Filomat 32:5 (2018), 1757–1764
https://doi.org/10.2298/FIL1805757Z

Published by Faculty of Sciences and Mathematics,
University of Niš, Serbia
Available at: http://www.pmf.ni.ac.rs/filomat

Design for Intelligent Prediction System of Oilfield Development Index Based on Pattern Recognition

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Abstract. In order to realize Digital Oil Field, some key problems need to be improved, esp. accurate and automatic prediction of oilfield development indexes which may be resolved by designing of intelligent prediction system. With the shortcoming of inference of system designed by us, automatic inference problem for a complicated intelligent prediction system was improved using pattern recognition method. First, intelligent prediction system and the methods as well as principles of pattern recognition were introduced. Then the framework of intelligent prediction system based on pattern recognition was formulated by using technologies and methods of human-computer interface, fuzzy processing and pattern recognition. Secondly, the knowledge base was extended as augmented knowledge base with introducing credibility to measure uncertainty of knowledge. Particularly, the methods and principles of pattern recognition were used to design two recognizers and one inferring machine. Moreover, the method of selecting predictive model based on reasoning of pattern recognition was presented by coupling them and intelligent prediction system. Finally, the design of improving intelligent prediction system of oilfield development indexes was simulated. Simulation result shows that improved system may automatically realize to select optimal prediction model by computer according to different reservoirs and different development stages. The results obtained in this thesis will helpful to design for intelligent prediction system.

1. Introduction

Since constructing Digital Oil Field (DOF) was proposed, many researchers and practitioners have being dedicated to this topic work. They have obtained much results and lessons learned [1], but there are still some key problems to need to be improved, such as real time production optimization (RTPO), production loss management, reservoir characterization and surveillance, oilfield development and planning as well as its adjustment. The key of these problems is to predicate and analyze the dynamic and performance of reservoirs developing. Because the law and characteristics for oilfield development indexes revealing are an important basis of predicating and analyzing the dynamic and performance of reservoirs developing, accurate and automatic prediction of oilfield development indexes is an important and key problem for

2010 *Mathematics Subject Classification*. 68T10, 97R40, 97M99, 37F99.
Keywords. Intelligent prediction system, Digital oil field, Oilfield development index, Pattern recognition, Credibility
Received: 18 October 2017; Accepted: 02 November 2017
Communicated by Hari Srivastava
Research supported by Double First-rate Higher School Construction Foundation of Sichuan Finance Department and Education Department Grant No.2050205 higher education.
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DOF. Until recently, we knew that a major special project of Sinopec just plans to study automatic prediction of oilfield development indexes that includes many traditional prediction methods.

Prediction of oilfield development indexes has being interested in many people's study. Moreover, its many prediction methods had been proposed. In 2008, I found that these methods would confuse the prediction workers of oilfield, and introduced intelligent prediction to solve it [2]. Since then, I and my students began to study intelligent prediction of oilfield development indexes [3-8]. Our studies are different from other people's studies [9-10] in intelligent prediction system. We focus on selecting the best prediction method from known prediction methods stored in the system, while other people use at most several prediction methods with intelligence. Thus, the intelligent prediction system proposed by us is more suitable for DOF construction, and is also very complicated. Although we have been studied it, we designed only conceptually the intelligent prediction system of oilfield development indexes. The core components of intelligent system designed by us include method base, model base and knowledge base as well as reasoning learning machines. In order to realize automatic reasoning of system, the rule libraries to select method type and candidate prediction model were first formulated with the association rules method, reasoning learning machines were then drove by the credibility and mean absolute percentage errors (MAPE) standard to get the best prediction model [8]. However, its inference is not perfect for a complicated system.

Because pattern recognition is a branch of artificial intelligence concerned with classification or description of observations, and which was applied to find patterns among non-linear and interdependent parameters involving in complex system [11-15]. Therefore, this thesis will use the methods and principles of pattern recognition to improve the system designed in [8]. By improving, new design may address automatic inference problem of a complicated intelligent prediction system.

