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Research on Expert System for Fault Diagnosis of Subsea Blowout Preventer

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Abstract

An expert system for fault diagnosis of subsea blowout preventer (BOP) has been developed. According to the expert knowledge, common faults could be diagnosed and the system will be enlarged with the increasing knowledge. Fault tree analysis method is used to extract the fault diagnosis information. By this way, the layers of faults and the logical relationship among them can be shown clearly. Production rules are employed to represent the knowledge extracted from layers of fault trees. It's convenient and easy to understand that the knowledge is connected together through its logic. The developed interfaces are friendly and easy to operate and the users can learn to use the system according to the one by one prompt and query the failure causes easily.

Keywords: *subsea blowout preventer; expert system; fault diagnosis*

1. Introduction

Expert system is based on knowledge. According to Prof. Feighaum from Stanford in 1982, expert system can be regarded as a series of computer programs. Based on the set knowledge and some inference rules, the difficult problem which only experts can solve will be worked out. It means expert system can solve the difficult problems in specific areas by imitating and learning the knowledge of human beings with some strategies and inference rules. A mature expert system is made up of these components: knowledge base, inference engine, man-machine interface, global database, knowledge acquisition subsystem and explanation subsystem [1].

Knowledge base is the core of the expert system. Experts' rich experience and knowledge is stored in it and the problems are solved by extracting rules and knowledge in the knowledge base. Inference engine is a way of using knowledge and can be regarded as a control system. Based on the facts given by users, certain search strategy and appropriate inference rules are adopted to get the final conclusion by reasoning the knowledge base. Global database is like a temporary database, which is used to store the initial evidence of the diagnosis and information generated in the progress. Knowledge acquisition subsystem is an intermediate system connecting knowledge base with experts in the field. Through it, knowledge base can acquire knowledge constantly from domain experts, making knowledge updated and improved and finally, the fault diagnosis expert system can be more and more "profound". Explanation subsystem is used in explaining the process of reasoning and conclusions. For example, explain the rules of inference, the route of reasoning and the cause of conclusions. Explanation

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subsystem marks it convenient for users to understand the reasoning progress. So the experience and knowledge of experts can be imparted. Man-machine interface is what we call the user interface, which is a link connecting expert system with the users. It is the medium of interaction between users and expert system. After users selecting or inputting some information through the hints on the interface, the system can convert it into internal form to operate and then display the result for users when the process is completed. So what the users can see is only the user interface. There is no doubt that friendly and easily operated interface, simple operation play an important rule in the expert system.

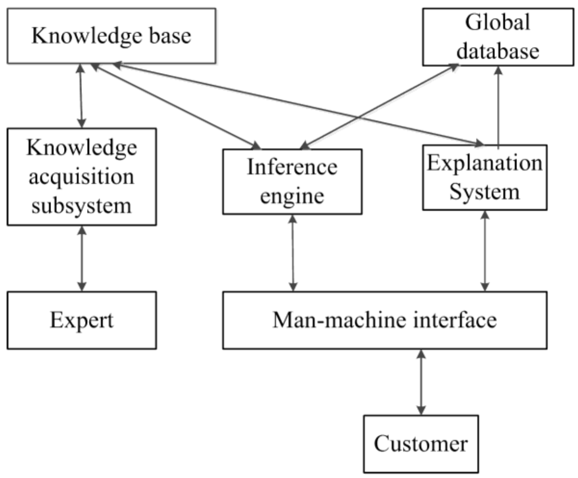

Figure 1. The general structure of expert system

Expert system has been widely used in various fields for developing fault diagnosis systems [2-5]. An expert system has been developed to assist citrus spray applications in planning and evaluating their sprayer operations [6]. A development process as well as system verification and validation is described based on a number of known test and reference waste dumps [7]. An expert system using Java-based expert system shell that allows students to seek quick responses to their queries regarding their plan of study and progress in the program is developed [8]. An expert system based on the fuzzy logic is presented to study and realize a toll to help the ergo-therapist for the decision on the capacity of the disabled person to drive safely a power wheelchair [9].

2. The Design of the BOP Fault Diagnosis Expert System

The keys to building a BOP fault diagnosis expert system are the construction of knowledge database and inference engine. This paper is based on fault tree analysis method to extract fault diagnosis information. Forward reasoning method is used for the realization of inference engine.

