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Using an expert system for the solution of operational failures in sludge pumps in oil well drilling equipment

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Abstract
It has been developed and we proposed to implement an expert system that acts as a permanent technical assistant that contains a knowledge base, a bank of solutions and a history of failures, which allows to solve the failures that occur in the sludge pumps, when the machinery, that form the drilling equipment, is working. We estimated that the system can reduce the downtime, caused by failure, using the advantages offered by this branch of artificial intelligence that simulates the process of learning, memorization, reasoning, communication and action to solve problems; binary trees being the main data structure that was implemented. We estimate that the training time, for the handling of the expert system, is near to eight hours for personnel related to sludge pumps. In particular, the solution of a fault such as the loss of communication with the J box, the expert system would be solved in approximately 60min, while in the traditional way it could take up to four hours, depending on the availability of the specialist in charge of the drilling area. Therefore, the saving in solution time, restart and, therefore, economic resources is highly significant.

Keywords: Expert system, failures in sludge pumps, drilling equipment, binary trees

Introduction

In Mexico, oil exploration and exploitation work has made it possible to evaluate geological formations and achieve the elaboration of the geological map of the country. Almost all the areas that currently produce hydrocarbons are located in the coastal plain and on the continental shelf of the Gulf of Mexico, on a strip that extends from the border of the United States to the western margin of the Yucatan Peninsula and from the front of the Sierra Madre Oriental to the continental shelf of the Gulf of Mexico [1]. Drilling objectives to the oil extraction is to build an useful oil well, that is, a conduit from the oil reservoir to the surface that allows its rational exploitation in a safe, environmentally friendly and at the lowest possible cost. The main components of the drilling equipment are, the sludge tanks, sludge pumps, the drilling tower, the winch, the rotary table, the drill string, the power generation equipment, and the auxiliary equipment. The drilling equipment is sometimes referred to as a "drilling package", particularly in marine areas [2]. The design of a well oil includes a detailed drilling program with the following features: safety during operation for both personnel and equipment, minimizing damage to the environment and, at minimal cost [3, 4].

Technological advances are increasingly and, are used more and more in different areas in the oil industry. It needs the support of several disciplines, especially those that involve data processing, process automation and, environmental data collection among others. Therefore, computational techniques involving artificial intelligence which, has been widely used in various fields of knowledge, are today part of solutions to problems in that industry [5]. In this search to speed up and possess high levels of precision in the identification of different failures in the drilling equipment (detecting a damage, can require a lot of time, precision in the diagnosis and a lot of expertise on the part of the personnel who are diagnosing), the need to make use of external methods becomes indisputable such as, Artificial Intelligence, for fault diagnosis. It is useful, successful, and convenient to recognize patterns to treat these cases. Artificial Intelligence (AI) methods are the most important motivation to approximate human behavior and thinking to different systems to obtain the solution to some problems [6].

On the other hand, the expert system is an intelligent computing program that uses knowledge and inference procedures to solve problems that, are difficult and require significant human expertise for their solution. The inference engine, in charge of providing reasoning to Expert Systems, which is the principle of Artificial Intelligence [7], is part of the development of the decision-making system of this work. In general, an expert system is formed by a knowledge base, an inference engine, and a user interaction block. The knowledge base is where the knowledge of the human expert it remains [8], and organized through decision rules, as well as a fact base that is a unit of auxiliary memory that contains the specific data of the situation to be analyzed. The inference engine, is a unit of the software which is responsible for using the knowledge hosted in the database to infer conclusions according the problem posed using backward or forward chaining methods to relate input situations and feasible solutions, or vic [9].

Finally, the user interface is a component that facilitates interaction between the expert system and the user through questions according to the written conversation pattern between human beings. So the main objective of an expert system is to simulate, using software, the reasoning of an expert in a specific area to obtain conclusions or advice that guide the decision-making process for the solution of a complex problem [10, 11]. On the other hand, a decision tree is a graph that uses the branching method as a tool to determine the best path within decision-making, especially when there are several alternatives that could lead to different solutions [12]. Thus, the tree-shaped diagram exhibits the structure of a particular decision, in addition to its correlation with other possible options, and decisions, considering them as classifiers. These classifiers are composed of test nodes, where decisions are makes, and leaf nodes, where the most accurate final value reached through the decision flow, is expressed. Because they divide the space of instances (cases), recursively, into small sets or classes according to a discrimination criterion improving the diagnosis, and solution of drilling equipment failures [13]. In the first version of this system, only the failures that occur in the sludge pumps are contemplated, that is, the knowledge base will be reduced to only one component, however, when the knowledge is expanded to cover the other components of a drilling equipment, the user interfaces and the inference engine will not undergo changes. This system would be supporting to solve the failures that commonly occur in sludge pumps and in whose solutions, patterns that allow their diagnosis and solution were recognized. Among the most frequent failures are band breakage, loss of communication of the J box with the control center in PCR (Power Control Room), the elevated temperature in the motor winding of the sludge pump, the loss of the blower in its motors, the high temperature in the bearings, the loss of body lubrication of the sludge pump, to name a few.