2. Intelligent prediction system and pattern recognition

2.1. Intelligent prediction system

Intelligent prediction system in [8] includes four modules: data base, method base, model base and knowledge base. These modules are integrated in the system to realize automatic prediction by three inference engines. Because only association rules were used to select the optimization method type and candidate prediction model, automatic inference mechanism of complicated intelligent prediction system with fuzzy information needs to be studied.

2.2. Pattern recognition

2.2.1 Principles of pattern recognition

- Principles suiting for single factor pattern recognition [16]

Maximum membership degree principle let U be domain of discussion, $F(U)$ be the set of fuzzy set on U, A_1,A_2,...,$A_n \in F(U)$ be standard modes, $\mu_0 \in U$ be an object to need to be identified. If A_i subjects to $\mu_{A_i}(\mu_0) = \max\{\mu_{A_1}(\mu_0), \mu_{A_2}(\mu_0), ..., \mu_{A_n}(\mu_0)\}$, then μ_0 is subordinate to A_i.

Near selection principle I let A_1,A_2,...,$A_n \in F(U)$, $B \in F(U)$, If exists i subjects to $(B, A_i) = \max\limits_{1\le j\le n}\left(B, A_j\right)$, then B is the nearest to A_i. Thus B is classified as mode A_i, where (B, A_i) is proximity of B and A_i.

- Principles suiting for multi factor pattern recognition [16]

Maximum membership degree principle II let U_j, $j = 1, 2, \cdots, m$ be jth domain of discussion, $F\left(U_j\right)$ be the sets of fuzzy set on U_j, A_{i1},A_{i2},...,$A_{im} \in F\left(U_j\right)$, $i = 1, 2, \cdots, n$ be m fuzzy features of ith standard modes $A_i = (A_{i1}, A_{i2}, ..., A_{im})$, $i = 1, 2, \cdots, n$, $u_0 = \left(u_1{}^0, u_2{}^0, ..., u_m{}^0\right)$ be an object to need to be identified. If A_i subjects to $\mu_{A_i}(u_0) = \max\{\mu_{A_1}(u_0), \mu_{A_2}(u_0), ..., \mu_{A_n}(u_0)\}$, then u_0 is subordinate to A_i, where $\mu_{A_i}(u_0)$ is the membership

function of synthetic fuzzy set by synthetic function representation.
The preferred principle let $A = (A_1, A_2, ..., A_m) \in F_m$ be given mode, $F_m = F(U_1) \times F(U_2) \times ... \times F(U_m)$, $u = (u_1, u_2, ..., u_n) \in U^*$ be waiting for identifying object. If exists i subjects to $\mu_A(u_i) = \max(\mu_A(u_1), \mu_A(u_2), ..., \mu_A(u_n))$, then u_i will be prior selected.
Near selection principle II let $A_i = (A_{i1}, A_{i2}, \cdots, A_{im}) \in F_m, i = 1, 2, \cdots, n$ be given n standard modes, $B = (B_1, B_2, ..., B_m) \in F_m$ be waiting for identifying object. If exists i subjects to $\delta^*(A_i, B) = \max\{\delta^*(A_1, B), \delta^*(A_2, B), ..., \delta^*(A_m, B)\}$, then B is regarded as the nearest to A_i, where $\delta^*(A_i, B)$ is the synthetic proximity of A_i and B.

2.2.2 Methods of pattern recognition [16]

- Direct method is the method to determine that given object belongs to which standard mode using maximum membership degree principle or maximum membership degree principle II and the preferred principle.

- Indirect method is the method to determine that given fuzzy object is near to which standard mode using near selection principle I or II.

3. Framework of intelligent prediction system based on pattern recognition

3.1 Framework idea

With the deficiency of system designed by us in [8], we integrated the results in [6, 8, 16] to improve intelligent prediction system. First, the human-computer interface and database were improved by using technologies and methods of human-computer interface as well as fuzzy processing. Then, knowledge base was built again with fuzzy technology. Finally, automatic inference machines were improved by pattern recognition to select automatically prediction model through method base, knowledge base and model base.

