Research on Rotary Dump Health Monitoring Expert System Based on Causality Diagram Theory

Liu Quan
School of Information Engineering
Wuhan University of Technology
Wuhan, China
qliu@whut.edu.cn

Li Jingsong
School of Information Engineering
Wuhan University of Technology
Wuhan, China
jingsongtree@163.com

***Abstract*—Causality diagram theory is a kind of uncertainty reasoning theory based on the belief network. It expresses the knowledge and causality relationship by diagrammatic form and direct causality intensity. Furthermore, it resolves the shortages of the belief network, and realizes a hybrid model which can process discrete and continuous variations. The theory of causality diagram model and the steps of causality diagram reasoning methodology are studied in this paper, and a model of rotary dump health monitoring expert system is proposed. In addition, this paper establishes the causality diagram of rotary dump and converts it to the causality tree. According to the causality tree of rotary dump, the causality diagram reasoning methodology composed of four steps is described. Finally, an application of rotary dump health monitoring expert system is shown, and the system performance analysis is discussed.**

***Keywords*—Causality Diagram, Reasoning on Uncertainty, Fault Diagnosis, Expert System.**

I. INTRODUCTION

With the development of social economy, the applications of large equipments become more and more popular. The rotary dump is a kind of high efficiency large mechanical equipments[1]. It has been implemented widely in metallurgy factories, electricity generations, chemical plants, ports, and etc. The rotary dump is one of the most complex and important equipments in the dump system, and its health has directly influence on the efficiency of dump work.

Expert system[2], which consists of computer programs integrated professional experience and knowledge to resolve problems related to the application domain, is one of the most mature and successful applications of AI (Artificial Intelligence). The expression of expert knowledge and the design of reasoning arithmetic are the core problems of expert system design. [3]

Causality Diagram (CD for short) is a new uncertainty reasoning methodology developed from the belief network. It introduces some new concepts, such as basic event, node event, logical gate and linkage event between different events into its knowledge representation. The linkage event could be represented independently so that it is more convenient for domain experts to express their knowledge than the belief network. Because of the symbol logical operation, the dynamic and online information could be included in the logic model of the application. Thus, it is very useful for the solution of multi-connectedness and cyclic causality in fault diagnoses of complex engineering system.

II. CAUSALITY DIAGRAM THEORY

A. Related work

Uncertainty knowledge representation and reasoning based on probability includes Belief Network [4], Markov Network [5], Fault tree[6], and etc. Due to the preciseness and consistence, the efficient local calculation and intuitional diagrammatic knowledge expression, the belief network model has attracted more and more attention. However, there are still some disadvantages in the belief network: (1) It can not process the structure of causality cyclic; (2) It is not intuitional that express causality with conditional probability. The data correlation is not the same with the knowledge of domain experts. Hence, it is difficult for experts to get knowledge and apply it to reality; (3) It does not consider the problems that conditional probability usually change dynamically with time.

Causality diagram (Ishikawa Kaori diagram) proposed by Ishikawa Kaori who was a professor of Tokyo University in 1953, is used to find or dispose the causes of the accidents.

Causality diagram theory proposed by Professor Zhang Qin in 1994 is one kind of knowledge expression methodology[7]. It is based on the belief network theory. It introduces Boolean logic algorithm, resolves the disadvantages in the belief network, and has some advantages as follows:

1) It can process the structure of causality cyclic. Because causality diagram expresses the relationship between domain random variants with the event probability, and there is a kind of joint probability distribution in it, so it is no restrict to the topology structure of the diagram (the Directed Acyclic Graph diagram is not necessary). In contrary, the belief network expresses the joint probability distribution between domain random variants with the diagram structure and digital components, and gives a Markov causality explanation of network. All of them determine the fact that the belief network only can be a Directed Acyclic Graph. The length of a submitted paper

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should be commensurate with the importance, or appropriate to the complexity of the work. For example, an obvious extension of previously published work might not be appropriate for publication or might be adequately treated in just a few pages.

