEM IMPLEMENTATION & VALIDATION

A. Fault Diagnosis Module

Make full use of expert system knowledge base, database, inference machine and explanation facility to carry out fault diagnosis on FCS. Since the faults of FCS are developed in a tree structure, each node is required to be node-tested during the fault diagnosis process, including test name, test condition, test method, test standard and test result, etc. Upon completion of test, fault isolation is being realized according to test prompts. With the fault tree is separated layer by layer, the fault range is gradually narrowed until the node becomes a leaf node. That means the fault location is successfully accomplished, and then maintenance measures are given. As shown in Fig. 7, the red words indicate the faults which are already located.

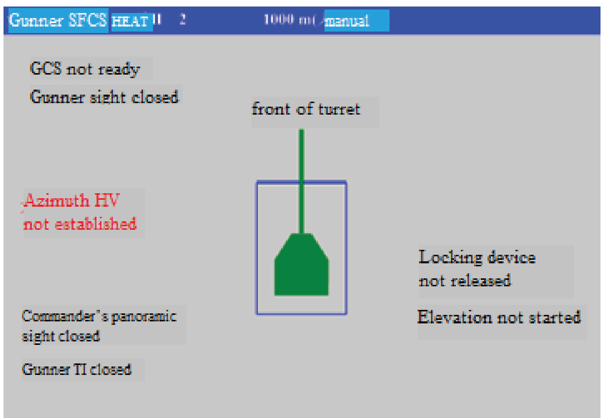


Figure7. Interface for fault diagnosis result

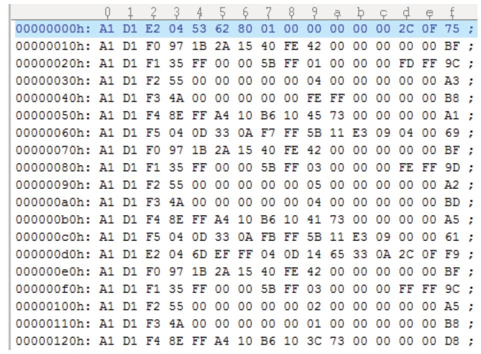
B. Fault Prediction Module:

Collect the key signal status of key location, and get the normal range of signal based on the expert knowledge base as built. Real-time monitoring of each parameter, it will be highlighted if the abnormal value occurs and early warn of the possible fault on the related component, as shown in Fig. 8.

Figure8. Key signal state monitoring interface

C. Data Rcorder Aalysis

Start data recorder, CAN, FlaxRay and Ethernet will make a record of data. For details of data record information, see Fig. 9. The data, after being analyzed, is given in form of curve as shown in Fig. 10. For the video signal recording, see Fig. 11.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00000070h: A1 D1 F0 97 1B 2A 15 40 FE 42 00 00 00 00 00 BF ;
00000080h: A1 D1 F1 35 FF 00 00 5B FF 03 00 00 00 FE FF 9D ;
00000090h: A1 D1 F2 55 00 00 00 00 00 05 00 00 00 00 00 A2 ;
000000a0h: A1 D1 F3 4A 00 00 00 00 00 04 00 00 00 00 00 BD ;
000000b0h: A1 D1 F4 8E FF A4 10 B6 10 41 73 00 00 00 00 A5 ;
000000c0h: A1 D1 F5 04 0D 33 0A FB FF 5B 11 E3 09 00 00 61 ;
000000d0h: A1 D1 E2 04 6D EF FF 04 0D 14 65 33 0A 2C 0F F9 ;
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00000110h: A1 D1 F3 4A 00 00 00 00 00 01 00 00 00 00 00 B8 ;
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Figure9. Data recording information

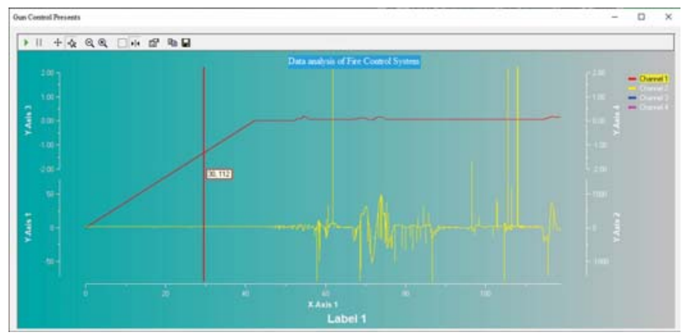

Figure10. Data analysis curve

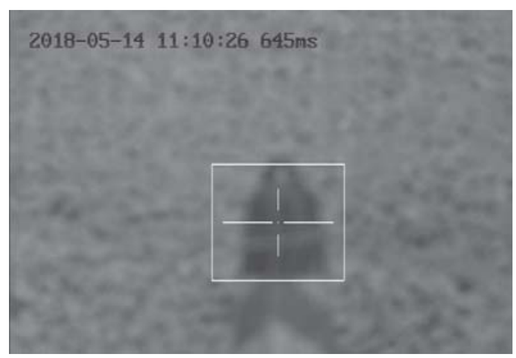

Figure11. Video signal analysis from data recorder

V. CONCLUSION

This paper takes special vehicle weapon control system as the object of research, discusses the characteristics of structure of modern weapon & equipment in terms of complexity, modularization and informatization. It introduces PHM technology based on requirement analysis. The PHM technology adopts ARM - LINUX + TI c2000 DSP embedded platform, makes a detailed design of module functions in 7-layered architecture, and follows the principle of user-friendly HMI. The related system implementation & test has been verified and basic function requirement been preliminarily realized. The experimental results show that this system has the features of fault diagnosis, fault prediction, data recording & analysis, and plays an important role in health management of weapon control system. Thanks to the application and preliminary implementation of PHM technology, the weapon control system will be provided with a powerful database support for design improvement, system evaluation and analysis in the future.

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