Materials and methods

To detect and classify failures in sludge pumps, we develop a comprehensive system as support for decision-making in the solutions of some failures in the drilling equipment; formed by an expert system of specific use [14, 15]. The expert system can be run on any computer with the minimum requirements, which has the installation of JRE version 8, or higher, with Windows, MacOs or Linux operating system. The Net beans IDE was used as a development tool in its version 12.0 using dialog boxes of the Swing category that are window model containers which typically used for user interfaces enriched with elements such as Combobox, Textbox, Button, Menus, multimedia modules, etc. A database was deployed in MySql server 8.0. The knowledge base was stocked with both formal and heuristic knowledge. Formal knowledge is that which is documented, it is said that it is a tangible knowledge to which we can resort and consult when will be necessary. Heuristic knowledge or also called tacit, is that which comes from good practices, is subjective, and is in the minds of people [16]. The purposes of this work, the formal part the information was collected from the printed and digital operation manuals of the sludge pump [17], and for the tacit part we worked with a specialist in maintenance in drilling equipment with more than 15 year experiences in the field, to solve the failures that occur in a sludge pump. To represent the heuristic knowledge, there are several techniques; among the most prominent are production rules, semantic networks and flowcharts [18]. In this research, the production rules will be chosen for its ease understanding by the maintenance manager. Enough knowledge was collected and stored in the database to solve a total of 35 different faults, which can occur during drilling process. For the development of the inference engine and user interfaces, the Model View Controller or MVC architecture was used, which separates in layers the development in a software: the model, the view and the controller. In such way, that the interfaces of the expert system will be implemented in the view layer, the inference engine will be programmed in the controller layer, and the database in the model layer.

Results & Discussion

In the petroleum sector, as the case we address for drilling equipment, unfortunately knowledge is often scattered in operational paper logs, individual notes, in manuals that have been enriched with empirical notes, files or isolated procedures browsing the network and that make its use complicated when a consultation is required. In other cases, knowledge is stored in specialist memory, and the employment status of them causes to swap in various areas of the company, taking their experience with them and the effectiveness in the work is violated, which can bring great losses of time and money for the company. In order to avoid these problems, an intelligent software was developed, including design of tables where the most common failures in a sludge pump are included. Fig 1, shows the Fault Table and detailed all attributes of that entity including the name of the fault, the component that failed, and the initial node or root of the binary tree that will be used as starting point to find the possible solution to the failure. In this way, the set of all the internal nodes and leaf nodes that will be used to form the body of the search tree is stored. Other tables were incorporated that support the management of the expert system, such as the connection to the database, failure report, and finally, the one used for user administration. For the above, an Entity-Relationship (ER) model was implemented with many-to-many relationships to ensure that the system supports various failures and that each of these has several nodes that guarantee the solution to the problem.

