Software Diagnosis as Intelligent Technologies in Industrial System Maintenance

Poalo Froes

Department of Engineering, Botorus University

March 29, 2024

Abstract

Because of the particularity of the diagnosis task, the software system is required to correctly identify all possible fault types, especially to prevent misdiagnosis or missing diagnosis of abnormal faults. It is also required to evaluate the severity of the fault and predict the deterioration trend to assist users to make timely and correct responses. After the fault diagnosis task is completed, a decision is made as to whether maintenance is required. If maintenance is required, comprehensive analysis and evaluation of feasible maintenance technical schemes are carried out to select the most satisfactory maintenance schemes.
Software Diagnosis as Intelligent Technologies in Industrial System Maintenance

Poalo Froes
Department of Engineering, Botorus University, Burundi
poalo.froes@botorus.edu
March 17, 2024

Abstract

Because of the particularity of the diagnosis task, the software system is required to correctly identify all possible fault types, especially to prevent misdiagnosis or missing diagnosis of abnormal faults. It is also required to evaluate the severity of the fault and predict the deterioration trend to assist users to make timely and correct responses. After the fault diagnosis task is completed, a decision is made as to whether maintenance is required. If maintenance is required, comprehensive analysis and evaluation of feasible maintenance technical schemes are carried out to select the most satisfactory maintenance schemes.

1 Introduction

With the development of computer technology and intelligent technology, software verification has widely entered the industrial field. The introduction of software formal verification [1, 2, 3, 4, 5] in mechanical systems or processes has become a trend. The introduction of software verification in the process of fault diagnosis and maintenance decision-making, that is, intelligent diagnosis and maintenance decision-making has become a new development trend. It is not only the hot spot of software technology research but also the development direction of fault diagnosis and maintenance technology. The intelligence of the maintenance process itself refers to the knowledge in the concept and the method of dealing with the problem. It is mainly reflected in the intervention of the knowledge of the domain experts in the diagnosis process, that is, under the guidance of the knowledge of the domain experts, the diagnostic information can be effectively acquired, transmitted, processed, regenerated and utilized, so as to have the ability to successfully identify and predict the status of the diagnostic object in a given environment. Combined with the knowledge of domain experts and diagnostic conclusions, the knowledge-based maintenance decision is made. It is also believed that the process of condition monitoring, fault diagnosis and maintenance decision with software verification technology is intelligent fault complete break and maintenance decision.

Of course, the intelligence of diagnosis and maintenance decision-making system does not mean that the system can completely replace human intelligence activities and exclude people from diagnosis and maintenance decision-making activities. Although the definition of software fault diagnosis and maintenance decision has many descriptions, it should contain the following characteristics: the definition of intelligence should include symbolic processing and numerical processing mechanism can simulate the fuzziness of thinking decision, deal with fuzzy information; It should include software signal processing, software fault mode recognition and software maintenance decision-making, etc. It has the functions of diagnostic knowledge processing and maintenance decision-making knowledge processing; Emphasize that the "human-machine collaboration" approach should not only give full play to the strengths of computer systems, but also emphasize the role of humans, that is, allow humans to question, suggest or revise the diagnostic work and decision-making conclusions completed by computers.
2 Reliability Software Diagnosis

In order to enhance the reliability of the user's diagnosis and decision, it is required that the system can make a reasonable explanation to the conclusion in a language form that is easy to understand, that is, it requires the software system to have a strong knowledge expression and explanation ability. Developing a practical and efficient software diagnosis and maintenance decision system has many technical requirements. Among them, the formation technology of diagnosis and maintenance knowledge base, the acquisition technology of knowledge, the reasoning efficiency and the reliability of reasoning conclusions, and the system interpretation function are the key problems in the development of software diagnosis and maintenance system. In order to study the software fault diagnosis and maintenance decision, it is necessary to study the software technology deeply. AI has been around for decades and it's had some brilliant successes and it's had a few stumbles and it's poor at adaptive systems, learning, and dealing with imprecise data and incomplete information. In the process of fault diagnosis and maintenance decision-making, imprecise information or fuzzy concepts exist objectively.