2) It adopts directly causality intensity rather than conditional probability, avoiding the correlativity between different knowledge. In this way, it is corresponding with the knowledge structure of the domain experts, and is easy to get expert knowledge.
3) It has agility reasoning modes, not only from causes/consequence to consequence/causes (Pr{X|Causes}/ Pr{X|Consequence}), but also the hybrid of causes and consequence (Pr{X|Causes&Consequence}).

In summary, this method can simulate objectivity efficiently and get exact reasoning consequence. Meanwhile, the causality diagram model is also the basis of probable spread diagram model and fault influence spread model. It is valuable for industry applications.

B. Causality Diagram Model and Definition

Causality diagram is a kind of knowledge expression model based on probability, its knowledge expression can be denoted as follows:

C=<S,A>, and S=<X,B,G,P>[8]

The signification of the symbol as follows:

C-causality diagram model

S-causality diagram topology. It can be a directed cyclic graph, and makes up of basic event, middle event, logical gate and linkage event.

X-middle event, or middle event variant. It represents any causes events. There is no less than one input border and zero, one or many output border in the graph.

B-basic event, or basic event variant. It represents the event which is no causes or ignored causes, and the event must be the cause of a middle event. Obviously, any basic event is not the cause of another basic event, so it is dependent between different basic events. It represents as a pane node which has no input borders but no less than one output border.

G-logical gate. It is composed of the output variants according to logic calculate input variants. The mapping from input variants to output variants is a true/false table, it not only can be the relationship of and, or, not, but also be more complicated relationship. There are no less than one input border and more than one output border in the graph.

P-linkage event, or linkage event variant. It represents the father node event (the cause) induces the child node event (the consequence). When the father node event and its linkage event occur, the child node event must occur. The probability represents the causality intense between the father node and the child node in the numerical value. As a event, it is independent from the father node event, and be described by a directed border which is from a basic event, a middle event or a logic gate to a middle event.

A-parameter. It includes the prior probability of basic event and the linkage intense of linkage event.

III. Design and Application

The rotary dump is a kind of high efficient large mechanical equipments, and also the most complex and important equipment in the dump system. It bears high load, working in the complex condition and bad surroundings. So it usually has some problems, such as local cracks and weld fault, all of the problems have obvious influence on its normal work. According to the theory of 'replace pre-maintenance based on time with advanced predictive maintenance' [9], in order to realize the predictive maintenance, the expert system should be established to monitor the state of the rotary dump.

The rotary dump health monitoring expert system is composed of three main components: sensor unit, signal process unit, and expert system unit. In sensor unit, all of the sensors monitor the stress change. Signal process unit processes and analyses all of the data. Expert system unit builds the causality model and diagnose the faults according to domain expert knowledge.

Causality Diagram Reasoning Methodology

There are many parts easily to go fault in the rotary dump, such as platform crossbeam, up staff, down staff, U crossbeam, front ring, rear ring. Sensors are disposed on different position to monitor the stress change. We take platform crossbeam example for illustrating the establishing of causality model and reasoning: X1, X2, X3, X4 represent the middle event of left up plank of platform crossbeam fault, left down plank of platform crossbeam fault, right plank of platform crossbeam fault, middle platform crossbeam fault. B7, B8, B9, B10 represent basic event of left up plank of platform crossbeam fault, left down plank of platform crossbeam fault, right plank of platform crossbeam fault, middle platform crossbeam fault. According to the causality theory, we establish the causality model of platform crossbeam as Figure1.

According to causality reasoning methodology, we take 4 steps as follows:

1) Find out the first order cut set expression of the node event

One node event has m directed boarder point to itself, then the node event could spread no less than m cut sets. Cut set (CS for short) is a group of events which be composed of logic and calculation. The relation between each CS is logic or. It is called the first order CS which consisting only the neighbor event of the node event (CSs-1 for short).