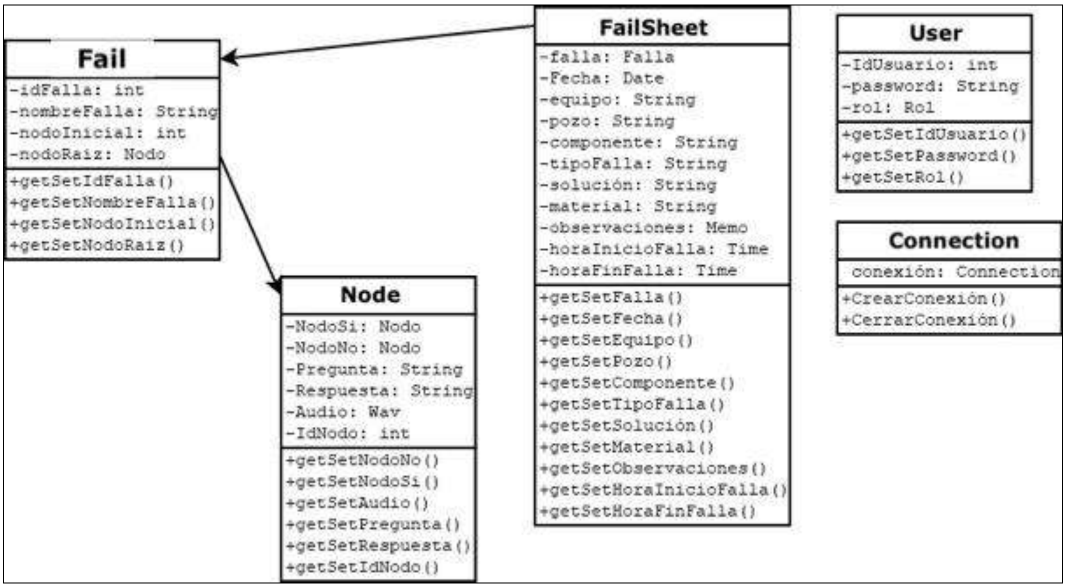

Fig 1: Expert System Database

Deductive reasoning was the method used for the development of this research. Deductive or data driven reasoning (also called forward-chained reasoning) consists of linking knowledge from the use of data (facts or properties of the entity) in order to obtain the solution of a problem. In this work, the entity is the sludge pump, the facts is part of the operation of the component, and its state will be the fault it presents. Binary trees were used to simulate reasoning and information modeling where the decision process starts at the bottom, which identifies the most noticeable traits, the more specific details that require closer observation are used as we climb the tree [19]. That is, the more general sets of alternatives are examined first, and then the decision process begins to reduce their odds to smaller groups. In drilling equipment, there is a dashboard with a fault notification system, which displays a fault notification code; this information will be the root of the binary tree that will be built for the search in the solution. In the graphical interface of the expert system, all the faults that the drilling equipment notification system has will be displayed on buttons so that the user can select one and begin the technical assistance of the software. The inference engine is responsible to build the binary tree and then the path to follow, so that when entering the first node we find a Boolean condition, with two possible options (yes or no), where half of the possibilities are discarded at each level, until reaching the leaves of the tree where the possible solution to the operational incidence is found [20]. If the fault is, Loss of communication of the J box with *PCR*, its searches in the database for that fault to build the root of the tree (Fig 2). With this node, as a starting point, the tree will be created, where each node contains an identifier, a Boolean question, a left child node for when the answer to the condition is negative, and equipment node for an affirmative answer. The left node and the equipment node in turn will have their two children, left and equipment, who will be linked by the identifier, and who track their path respectively.

```java
public Nodo createNode(String question, int id){
    Nodo nodo= new Nodo();
    nodo.setId(id);
    nodo.setQuestion(question);
    nodo.setNodoNo(null);
    nodo.setNodoYes(null);
    return nodo;
}
```

```java
public Nodo createRoot(Connection conn, Fail fail){
  try {
      PreparedStatement consulta=conn.prepareStatement("Select * from n
          + fail.getNodoInicial() + " and idFalla=" + fail.getIdFal
      ResultSet resultado=consulta.executeQuery();
      if(resultado.first()){
          nodo=new Nodo();
          nodo.setId(resultado.getInt(2));
          nodo.setQuestion(resultado.getString(3));
          nodo.setAnswer(resultado.getString(4));
          nodo.setAudio(resultado.getString(5));
      }
      conn.close();
  } catch (SQLException ex) {JOptionPane.showMessageDialog(null,ex.toSt
  return nodo;
}
```

Fig 2: Creating trees and leaves in the expert system

After branching the root node, and choosing the path of the tree that leads to the next node based on the value of the parent node, this process is repeated as long as there are variables to be queried and a terminal leaf node has not been reached. Once the end of the tree is reached, the leaf node has the information regarding the route that has led to it and the corresponding action decision. The decision on entry conditions is a written message implemented using the pathing method as shown in Fig 3.

```
public String pathing(Nodo raiz) throws Exception {
    Nodo path=raiz;
    int steps=1;
    int answer=3;
    String question, acumulado="";
    while(path!=null){
        acumulado+="Step " + steps + ": ";
        question=path.getQuestion();
        acumulado+=question.replace('\n', ' ') + "\n";
        audio.play(path.getAudio());
        if(path.getNodoNo()==null && path.getNodoYes()==null){
            question=question.replace('\n','\n');
            JOptionPane.showMessageDialog(null,question, "Paso "+ steps, 1);
        }
        else{
            question=question.replace('\n', '\n');
            answer= JOptionPane.showConfirmDialog(null,question, "Paso "+ steps, 0);
        }

        if(answer==0){
                path=path.getNodoYes();
                acumulado+="Si\n";
            }
        else if(answer==1){
                path=path.getNodoNo();
                acumulado+="No\n";
            }

        steps++;
    }
    return acumulado;
```

