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Skeletal tool of mineral processing expert system[①]

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Abstract: By use of the integrated knowledge of mineral engineering, mineral processing, expert system, artificial neural networks(ANN), genetic algorithm, fuzzy mathematics and multimedia technology etc., MPES(mineral processing expert system) skeletal tool has been built, which is a construction tool for expert systems in the field of mineral processing. This system is programmed by C^{++} language on microsoft windows platform, including multiple knowledge and reasoning methods, and can be used to build new expert systems for ore beneficiability prediction, mill design, faults diagnosis, production control and management decision.

Key words: mineral processing; expert systems; skeletal tool; mill design **Document code: A**

1 INTRODUCTION

The traditional research on mineral processing, which includes ore beneficiability, mill design, device maintenance, process control and production management decision, is a basic and necessary work in mineral industries. It is also a miscellaneous work that consumes a lot of manpower, money, material resources and time.

Since 1980s, many researchers have paid much attention to the application of artificial intelligence, and have gradually made use of expert systems, decision supporting systems and artificial NN(neural networks), in the field of mineral processing. Now some expert systems for mineral processing have appeared, for example ore beneficiability prediction expert system, mill design expert system, process control expert system, faults diagnosis expert system and intelligent management decision supporting system. But these expert systems were built only for special and narrow fields or single mills.

The mineral processing expert system(MPES) developed by the authors is able to predict the ore beneficiability, and carry out mill design, process control, production consultation, faults diagnosis and management decision by use of process mineralogy, mineral processing, fuzzy mathematics, artificial intelligence and computer techniques. According to imperfect statistics, there are thousands of mills, hundreds kinds of nonferrous metals, ferrous metals, rare metals and nonmetallic ore deposits in China; if some integrative expert systems corresponding to these mills and ore deposits are established, both the economic and social benefits will be inestimable.

Establishment of MPES for every kind of mill or every narrow field from the beginning would consumes considerable manpower, material resources and time. For this reason, a developing tool of MPES for all kinds of mills and fields has been studied, which can simplify the procedures of building MPES of different mills. By analyzing the solving steps for mineral processing problem, it can be seen that the procedures for any mills are similar, so it is feasible to build MPES skeletal tool for new MPES of other mills.

2 SYSTEM FORMALIZATION DESIGN

2.1 Neural network module(NNM)

Neural network algorithm is a data computation procedure, so its input and output are all data. Only by two translations of logic and data, neural network system can get message directly outside. NNM may carry out the functions of the translation between logic and data, it includes three parts: input translation machine(ITM), neural network processing machine (NNPM) and output translation machine(OTM). Its structure is shown in Fig. 1.

ITM can translate factual logic information into data information so that the information can be processed by NNPM, OTM can translate NNPM data into logic information which can be optimized and used by the outside. We use genetic algorithm to optimize general parameters and network structure and use back propagation algorithm to optimize local parameters.

Input translation schema adopts linear or nonlinear transformation, and changes numeric and describes data into a certain range, for example, from 0 to 1. For output translation schema, if NNM output,

$\overline{O_N} = (a_1, a_2, \cdots, a_n)$ and

sample $\overline{I_i}$ output, $\overline{O_i} = (b_{i1}, b_{i2}, \cdots, b_{in})$ and

$\langle \overline{O_N}, \overline{O_i} \rangle = \min\{\langle \overline{O_N}, \overline{O_i} \rangle\}$ and

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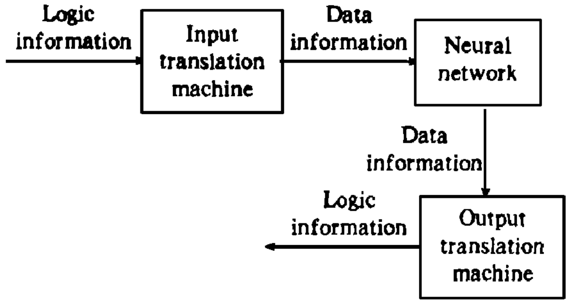

Fig. 1 Structure of NNM

$$\langle \overline{O_N}, \overline{O_i} \rangle = \sqrt{(b_{i1}-a_1)^2+(b_{i2}-a_2)^2+\cdots+(b_{in}-a_n)^2}$$

then I_i is the output of NNM.

NN processing unit adopts multilayer feedforward neural network. Each network consists of binary string chromosome, and each connection weight is shown by 10 binary gene, i. e., $W_{11} \rightarrow 1100010101$, $W_{12} \rightarrow 0100011010$, …, $W_{ij} \rightarrow 0111110001$.

2.2 General frame

The black box structure is used in MPES, symbol processing method and connection mechanism are allowed to coexist in all the functional modules. They all accept and output symbol information. Its general frame is shown in Fig. 2. In this frame, different knowledge has different representation and corresponding inference mechanism.