3.2 System framework

According to the above idea, the frame diagram of new intelligent prediction system is as shown in Figure 1 combined with the intelligent prediction system and pattern recognition system [16].

4. Design of intelligent prediction system based on pattern recognition

4.1 Improving of human-computer interface and database

The human-computer interface used the question and answer method to inquire about the prediction objective, such as the accuracy requirement of the prediction method. When the system infers the prediction model, it will ask the user whether the result is the predicted expected value or not. If it is not, then the system will prompt the user to reset the relevant data and parameters, and do prediction again.
Fuzzy processing technology was introduced into database. Since relevant parameters of most models and the historical data needed by them are fuzzy, the data of inputting model can be stored in the database with certain of membership degree determined by triangle and trapezoid membership functions.

4.2. Construction of knowledge base

The knowledge base is a memory used for storing and managing knowledge in a system. The intelligence of intelligent prediction system is mainly reflected in system using knowledge, which is a concrete description of human expert experience and factual rules. The knowledge base of intelligent prediction system contains two sub libraries: one is the rule base; the other is the factual knowledge base.

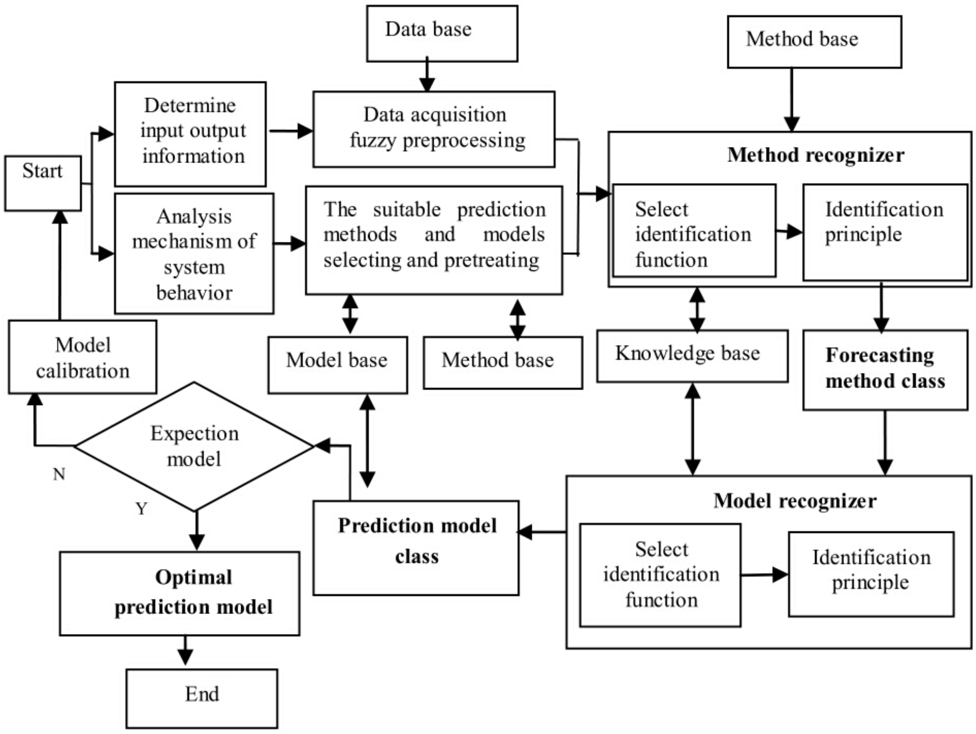

Figure 1: Working principle diagram of intelligent prediction system based on pattern recognition

4.2.1. Construction method

The knowledge base was built with fuzzy technology, which was first given the knowledge and prediction-experience of the prediction expert and domain expert a certain degree of credibility. Then, the rule base of selecting method class and model class was established. Finally, the fuzzy knowledge base was integrated. It has also the functions of retrieval, query, edit, add, delete etc.

4.2.2. Establishment of knowledge base

- Establishment of factual knowledge base

The construction of a factual knowledge base should take full account of various influencing factors and follow various rules. Establishing factual knowledge base includes mainly the system's domain characteristics, background features, characteristics of usage and attribute characteristics, and so on [16].