Fig 3: Pathing method for tree traversal

The way the expert system interacts with the user is through the interfaces, which were implemented to guide the user to find the solution to the fault that has been presented to him. The system has authentication to determine the role of the user: administrator, expert, and user, to provide security and privileges. A display will allow the user to enter the fault diagnosis module or consult the electrical and control diagrams of the sludge pump. The fault diagnosis module was made up of a cluster of buttons with the set of all possible faults that the expert system can detect and, in turn, lead to a solution (see Fig 4).

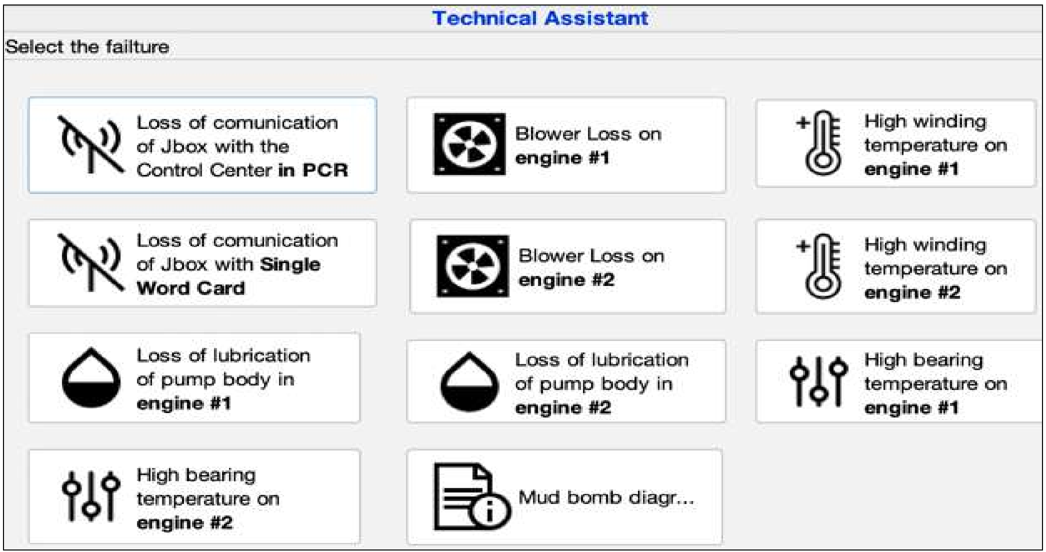

Fig 4: Sludge Pump Fault Catalog

Once the incident in the fault catalog has been identified, the inference engine of the expert system begins to run, going through the binary search tree through questions that will be presented in the form of dialog boxes with only two possible options, Yes or No. The entire diagnostic procedure will be stored and displayed in a j Text Area. When you reach the end of a road, the actions that the operator must follow to solve the fault, will be shown in another dialog box. In Fig. 5, an example of the final path for the failure loss of communication of the J box with the control center in the PCR is shown; the action to be performed indicates adjusting the connection and performing new tests.