2.1. Knowledge base

The source of fault tree in this system comes from Reference [10]. The fault tree of subsea BOP is shown in Figure 2. Through analysis of the main fault tree, Figure 2 demonstrates that a blowout will occur if LFLRPCSE or SUBBLOW appears. LFLRPCSE is caused by LFLRP, CSNO or BBPYPF, so the relationship among them is serial. Similarly, LFLRP analysis will be caused by LRPIL, PIHF or SULPL. Figures 3-5 are the fault trees of

SUBBLOW, CSNO and BBPYPF, respectively. The detailed faults and their relationship are listed in the figures.

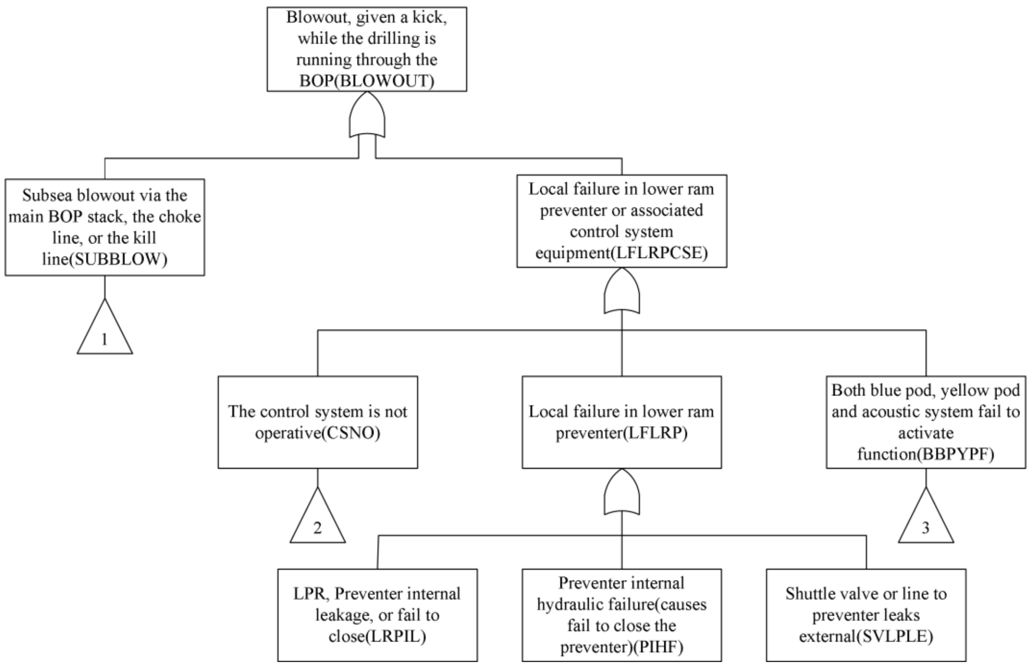

Figure 2. Fault tree of BLOWOUT for subsea BOP

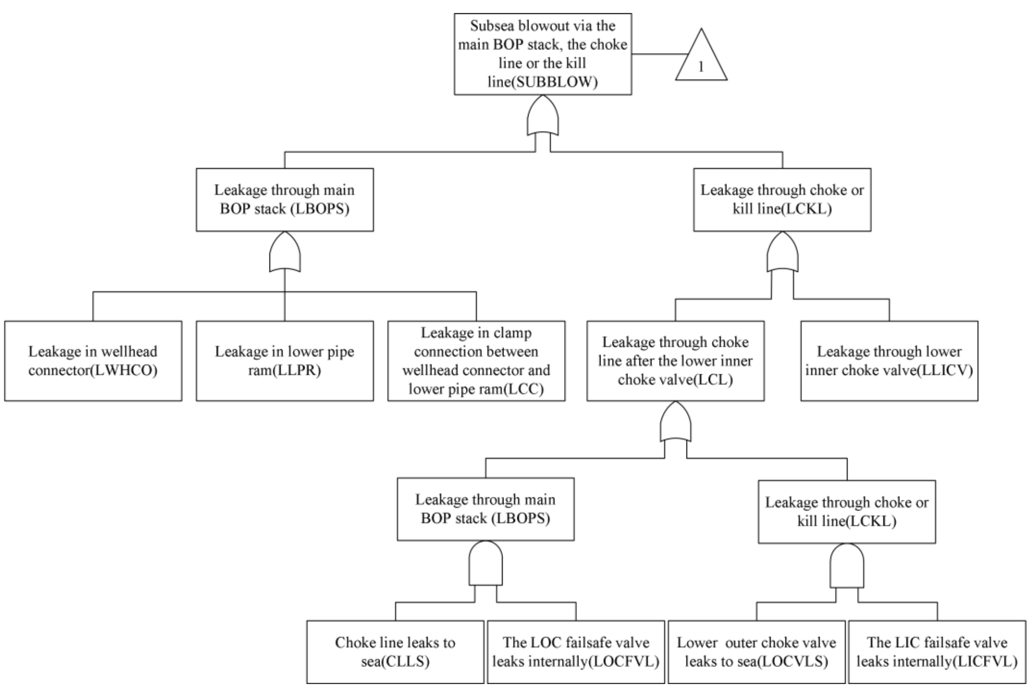

Figure 3. Fault tree of SUBBLOW for subsea BOP

The essence of expert system is processing knowledge. But the knowledge can only be represented in the form of binary data, as the form on computer, to be stored, operated and used for actual problem. Representation of knowledge is to turn human intelligent behavior into a kind of description that computer can understand.