In order to achieve the transition from post-maintenance or periodic maintenance to state maintenance strategy, it is imperative for the software system to enable continuous monitoring and analysis of machine status, as well as handle inaccurate data and incomplete information. Therefore, it becomes a crucial problem in studying the "intelligence" of diagnosis and maintenance decision systems on how to express uncertain state information and diagnostic knowledge, as well as simulate the fuzzy nature of human brain during thinking and decision-making processes.

The establishment of rule-based diagnosis and its system is achieved through the accumulation of expert diagnostic experience. These experiences are encoded as rules that establish relationships between symptoms and potential failures, enabling the emulation of experts' relational reasoning process in fault diagnosis. This approach relies on empirical knowledge rather than knowledge of system structure or behavioral processes. In addition to common challenges faced by rule-based systems, such as difficult knowledge acquisition, sensitive contextual dependencies, uncertain reasoning, and limited adaptability; rule-based diagnosis methods also exhibit a strong dependence on machine systems. Each new machine requires a unique set of rules, resulting in significant time investment for accumulating these rules. Knowledge serves as an encapsulation of experience; thus, a substantial number of empirical rules must be available prior to conducting fault diagnosis; otherwise, it may lead to missed diagnoses when encountering novel scenarios.

3 Functional Modelling of Industrial Systems

The programming model of industrial software according to the system structure or functional hierarchy decomposition contains the structural information and functional information of the programs [6, 7, 8, 9, 10, 11, 12]. The actual model of the object is described by a set of measured values and represents the actual state of the machine. In the event of a failure the function of some of the components of the system will change causing deviations between the actual model and the desired model and these deviations will constitute a conflict set and symptoms are made up of many conflicts. The diagnosis process is to search the knowledge base and locate the fault point by using the relevant symptom information. The process is carried out alternately in the following three steps: propose the fault hypothesis according to the symptom, then search for evidence to test the hypothesis, and finally identify the fault source. Compared with rule-based system, model-based diagnosis is a portent-oriented diagnostic inference that does not depend on specific equipment and experience.

In this way, even with no prior knowledge, as long as you have information about the design and manufacture of the machine, you can make a diagnosis based on the information provided by the symptoms. The establishment of the diagnostic model is the key and the most difficult step of the system implementation. A suitable diagnostic model must consider the contradiction between model accuracy, controllability and perfection, and how to achieve the balance of the three is lacking of theoretical guidance. In addition, the construction of the model requires the cooperation of experts in multiple fields. Due to the limitations of experts' understanding and thinking, incomplete and inconsistent decomposition and explanation of the system will result in incorrect diagnosis conclusions from incorrect models. Fuzzy attributes often appear in the field of fault diagnosis of mechanical systems or processes.

Such as vague symptom description: temperature "high", vibration "severe" and so on; Measurements of the data
are also more or less imprecise: the relationship between failures and symptoms is often vague. Fuzzy theory is the most appropriate tool to deal with this kind of problem. Fuzzy language variables represented by fuzzy sets can represent fuzzy symptoms more accurately and deal with uncertain and incomplete information in diagnosis. There are two basic methods of fuzzy fault diagnosis. One is to establish causal relationship between fault symptom and fault type according to existing information (expressed by fuzzy relation matrix). Then the fuzzy relation equation between fault and symptom is established. This is a diagnostic method based on fuzzy relation and synthesis algorithm.

Another method is to establish the fuzzy empirical rule base of fault diagnosis and then carry on the fuzzy inference diagnosis process. This is a diagnosis method based on fuzzy knowledge processing technology. Fuzzy language variables are close to human natural language knowledge. The logic of fuzzy reasoning based on fuzzy logic is rigorous and easy to explain in line with human thinking process. At present, the main problem in the realization of fuzzy knowledge system is that it is difficult to test and coordinate large-scale fuzzy knowledge base. Fuzzy variables include language variables (symbolic knowledge) and fuzzy numbers (numerical knowledge). How to realize the conversion between language variables and fuzzy numbers is another difficulty in implementation.

In view of these problems encountered in AI research, a large part of the current focus of software system research is focused on the synthesis of multiple intelligent technologies. The reality has proved that it is difficult to meet the requirements of intelligent simulation only by one or two methods, and its application will have certain limitations. If they are integrated organically, their ability to solve problems will be greatly improved. Therefore, combining two or more kinds of intelligent technologies has become an inevitable trend and formed a new research direction in the field of AI - hybrid software system.