- Establishment of rule knowledge base

Rule base is the reasoning basis of inference engine, in which it stores system information providing by database and the criteria information, identification principles, identification functions and so on corresponding to selecting method class and model class. The rule base here is different from that of [8], which was constructed as an augmented knowledge base by introducing credibility to measure uncertainty of knowledge. Its rules may express as: $if\ A\ then\ B\ with\ CR = i,\ i \in [0, 1]$ or $if\ A_1\ and\ A_2\ and \cdots and\ A_n then\ B_1\ and\ B_2 \cdots and\ B_m with\ CR = i,\ i \in [0, 1]$.

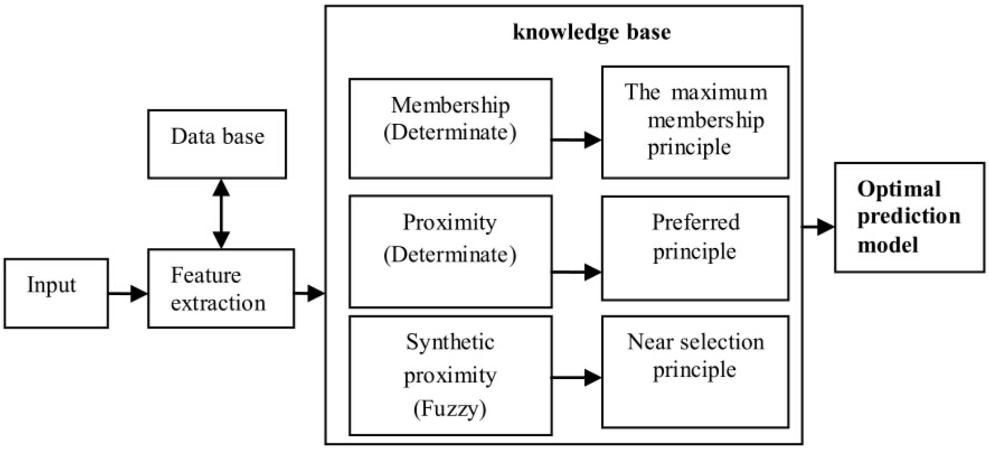

Figure 2: Reasoning design of the recognizer

4.3. Design of the recognizer

The recognizer is an intelligent mechanism that controls and coordinates the whole intelligent predictive system. According to the known facts in the current database of the system, it first extracts its mode features, then identifies it with the method base by single or multi factor identification method to choose a prediction method class; Secondly, the method category is identified with the model base by multi factor identification method to select the candidate prediction mode; Finally, by using the knowledge and rules in the knowledge base, reasoning according to certain reasoning method and control strategy, the optimal prediction model which is suitable for the research object under the current conditions is obtained. Its design was divided as following two parts.

4.3.1. Design of identification and judgment on method class

Identification and judgment on method class may be achieved by method recognizer module in Figure 1. The steps of its design are as follows:
Step1 analyze the behavior mechanism of intelligent prediction system to obtain the information on prediction method class and model class.
Step2 determine the type of prediction method class suitable for the system by using the information in Step1 and the rules of selecting method class in method base.
Step3 determine the membership functions $\mu_{A_i}(x), i = 1, 2, ..., n$ of prediction method class A_i got in Step2 with respect to their affecting factors.
Step4 input the object to need to be identified, if it is deterministic μ_0, then go to Step5; if it is deterministic multi-factors pattern recognition $u_0 = \left(u_1{}^0, u_2{}^0, ..., u_m{}^0\right)$, then go to Step6; if it is fuzzy multi-factors pattern recognition $B = (B_1, B_2, ..., B_m) \in F_m$, then go to Step7.
Step5 determine membership function of μ_0 about A_i, and recognize forecasting method class by the maximum membership principle I and selecting rule in knowledge base.
Step6 compute the proximity of membership function $\mu_{A_i}(u_0)$ on $u_0 = \left(u_1{}^0, u_2{}^0, ..., u_m{}^0\right)$ belonging to synthetic fuzzy set A_i by synthetic function representation, and recognize forecasting method class by maximum membership degree principle II and selecting rule in knowledge base.
Step7 select the proximity formula, calculate the proximity $\delta\left(A_{ij}, B_j\right)(i = 1, 2, \cdots, n; j = 1, 2, \cdots, m)$ of prediction model A_{ij} and method B_j; select synthesis function M, calculate the synthetic proximity $\delta^*(A_i, B)$ of prediction model $A_i = (A_{ij})$ and method class $B = (B_1, B_2, ..., B_m) \in F_m$, and identify the forecasting model