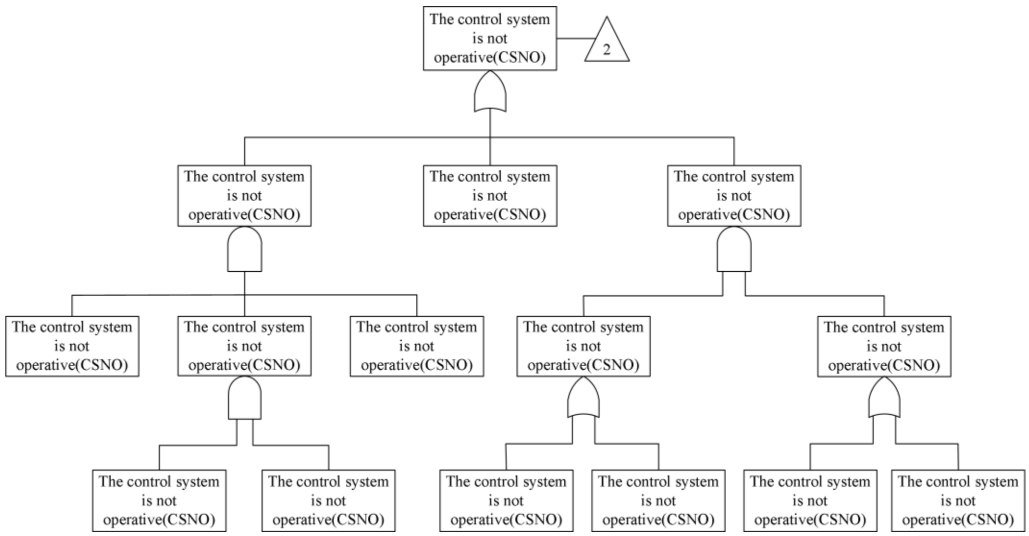

Figure 4. Fault tree of CSNO for subsea BOP

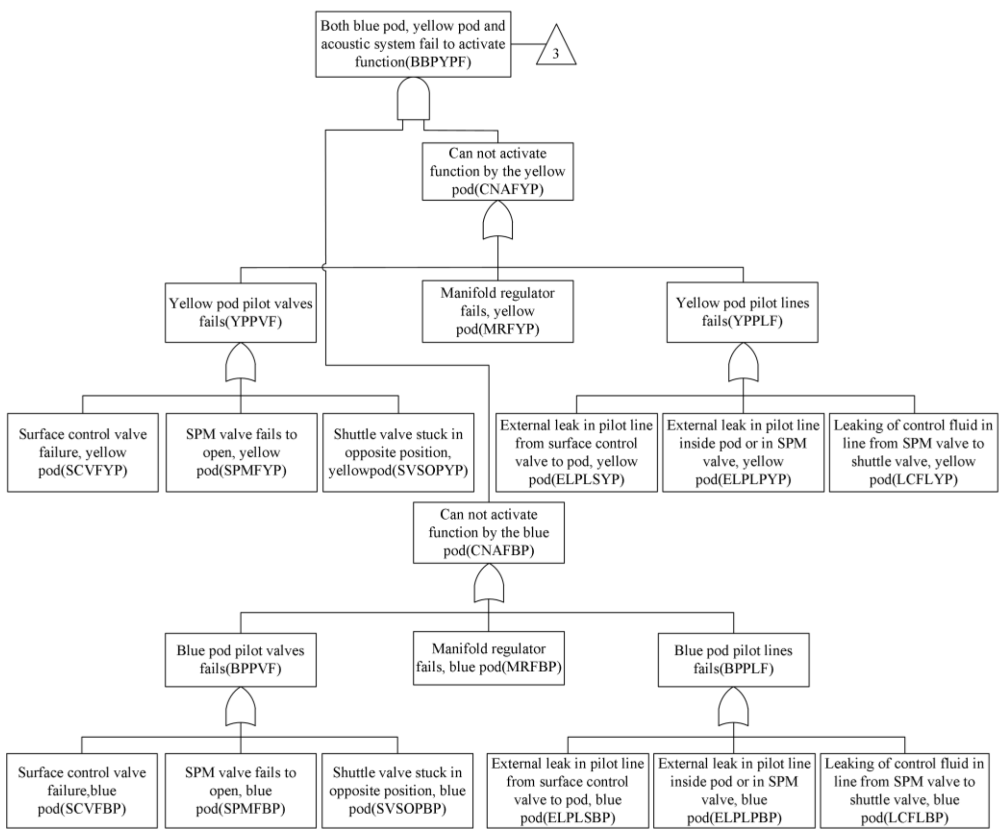

Figure 5. Fault tree of BBPYPE for subsea BOP

Production rules which has been proposed since 1972, has become the most widely used knowledge representation method in the field of artificial intelligence, especially in expert systems. The general form of production rules “IF P THEN Q”. P and Q generate a rule. P denotes the premise, condition or reasons, while Q represents the action, conclusions or consequence. It can be regarded as that when the precondition P is met, it will lead to the conclusion Q. In addition to the deterministic production rules above, there is another kind of knowledge representation called uncertain production rules with the credibility. Its basic form is the expansion of the former formula “IF P THEN Q (credibility)”. It means if the condition P occurs, then the conclusion Q may occur with some certain credibility. Production system consists of the following three parts: rule base, comprehensive database and reasoning structure. This paper chooses production representation for the knowledge in the expert system.

The principle of knowledge database establishment is to make the expression of knowledge clear, logical, convenient for reasoning and easy to maintain. Access 2007 is employed to develop the knowledge database of the fault diagnosis expert system for subsea BOP system. The process to establish knowledge base is to convert the information of fault tree into the rules of expert system. Based on the definition of top event, intermediate