In order to get CSs-1 of the node event, we should change the causality diagram to the causality trees. Then we can write down the logic expression of the causality tree's root node. The causality tree of platform crossbeam is illustrated as Figure2. And the expressions are shown as follows:

$X1=B7 \cup P21\ X2$

$X2=B8 \cup P12\ X1 \cup P32\ X3$

$X3=B9 \cup P23\ X2$

$X4=B10 \cup P14\ X1$

X5=B11∪P64 G6= B11∪P64(X2∪X4)

In the equations, G6 is or gate, G6=X2∪X4.

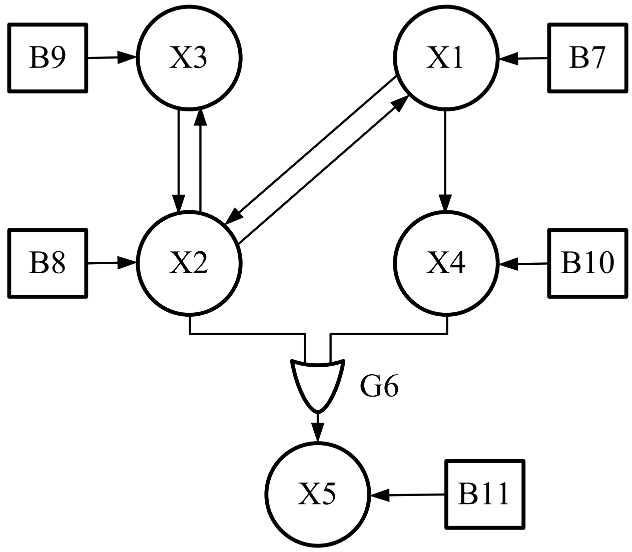

Figure 1. Causality diagram of platform crossbeam

2) Find out the final cut set expressions of node event.

It is final cut set which is only composed of basic events and joint events (CSs-f for short). We could spread the CSs-1 expression, expurgate all the node events, and get the final cut set. In the process of spreading, we should untie the cycles as rules.

The untie cycle rule: One node event can’t be its cause at the same time. When the causality cycle occurs, it should be truncated in the repeat node. The other CS expression is considered as null.

The CSs-f expressions of each node are shown as follows:

X1=B7∪P21 B8

X2=B8∪P12 B7∪P32 B9

X3=B9∪P23 (B8∪P12 B7∪P32 B9)

= B9∪P23 B8∪P23 P12 B7∪P23 P32 B9

X4=B10∪P14(B7∪P21 B8)

= B10∪P14 B7∪P14 P21 B8

X5=B11∪P64 G6= B11∪P64(X2∪X4)

= B11∪P64(B8∪P12 B7∪P32 B9∪B10∪P14 B7∪P14 P21 B8)

3) Calculate the Disjoint cut sets expressions of node event (DCSs-f for short)

The CSs-f expressions of one node event X could be expressed as:

$X=\bigcup_{i=1}^{m} C_i$, $C_i=\bigcap_{j=1}^{n_i} V_{ij}$, C_i is one CS, then the DCSs-f expression of X is

$$X = C_1 + C_2\overline{C_1} + C_3\overline{C_1 C_2} + \cdots + C_m\overline{C_1 C_2}\cdots\overline{C_{m-1}}$$

In the equation, ‘+’ represents or operator.

4) Calculate posteriori probability (Pr{H|E}) of interesting events in the condition of the given evidence.

The given evidence is that observe some node events or basic events occur. E is the evidence set, $E = E_1 \bigcap E_2 \bigcap \cdots \bigcap E_K$, K is the amount of received evidence. H is the event to be check. H , E_1,…, E_K are basic events or middle events.