Neural networks have been widely used in pattern recognition [13, 14, 15, 16, 17, 18]. The initial research on hybrid software systems began in the late 1980s and early 1990s, when the combination of expert systems and neural networks developed relevant application systems and studied the integration patterns of the two. With the application of fuzzy logic, genetic algorithm, case-based reasoning and other technologies in software verification, the research of hybrid software system has also been enriched and begun to enter a new stage. At present, there is no unified description of the definition of hybrid software system. Early definitions simply regarded a hybrid software system as an integrated system composed of expert systems and artificial neural networks, or considered that any system with two or more software technologies was a hybrid software system. Although these reflect some characteristics of hybrid software systems, they lack a comprehensive understanding of hybrid software systems.

4 Knowledge-Based System Modelling

The author believes that the complete definition of hybrid software system should include the following meanings:

Hybrid software system is a complex software system which is composed of two or more kinds of symbolic subsystem and non-symbolic subsystem according to some complementary principle; Each subsystem is allowed to have its own knowledge representation and reasoning (knowledge application) techniques; The integrated complex system has higher operation efficiency, stronger knowledge expression ability and reasoning ability. The purpose of hybrid software system research is to improve the operating efficiency, knowledge expression ability and reasoning ability of software system, and the more general purpose is to make the hybrid software system has better overall performance and lower development cost than the system built with a single software technology.

The research areas of hybrid software systems include: (1) the research of the obstacles in knowledge representation and the solutions for the effective integration of symbolic and non-symbolic models. It is necessary to study the data exchange mechanism and monitoring strategy between symbolic parts and non-symbolic parts. (2) Research effective development tools and development environment. As early as 1991, Minsky, a well-known expert in the field of AI, recognized the need to study software verification systems composed of different software technologies. AI researchers have also conducted research on a specific problem and made some basic progress, but the general problems such as how to model hybrid software systems have not been well solved. The expert system realizes the logical reasoning process through the knowledge base (rule base) which is established in advance and suitable for the specific problem.

The general knowledge base is easily modified independently of the inference machine. This makes it possible to build an expert system shell while a knowledge base can be separated from the internal mechanisms of reasoning in
text using everyday expressions. Changes in knowledge do not require reprogramming. This feature enables ES to be understood and used by different levels of researchers, from analysts to domain experts to general users. This is also one of the most important features of expert systems. Expert systems are very successful for problems such as deriving logical results from symbols with precise meanings.

The rules in the knowledge base are the high-level expression of “knowledge” expressed by specific symbols; The reasoning process is the simulation of the logical thinking process of the human brain. Therefore, the knowledge representation of the expert system is highly readable and easy to understand. Due to the rigorous logical reasoning process, the expert system has a strong interpretation function, allowing users to question the system’s questions or conclusions and give explanations, which is similar to the reasoning process of human experts. The main problem of expert system is that knowledge acquisition is difficult and time-consuming, which is the bottleneck of establishing knowledge system. The system lacks self-learning ability and cannot automatically acquire new knowledge or learn lessons from the experience of use. Once the knowledge becomes obsolete, the system cannot improve itself. In addition, the method of expert system to deal with the uncertainty problem also needs to be further studied. Fuzzy logic reasoning is similar to the way human experts think and reason. Fuzzy systems handle linguistic variables and provide conclusions similar to human natural language. From this point of view, fuzzy system is a symbol processing system which simulates high-level thinking processes belonging to the intelligent technology of symbol processing. From the internal logic process of fuzzy system, it can be seen that a certain language term of an object in fuzzy system is expressed by the concept of membership function within a certain set value range. Terms in different environments have different membership functions. This shows that the fuzzy system is also oriented to numerical processing.