event and basic event in fault tree, conclusions can be drawn that blowout is top event and the bottom events are basic event. The other events are intermediate events. Branches in fault tree correspond to rules. Thus according to the representation method, take the main fault tree in Figure 2 as an example, the rules extracted from the fault tree as follows:

Rule 01: IF Blowout

Then Local failure in Lower Pipe Ram or associated control system equipment

Rule 02: IF Blowout

Then Blowout through the BOP stack, the choke line or the kill line

Rule 03: IF Local failure in Lower Pipe Ram or associated control system equipment

Then Control system is not operative

Rule 04: IF Local failure in Lower Pipe Ram or associated control system equipment

Then Local failure in Lower Pipe Ram

Rule 05: IF Local failure in Lower Pipe Ram or associated control system equipment

Then Blue pod, yellow pod and acoustic system fail to activate function

Rule 06: IF Local failure in Lower Pipe Ram

Then Preventer internal leakage or fail to close

Rule 07: IF Local failure in Lower Pipe Ram

Then Preventer internal hydraulic failure

Rule 08: IF Local failure in Lower Pipe Ram

Then Shuttle valve to preventer leaks external

According to the rules above, a knowledge database of an expert system is established by Access 2007. Rule fact sheet includes all the facts and their codes in fault tree. First, list all the facts in fault tree, and then number them according to their layers regularly. For example, the code of top fact is T and the code of intermediate fact is led by E, while the basic fact is X.