According to Bayesian equation:

$$\Pr\{H \mid \mathrm{E}\} = \frac{\Pr\{HE\}}{\Pr\{E\}} = \frac{\Pr\{H \bigcap A\}}{\Pr\{E\}}$$

$$= \frac{\Pr\{H \bigcap E_1 \bigcap \cdots \bigcap E_k\}}{\Pr\{E_1 \bigcap \cdots \bigcap E_k\}}$$

Calculating Prior Probability of evidence E and HE is needed. According to logic and calculation with every evidence event include in E, we can get the DCSs-f expression of evidence E. In the same way, we can get the DCSs-f expression of evidence HE by and calculator between the DCSs-f expression of E and the DCSs-f expression of H. Finally, we get posteriori probability (Pr{H|E}) by instead with Prior Probability of each basic event and joint event.

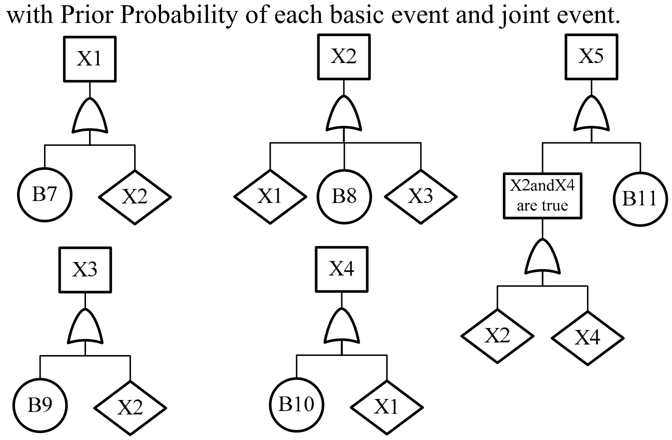

Figure 2. Causality trees of platform crossbeam

Main Interfaces of System

The main interfaces of the rotary dump health monitoring expert system are shown in Figure3. Picture 1(top and left) is the main form. Picture 2(top and right) is the monitor curve form. Picture 3(bottom and left) is the expert knowledge base form. Picture 4(bottom and right) is the fault diagnosing form.

There are many sensors on the rotary dump. It is shown in the main form (Picture 1). According to the sensors, the real data including stress and temperature are collected.

The monitor curve is shown in the monitor curve form (Picture 2). Each monitor node curve is clearly shown in this form.

The knowledge database is modified in the expert knowledge base setting form (Picture 3).

Once the fault takes place, it is analyzed by the Causality Diagram. The fault diagnose result is shown in the Picture 4.

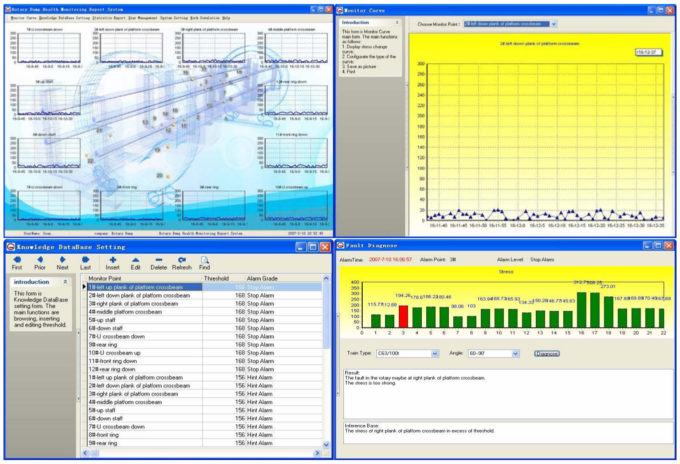

Figure 3. The main interfaces of the rotary dump health monitoring expert system

IV. ANALYSIS

Causality diagram is one kind of probability reasoning model, the reason consequence presents as a form of probability. It resolves some problems of the belief network and the fault tree, realizes the online monitoring and fault diagnosing. Meanwhile, the NP hard problem usually exists in the domain of artificial intelligence in the causality reasoning. Furthermore, it is important to find high efficient approximately reasoning algorithm in the study of causality diagram theory.

V. CONCLUSION

This paper introduces causality diagram methodology, analyses causality diagram model and reasoning method. In addition, a knowledge database and an inference Engine are established. Finally, an application of rotary dump health monitoring expert system is described.

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