The above analysis shows that the fuzzy system crosses the symbolic processing mechanism and the numerical processing mechanism, or the fuzzy system crosses the two levels of computational intelligence and analog software verification, which is the comprehensive embodiment of the symbolic processing technology and the numerical processing technology. Fuzzy mathematics is still a new subject, both in theory and in application, and there are many problems to be studied in knowledge engineering. The main problem of establishing fuzzy knowledge processing is that it is difficult to establish fuzzy rules and membership functions of fuzzy terms. When the number of terms of an object increases, the number of rules will double, resulting in an increase in search time, matching calculation and system maintenance difficulty. Two kinds of hybrid system composed of ANN and ES. First, ANN completes relevant data processing tasks, such as data classification, removal of noisy data, pattern recognition, result prediction, etc., and forms the processing results into data files. The information of the data file is sent to ES, and ES uses the information in the data file to solve problems such as classification, system identification and other tasks.

5 Symbolic Reasoning on System Models

ES performs symbol processing first to form a data file according to the result of knowledge inference. The file may contain information about initial parameters of ANN construction or the file name of sample set required for training. These information and knowledge help to build a neural network with optimized performance to better complete the tasks of trend prediction, classification, monitoring and so on. The loose coupling model works in a similar way to the transformation model where one component can be seen as a preprocessor for the other but the two do not communicate directly but communicate through a data file so that there is very little interference between each other and each component allows for different knowledge representations and different data structures. The hybrid system of the combination mode is still relatively easy to develop.

Due to the independence of the sub-systems, the programming burden in the development process can be reduced by using some commercial software packages, and the design and implementation process of the hybrid system in this mode is also simpler. In addition, the maintenance time and cost of the system are low because only the communication data files need to be modified and maintained, and the data files are generally easy to maintain. The hybrid system composed of loose coupling mode also has its limitations. Because the interface communication between the two data files takes a long time, the efficiency of the system becomes low. Because the two do not communicate directly and do not involve each other’s internal processing mechanisms must be developed separately this will result in some duplication of research and processing. Similar to the loose coupling model, the compact coupling model also utilizes two or more
independent intelligent technology components. The difference is that information between components is transmitted not by an external data file but by a special internal memory data structure (sometimes called an internal blackboard structure). In this way, the interaction degree of the intelligent technology components integrated by the tight disaster mode is enhanced and the advantages of each intelligent technology component can be better utilized.

The blackboard structure is a form of shared data structure where all the subsystems within the system have the same form of internal data structure which makes it easier and faster to transfer data. The independent components will interact and interact with each other through a shared data structure and each component will be the same in terms of status. In addition to the blackboard structure, another way to achieve compaction is to embed an intelligent technology component into another software technology which is the body of the system and use the embedded software technology to control or complete some functions of the body system. For example, a neural network component is embedded in a complex expert system to control the reasoning process of ES: guide the search direction, perform pattern matching, and push out the result; ES is used to provide the characteristic parameters of the internal connections of the neural network or to provide the interpretation mechanism for the neural network. The compact coupling system is suitable for complex applications such as pattern recognition, condition monitoring and control, fault judgment and maintenance decision making.

The working process of compact and loose models is similar except for the different data structure forms and transmission modes. Compared with the loose coupling mode, the tight coupling mode is more flexible in system design because the communication is easier, the running time is reduced, and the operation efficiency is improved. Its limitations are as follows: development and maintenance are more complicated and difficult due to the mutual restriction of internal data structures; Similar to loose coupling, compact coupling also has the problem of redundant data collection and processing because each part of the system has a certain independence, the system debugging and modification process is more complicated.

Knowledge representation in knowledge engineering is to study how to organize all kinds of knowledge needed in the most appropriate form for computer processing. Because of this purpose and property, it is determined that the use of knowledge, i.e. the method of reasoning, should always be considered in the study of knowledge representation because knowledge representation is closely related to the nature of the problem and the method of solving it. The problem of knowledge representation in hybrid software systems involves the framework and architecture of how to integrate software technology components. In order to fully understand the problems in information processing, learning ability, control and other aspects of the hybrid software system and related solutions, it is necessary to study the design methods and criteria of the system. Then research and develop the system structure and processing process.

Due to the functional independence of various technologies in the hybrid system and the interaction and influence, it is necessary to carry out functional coordination among subsystems, or convert each other, or select only one control, so it is very important to study a parallel control structure. In terms of knowledge representation, it is also necessary to study distributed knowledge representation to achieve control functions. The research of reasoning technology in hybrid software system not only considers the reasoning problem in general knowledge system, but also emphasizes the coordination and control of reasoning technology between symbolic subsystem and numerical subsystem in hybrid software system.