Rule condition sheet includes rule codes and condition codes. Based on the rules of extracted from the fault tree, the rule conditions and consequences are obtained. Besides, all the conditions and consequences are numbered. Rule fact sheet, rule condition sheet and rule consequence sheet establish a one-to-one correspondence.

2.2. Inference engine

This system uses a forward reasoning method. The solving process of this inference engine is a dynamic (comprehensive) process from database to the end of reasoning. First, the initial fact is stored in database, and then the rule conditions are searched according to certain control strategies. Enable this rule and get a rule consequence. The consequence or fact is added into the dynamic database to update it. Continue this process until getting a conclusion can't reason. In this paper, a few rules are analyzed to illustrate the inference engine's actual work process. Figure 6 shows the summary rules of the knowledge base.

Rule code	Condition	Consequence
R01	T Blowout	E04 Local failure in low ram preventer or assoclated control system equipment
R02	T Blowout	E01 Subsea blowout via the main BOP stack, the chock line, or the kill line
R03	E04 Local failure in low ram preventer or assoclated control system	E02 The control system is not opetative
R04	E04 Local failure in low ram preventer or assoclated control system	E05 Local failure in lower ram preventer
R05	E04 Local failure in low ram preventer or assoclated control system	E03 Both blue pod, yellow pod and acoustil fall to activate function
R06	E05 Local failure in lower ram preventer	X01 LPR,Preventer internal leakage,or fail to close
R07	E05 Local failure in lower ram preventer	X02 Preventer internal hydraulic failure
R08	E05 Local failure in lower ram preventer	X03 Shuttle valve or line to preventer leaks external
R09	E01 Subsea blowout via the main BOP stack, the chock line, or the k	E06 Leakage through main BOP stack
R10	E01 Subsea blowout via the main BOP stack, the chock line, or the k	E07 Leakage through choke or kill line
R11	E06 Leakage through main BOP stack	X04 Leakage in wellhead connectry
R12	E06 Leakage through main BOP stack	X05 Leakage in lower pipe ram
R13	E06 Leakage through main BOP stack	X06 Leakage in clamp connection between wellhead connector and lower pipe ram
R14	E07 Leakage through choke or kill line	E08 Leakage through choke line after the lower inner choke valve
R15	E07 Leakage through choke or kill line	X09 Leakage through lower inner choke valve
R16	E08 Leakage through choke line after the lower inner choke valve	E09 Blowout via a failed choke line
R17	E08 Leakage through choke line after the lower inner choke valve	E10 Blowout via lower outer choke valve
R18	E09 Blowout via a failed choke line	X07 Choke line leaks to sea and the LOC failsafe valve leaks internally
R19	E10 Blowout via lower outer choke valve	X08 Lower outer choke valve leaks to sea and the LIC failsafe leaks internally
R20	E02 The control system is not opetative	E11 Leakage out in the accumulator area
R21	E02 The control system is not opetative	X11 Severe leakage in pod selector valve that causes both pod supply lines to loos
R22	E02 The control system is not opetative	E12 Combination of failures that will cause no supply of hydraulic fluid for both
R23	E11 Leakage out in the accumulator area	X10 Sever leak through the stack mounted accumulator valve,External leakage in sub
R24	E13 Leakage in both mounted isolator valves	X12 Leakage in pod mounted isolator valve for yellow pod and leakage in pod mounte
R25	E12 Combination of failures that will cause no supply of hydraulic	X31 Major blue pod failure and major yellow pod failure,please find the causes
R26	E14 Major blue pod failure	X13 Fails to select blue pod
R27	E14 Major blue pod failure	X14 External leakage in blue control fluid hose,associated equipment or and supple
R28	E15 Major yellow pod failure	X15 Fails to select yellow pod
R29	E15 Major yellow pod failure	X16 External leakage in yellow control fluid hose,associated equipment or any supp
R30	E03 Both blue pod, yellow pod and acoustil fall to activate functio	X32 Can not activate function by the yellow pod and can not activate function by t

Figure 6. Summary rules of the knowledge base

Some trouble shooting rules are listed above, including rule codes, rule conditions and rule consequences. Assume the input fault code be *E04 Local failure in Lower Pipe Ram or associated control system equipment*，the reasoning process is as follows.

(1) Import E04 *Local failure in Lower Pipe Ram or associated control system equipment* into the dynamic database.