2.3 Knowledge representation

Knowledge representation module is the first key of constructing expert system. Inside NNM, knowledge is hidden and represented with NN, the general structure of network indicates a kind of logic knowledge. Outside NNM, some traditional methods, such as fact, production rule, frame prototype, semantic model and object-oriented method are used. The following is an example of:

Object identifier	Types
Object name: flotation	Character
Superclass name: separation method	Character
Variables: stage number of grinding-flotation,	Number
Cycle number,	Number
Cleaning and scavenging number,	Number
Sequence of flotation.	Character

Knowledge

Flotation plant name:

Plant address:

Ore deposit type:

Plant scale:

Mineral type:

Knowledge processing methods

Prediction rule 1: IF [Cu, Pb, Zn ore] THEN [flotation]

Prediction rule 2: IF [single metal, coarse disseminated ore] THEN [one stage, one circuit flotation]

Prediction rule 3: IF [single metal, non-uniform disseminated ore] THEN [tail-regrinding, two or three stage flotation]

Prediction rule 4: IF [high content of valuable mineral, low requirement of concentrate quality] THEN [rougher concentrate]

Knowledge acquisition 1: asking about mineral composition, grades of valuable minerals in run-of-mine ore and oxidation rate

Knowledge acquisition 2: asking about the dissemination size, dissemination character

Knowledge acquisition 3: asking about ore texture, product kinds, etc.

2.4 Knowledge acquisition

The knowledge acquisition module is a focus on building ES (explaining system). The knowledge learning engine can realize artificial knowledge acquisition. When one inputs knowledge concluded as rules and frames into KB (knowledge base), all relative rules and frames will be shown by the system, and can be deleted or modified after analyses.

Inside NNM, knowledge automatic learning is realized by networks, The neural networks can adjust automatically the connecting weight between neurons during learning. The knowledge obtained is distributed and saved in the whole networks so as to realize the automatic learning function of neural network.

Outside NNM, learning based on explanation is adopted in MPES. After every successful reasoning, the valid reasoning route would be recorded. When similar conditions appear next time, the inference engine would find the knowledge quickly in terms of the routes recorded. This is a control knowledge improving the reasoning efficiency of the inference engine.

2.5 Inference mechanism

Inference mechanism module is the most important part of ES. Inside NNM, forward reasoning is used. At first, we can put original logic knowledge into ITM, logic knowledge is then translated into data knowledge in ITM; after the forward computation of NN, OTM translate NN data knowledge into logic one; at last, new logic knowledge is put out of NNM. Knowledge representation and reasoning are closely integrated and parallelly processed. Outside NNM, this system adopts object reasoning, backward chaining reasoning, forward chaining reasoning and fuzzy reasoning by the control of management module, reasoning knowledge is put into traditional KB. These reasoning methods are integrated in an object, one can select a method from those; the

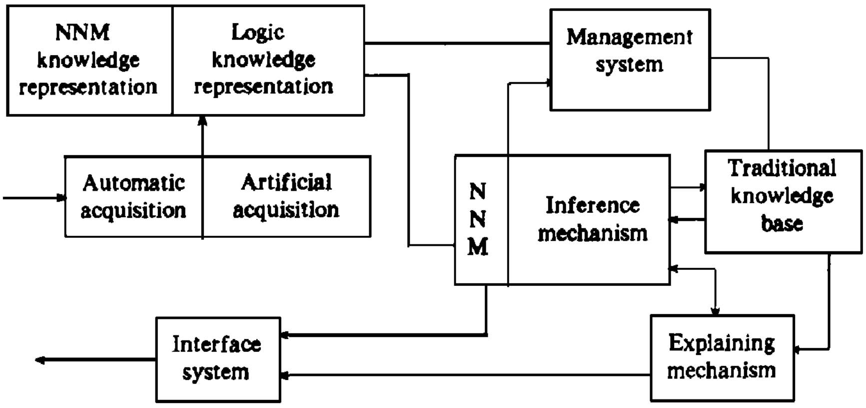

Fig. 2 General frame of MPES

system can take an optimized reasoning method when one selects default data, as shown in Fig. 3.

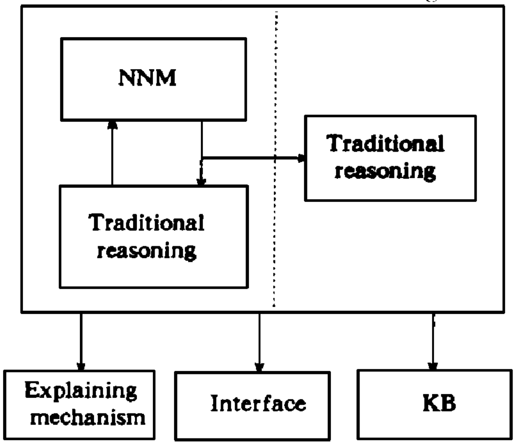

Fig. 3 Knowledge reasoning of MPES

2.6 Explaining mechanism and interface

Explaining system of MPES can describe the reasoning process with rolling screen, including on-line reasoning route and objects, and certainty factor and real-time explanation. Interface includes menu selection, user input and multimedia technology.