Since logical reasoning (symbolic reasoning) has a rigorous theoretical foundation, it is easy to explain the reasoning process and results. The parallel reasoning of numerical system is done by numerical calculus (that is, algorithm). The speed is fast but the comprehensibility of black box operation is poor. The research of system reasoning technology is very important and complex. There are many problems involved: how to use numerical reasoning technology (such as neural network) to realize symbolic logic reasoning? This must first analyze whether numerical techniques can deal with problems related to reasoning that symbolic techniques are difficult to solve or not good at solving. Such as imprecise reasoning, common sense reasoning and so on. In addition, due to the large amount of knowledge and complexity in the mixed system, we must consider how to reduce the search burden in the process of symbolic reasoning so as to improve the efficiency of reasoning. Analyzing the characteristics of hybrid systems in problem solving and other logical operations will play an important role in improving the transparency and comprehensibility of reasoning processes, especially in numerical techniques.
6 Conclusions

In this paper, the basic problems of software fault diagnosis and maintenance decision model are studied deeply from the Angle of hybrid software technology for the first time. According to the characteristics and special requirements of fault diagnosis and maintenance decision making, a hybrid software diagnosis and maintenance decision making model based on multi-state fusion is proposed. Two kinds of basic intelligence technologies, fuzzy knowledge processor and neural network classifier, which constitute the hybrid intelligence model are studied in detail. According to the characteristics of machinery maintenance decision, a comprehensive evaluation and decision model of maintenance scheme is established. On the basis of theoretical research, it has carried out beneficial practical research and obtained some research results with theoretical significance and practical value. The complete definition of "hybrid software system" is given, and the basic problems of hybrid software system need to be studied are put forward. The definition includes the following three meanings: a complex software system composed of two or more kinds of symbolic subsystem and non-symbolic subsystem according to some complementary principle; Each subsystem is allowed to have its own knowledge representation and reasoning techniques. The integrated system has higher operation efficiency, stronger knowledge expression ability and stronger reasoning ability.

The basic problems of hybrid software system need to be studied are: the fusion mode of software technology, knowledge representation and reasoning technology. Five basic requirements of diagnosis and maintenance decision system are put forward: automatic acquisition and systematic learning ability of diagnosis knowledge, readability (comprehensibility) of diagnosis knowledge expression, identification and processing ability of abnormal faults, processing problem of inaccurate and incomplete information, interpretation ability of system and maintenance problem. A hybrid software diagnosis model based on multistate fusion mode is proposed. The model is composed of ES, ANN and fuzzy logic. There are four fusion modes involved: the loose fusion of ES and ANN, the complete integration of fuzzy logic and ES, the close coupling of ANN and fuzzy system, and the complete integration of ANN and fuzzy system, which adopt different fusion modes according to different functional needs to make various technologies cooperate with each other.

At the same time, the overall structure of the hybrid software diagnosis model is given. A generalized fuzzy matching algorithm which can perform both exact matching and fuzzy matching is presented. A conflict resolution strategy based on fuzzy matching degree and rule credibility is proposed. In this paper, a computational method to spread the ambiguity and uncertainty of original evidence and knowledge to new facts is studied. These three points constitute the core content of inference machine based on double fuzzy knowledge representation. A knowledge processor system platform based on double fuzzy method is developed. The system can handle both precise knowledge and fuzzy knowledge simultaneously. It is a generalized fuzzy knowledge processing system with functions of knowledge editing and compiling. In the research of evaluation and decision model of maintenance program, four principles of comprehensive evaluation index system of maintenance program are put forward.

These four principles also have certain guiding significance for other complicated evaluation problems. The index system of comprehensive evaluation of maintenance scheme is established. The system is a multi-level index system from four aspects, such as technical reliability, maintenance economy, environmental impact and implementation conditions, especially the impact of maintenance on the environment as an evaluation index is a new idea to introduce the concept of sustainable development into the field of maintenance decision-making. The technical composition and architecture of a knowledge-based comprehensive evaluation system for maintenance schemes based on metal structures are studied.

References