(2) Expert system would traversal the rule condition sheet according to the information in dynamic database. If any rule condition matches the fact, this rule will be activated. Rules conditions that match with E04 are R03, R04, R05.

(3) According to rule codes R03, R04, R05 in rule consequence sheet, the rule consequences are E02, E03, E05. Store these three rule consequences in the dynamic database and then regard them as the rule conditions for the next inference. Similarly, rule consequences R06, R07, R08, R20, R21, R22, R30 are obtained based on E02, E03, E05. According to these rule code, rule consequences X01, X02, X03, E11, X11, E12, X32 can be found in the sheet.

(4) Like step (3), store these rule consequences in the dynamic database, and then regard them as rule condition for the next inference. The codes led by X are basic events without

rule conditions. So, X01, X02, X03, X03, X32 are the final conclusions. But E11, E12 correspond to rule R23, R25.

(5) According to the rule code R23, R25, X10, X31 can be found in the rule consequence t sheet. Until now, all the inference process ends. The final conclusions are X01, X02, X03, X32, X10, X31.

3. The Realization of BOP Fault Diagnosis Expert System

3.1. The selection of development tools of expert system

In order to make the expert system supply a good man-machine conversation, Visual C++ 6.0 is used as the main developing tools to develop an easily operated, convenient, and friendly interface for the fault diagnosis expert system.

ADO (ActiveX Data Object) is a kind of data access technology based on OLE DB technology, which has the advantages of high speed access and the ability to access different databases. Before using ADO to access database, three important objects must be paid attention to, namely connection subject, command subject and recordset subject.

The first step to access database through ADO in VC is to import the ADO library. In this program, adding the following code: *#import "C:\Program Files\Common Files\System\ ado\ msado15.dll" no_namespace rename ("EOF","rsEOF")* in ADO compilation header file, then *msado15.dll* dynamic link library is imported into VC++. The second step is to initialize COM library using *AfxOleInit()* in MFC environment and *CoInitialize(NULL)*, *CoUninitialize()* in NON-MFC environment to achieve this function. The next step is using *Open ()* and *Execute ()* and the other functions for specific operations.

3.2. The introduction of the interface for BOP fault diagnosis expert system

The main interface includes knowledge database management, fault diagnosis and system introduction menus and their toolbars. The main window is created by MFC AppWizard (exe) in Visual C++ 6.0. Besides, a bitmap is added to the main window as shown in Figure 7.

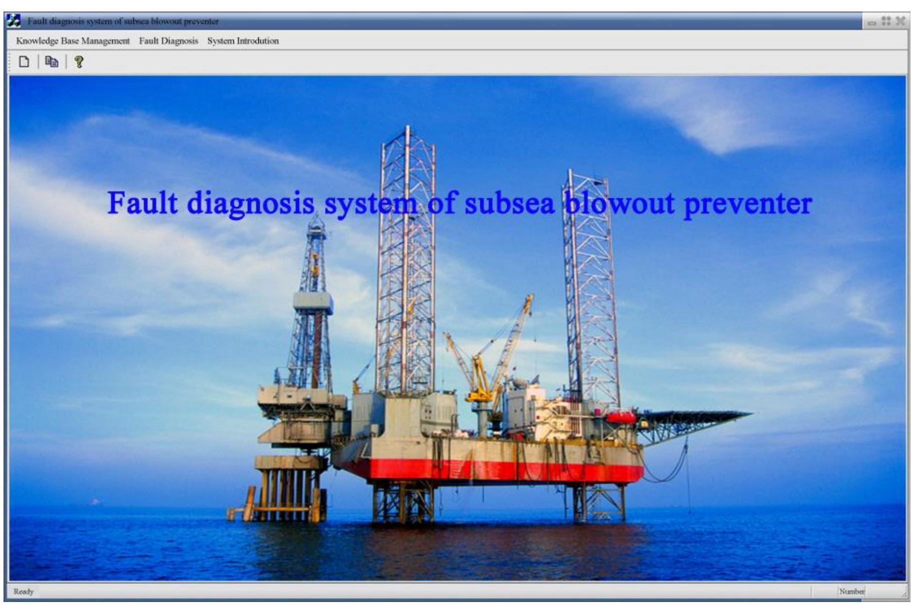

Figure 7. The main interface of BOP fault diagnosis expert system

Click the fault diagnosis menu bar and keyword searching interface will pop up. Seven keywords are listed to represent the intermediate events in fault tree after summarizing the rule facts. All the faults are divided into seven categories, namely control system, choke line, blue pod, yellow pod, BOP stack, isolated valves and accumulators. If "control system" is chosen as the keyword, symptom dialog will appear, as shown in Figure 8.