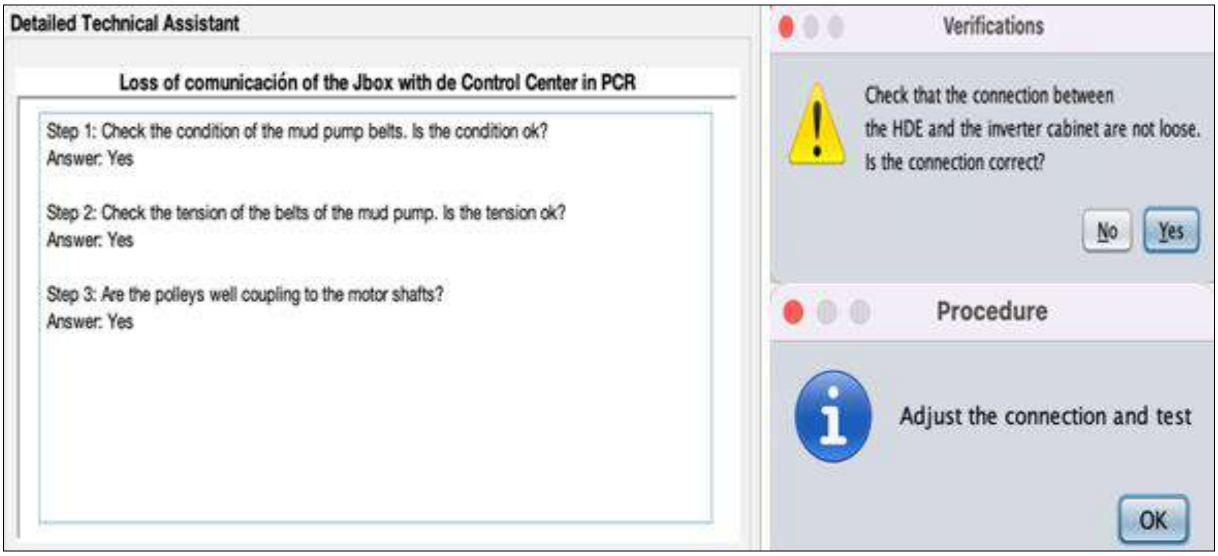

Fig 5: Detailed technical assistant

The expert system has a multimedia resource that allows the user to listen the messages shown in the dialog boxes, both the verification questions and the actions, in order to achieve a more reliable interaction with the user. Finally, the system will ask if the fault was fixed. If so, the "Fault Sheet" window will open that captures and displays information related to the fault resolution process such as the refurbishment that was required, the oil well number, the drilling equipment, the time it took to recover and restart the sludge pump, as well as observations by the user. If the expert system has not found the solution to that failure, the procedure followed by the user will be stored in a report that will be sent to the specialist engineer to feed the knowledge base and the factual base, so that when that failure occurs for the second time, the expert system has new information that makes it capable of solving it. Through this procedure, feedback will be made to the expert system which will allow you to have a broader database, to cover solutions to more failures that may occur in the sludge pump.

Discussion

The Expert System is in experimental stage, and contains the most common faults (35 in total) that can occur in the sludge pump of drilling equipment. The expert system does not learn alone, as artificial intelligence does, however it has a learning module that runs when a failure occurs, and the expert system does not lead the user to the solution of it. The lack of information is analyzed, assessed, and validated by the engineer specializing in drilling equipment who decides if the software should learn from the incident, taking into account the relevance of the new knowledge generated, or only places an informative note. The rate of increase in the number of failures is low because drilling equipment have a service life of at least 10 years, the solution techniques applied do not change, and the technology applied in this area has a minimum change factor. The expert system pretends to be intuitive so, the training time required for its use estimated is near to 8 hours (for any personnel involved in the drilling equipment), the software would be available on a personal computer in the engine room which is where the board with the failure warnings of the drilling equipment is located.

Conclusions

The operational incidents consulted in the developed software are failures recorded in detail, and can be used in control and management reports that lead to management decisions that optimize the operating time of the sludge pump and thereby reduce drilling costs. The big advantage offered by this expert system is the time in which a fault is solved. Nowadays, a specialist engineer in Mexico, is the supervisor of several drilling equipment that are located in different locations, in some cases nearby, in others the distance can be considerable (up to 100 km). The latency time, once the failure occurs until the specialist arrives, depends largely on its availability and the time it takes to reach the drilling well. Meanwhile, the expert system would begin to find the fault immediately after it occurs, needing only a technician familiar with the use of the software, who is permanently on location, to follow the steps indicated by the expert system; in this way, it would pre-empt the settlement process.

The software developed, with the aforementioned techniques, offers security in the execution of the same for the solution of a detected fault since the creation of a tree and its respective nodes, ensures a reliable route to solve certain problems that occurs in the sludge pump. Relationship Entity management allows the possibility of including many failures and relating them to many solutions. In such a way, the system is not limited to the 35 failures mentioned here, but others can be implemented. There is also a module that allows feedback to the expert system, with the intention to make it more robust in this case the sludge pump specialist will validate if it is necessary to introduce new information to the expert system or simply place a warning note. We estimated that, the implementation of the expert system in the control room could help to considerably reduce the latency time of restarting the sludge pump and thereby generate a significant decrease in the costs of drilling the oil well that is being working. In general, when a failure occurs such as the loss of communication with the Jbox, we estimate, the failure is solved on average in about four hours (including the detection of the fault, as well as transfer times of the specialist), in a traditional way. If we use the proposed expert system, the solution could be reached in about 60min; this represents a considerably shorter time than the traditional time expected (until 2hrs) for the restart of the pump. For this reason, developing an expert software is of great help to the oil industry since it allows you to solve specific problems in relatively short times, which translates into a considerable saving of both time and economic resources.

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