3 SYSTEM COMPOSITION, WORKING PRINCIPLE AND APPLICATION EXAMPLE

3.1 System composition

The MPES skeletal tool consists of some parts: knowledge base (KB), inference engine, utilities, MPCAI (mineral processing computer aided instruction) developing tool and help system. The system written by C++, Notes and Java language on windows platform can be performed on internet.

The KB part includes KB construction, management, organization and maintenance. One can select suitable methods from the knowledge representation methods provided by the system according to the characteristics of the domain. The skeletal tool has a superior system of knowledge input, which can find errors when one inputs knowledge and examine the consistence and the redundancy of the input knowledge. The KB part also has such functions as addition, deletion, edition and copy of knowledge.

The inference engine processes the knowledge in KB and determines the current state and the strategy taken in the next step. One can select different kinds of inference mechanisms, such as forward reasoning, backward reasoning, complicated reasoning, neural network simulation reasoning and other kinds of fuzzy reasoning methods.

The utilities can help users exchange information with the skeletal tool. The present ES is browsed, executed or traced partly by the user interface, which displays the general questions, explanations and text information, and provides processing to the middle state of KB. The inference chains formed in inference process are displayed on graphic browser. The inference results can be output in the form of table by the general table function. Users can guide directions of searching and problem solving to make inference go on along the direction expected. The design tool helps users to design interfaces for new ES, including different kinds of windows, menus, dialog frames, click-buttons, graphics, etc.. The interface with external database provides communication means between ES and external database. The multimedia editors can edit and play some scripts, including text, sound, picture, movie and video, which can show the inference results with real-time sound explanation, friendly picture, movie and video expression.

3.2 Working principle and application example

MPES skeletal tool is used to provide overall architecture, KB building tool, inference mechanism selection, multimedia utilities and other practical tools (such as MPCAI developing tool, debug tool, graphic tool, general table design tool, executing external procedures, etc.) for the construction of MPES for given ores and mills.

According to those working principle, a new expert system of Huang Shaping lead-zinc sulphide ores plant has been established, which can make a precise prediction of some parameters and make good consultation for production process. Some prediction results are shown in Table 1.

Table 1 Comparison table of parameters prediction

Parameters	Mill design	System prediction
Crushing flowsheet	3 stages, closed circuit	3 stages, closed circuit
Grinding flowsheet	1 stage, closed circuit	1 stage, closed circuit
Separation method	Lead equal flotation	Lead equal flotation
Separation flowsheet	Pb(I): 1 rougher, 2 scavengers Pb(II): 1 rougher, 4 cleaners 2 scavengers Zn•S: 2 roughers, 2 scavengers Zn/S: 1 rougher, 2 cleaners 2 scavengers	Pb(I): 1 rougher, 2 scavengers Pb(II): 1 rougher, 4 cleaners 2 scavengers Zn•S: 2 roughers, 2 scavengers Zn/S: 1 rougher, 2 cleaners 2 scavengers
Flotation agents	Xanthates: 448; $CuSO_4$: 537; $ZnSO_4$: 181; SN-9: 18.3; 2# Oleic: 180; CaO: 15550	Xanthates: 460; $CuSO_4$: 551; $ZnSO_4$: 175; SN-9: 20; 2# Oleic: 182; CaO: 16000
Grade recovery	β_{Pb}= 71.36; ε_{Pb}= 90.23; β_{Zn}= 44.93; ε_{Zn}= 92.75; β_S= 35.78; ε_S= 56.67	β_{Pb}= 72.21; ε_{Pb}= 89.55; β_{Zn}= 46.74; ε_{Zn}= 90.01; β_S= 34.52; ε_S= 57.89

Notes: Zn•S —Lead and zinc flotation; β —Grade; Zn/S —Lead and zinc separation; ε —Recovery

The steps to use MPES for given ores and mills are described as follows:

1) Collecting, analyzing and including the domain knowledge of a given mill, selecting knowledge representation method, determining KB structure and building the KB; 2) Selecting the inference mechanism, applying the graphic browsers to trace the reasoning process, and consummating the KB and inference engine continuously; 3) Designing the interface including windows, menus, click-buttons and dialog frames by use of interface design tool; 4) Improving the interpreter and help functions of the ES; 5) Combining various functions with menus and click-buttons on the interface to make up preliminary ES; 6) Using the application utilities of the skeletal system to test the newly-built ES and consummate it continuously.

4 CONCLUSION

The feasibility of MPES skeletal tool was analyzed. The structure of the system, the main function of each part, the working principle and application step are discussed.

This research makes use of expert system, artificial neural network, genetic algorithm, multimedia technique, fuzzy mathematics and other computer techniques in the field of mineral processing, it provide a new and efficient research method. By inputting the factual knowledge base, MPES can build a new expert system to carry out ore beneficiability prediction, mill design, crushing and grinding facilities, faults diagnosis, crushing, grinding and floating production consultation, and it has made a good try for constructing intelligent mill.

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