The system will search the matching symptom in rule fact database when the users select a keyword. The users can select a symptom displayed in list box for the next step. If no symptoms are selected, a dialog will appear for reminder. For example, *"E04 Local failure in Lower Pipe Ram or associated control system equipment"* is selected as a symptom and "The selected fault" dialog box will appear after clicking the "select" button, as shown in Figure 9.

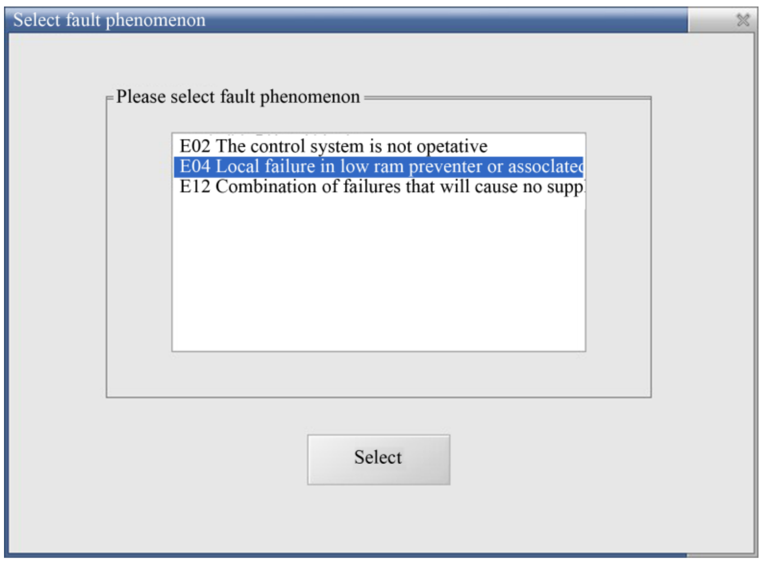

Figure 8. "Select fault phenomenon" dialog box

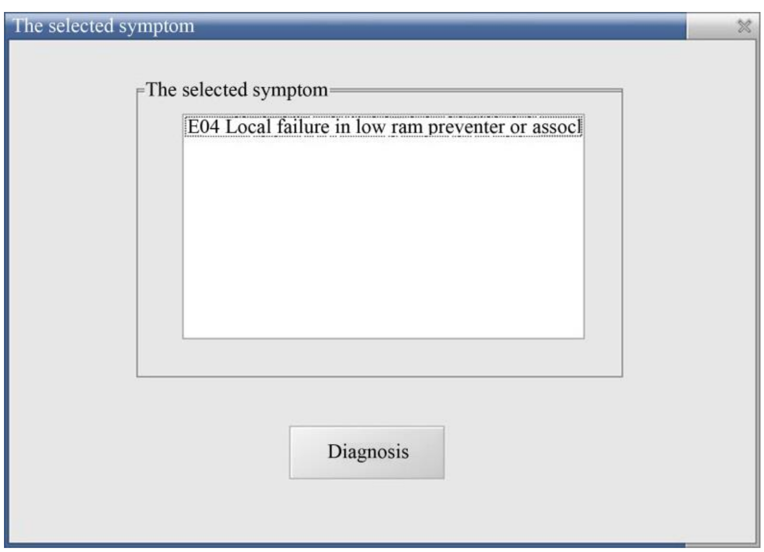

Figure 9. "The selected symptom" dialog box

This dialog box is used to display the fault we select in last dialog box. The system can get a diagnosis result after users selecting a symptom as the initial evidence. Click "diagnosis" button and "diagnostic results display" dialog box will appear. For example, the possible diagnoses results of symptom "*E04 Local failure in Lower Pipe Ram or associated control system equipment*" are X01, X02, X03, X10, X11, X31and X32, as shown in Figure 10.

Figure 11 shows that the management interface can display, add, delete and update the rules. Click "adding rule" button and its dialog box will pop up. Adding rules is the main method to enrich the knowledge database of expert system and it plays an important rule. The users fill in specific rule codes, rule conditions and rule consequences before clicking "adding" button. Clicking "delete" button in the main interface will delete the new added rule. Along with adding function, the rules can be added accurately and conveniently. The rules sheet will change after adding or deleting. The system will update the rules in knowledge database and display the latest rule in main interface after clicking "Renew" button.

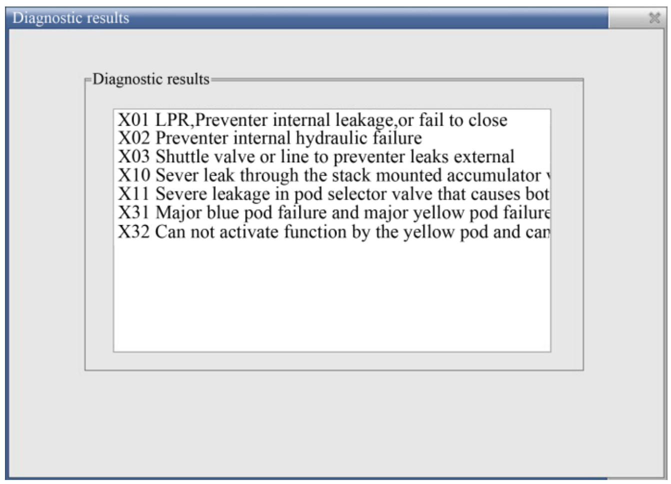

Figure 10. "Diagnostic results display" dialog box

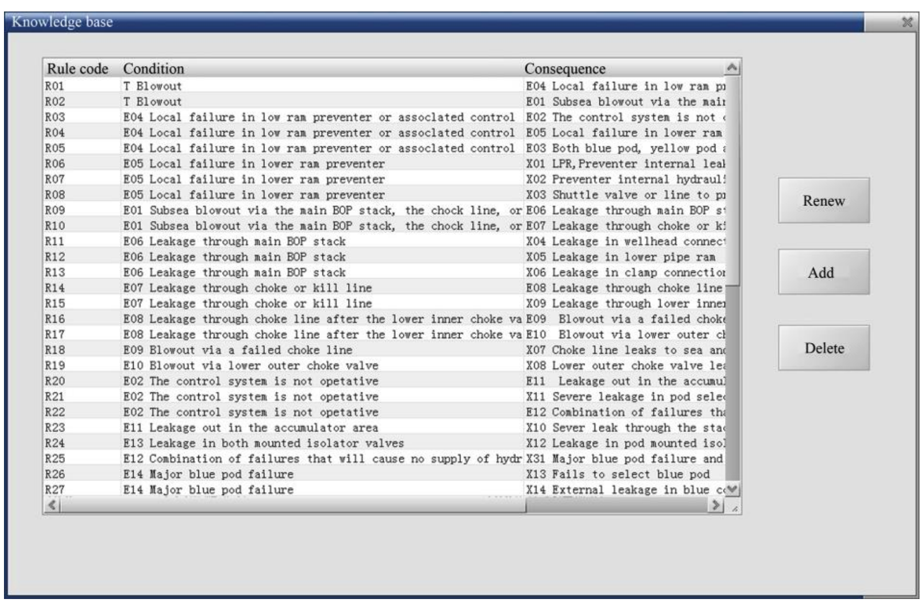

Figure 11. "Display knowledge base" dialog box

4. Conclusion

The interfaces of expert system are developed by Visual C++6.0 and knowledge base is built by Access 2007 with ADO data accessing technology. Finally, the expert system for fault diagnosis of BOP is developed successfully and the conclusions are as follows.

(1) An expert system for faults diagnosis of subsea BOP has been developed. According to the expert knowledge, common faults could be diagnosed and the system will be enlarged with the increasing knowledge.

(2) Fault tree analysis method is used to extract fault diagnosis information. By this way, the layers of faults and the logical relationship among them can be shown clearly.

(3) Production rules are employed to represent the knowledge extracted from layers of fault trees. It's convenient for users to understand the knowledge that are connected together through its logic.

(4) The developed interfaces are friendly and easy to operate. The users can learn to use the system according to the one by one prompt and query the failure causes easily.

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