class A_i by the preferred principle II.
Step8 do defuzzification and output prediction method class.

4.3.2. Design of recognition and judgment on predictive model class

Recognition and judgment on model class may be achieved by model recognizer module in Figure 1. The steps of its design are as follows:
Step1 input the information on prediction model class of step1 in 4.3.1, select prediction model class $A_i, i = 1, 2, \cdots, n$ by model base.
Step2 determine the membership functions $\mu_{A_i}(x), i = 1, 2, \cdots, n$ of each prediction model A_i in obtained prediction model class in Step1.
Step3 input the prediction method class selected in 4.3.1 as the object need to be identified, if it is deterministic multi-factors sample recognition $u_0 = \left(u_1{}^0, u_2{}^0, ..., u_m{}^0\right)$, then go to Step4; if it is fuzzy multi-factors pattern recognition $B = (B_1, B_2, ..., B_m) \in F_m$, then go to Step5; if it is deterministic multi-factors preferred recognition $u = (u_1, u_2, ..., u_n) \in U^*$, then go to Step 6.
Step4 select synthesis function M, calculate membership function of $u_0 = \left(u_1{}^0, u_2{}^0, ..., u_m{}^0\right)$ about A_i , and identify the forecasting model class by the maximum membership principle II.
Step5 select the proximity formula, calculate the proximity $\delta\left(A_{ij}, B_j\right)(i = 1, 2, \cdots, n; j = 1, 2, \cdots, m)$ of prediction model A_{ij} and method B_j; select synthesis function M, calculate the synthetic proximity $\delta^* (A_i, B)$ of prediction model $A_i = (A_{ij})$ and method class $B = (B_1, B_2, ..., B_m) \in F_m$, and identify the forecasting model class A_i by the preferred principle II.
Step6 select synthesis function M, calculate membership function of $u = (u_1, u_2, ..., u_n) \in U^*$ about A_i, and identify optimal prediction model A_i by the preferred principle.
Step7 output the forecasting model class to obtain candidate prediction model.

4.4. Design and method of reasoning of intelligent prediction system based on pattern recognition

4.4.1. Reasoning design of the recognizer

The reasoning part of the recognizer is the key and kernel part of the recognizer, which is the brain of the whole recognizer. Whose aim is to estimate the degree of similarity on facts or rules in the knowledge base and the conditions given in the database. According to the threshold of confidence degree estimated by the user and the deterministic or fuzzy object considered, the optimal prediction model was obtained by comparing the maximum membership degree or proximity degree or synthetic proximity degree with the threshold of confidence degree, using the maximum membership principle, the preferred principle or the near selection principle. The detailed design is shown in Figure 2.

4.4.2. Method of reasoning

Reasoning of intelligent prediction system is implemented by recognizer reasoning. On the base of section 1 and section 2, it uses reasoning of pattern recognition to select optimal prediction model. It includes prediction method identification and predication model identification by matching input information and data base as well as knowledge base. The steps of its algorithm are as follows:
Step1 determine input information, collect the determined information, select and pretreat useful data for recognizing.
Step2 analysis behavior mechanism of system, select the prediction method class and prediction model suitable for the system by knowledge base, and pretreat these prediction method class and prediction model.
Step3 judge whether inputting information is determinate or fuzzy.
Step4 select the formula and principle of pattern recognition according to the inputting information and the type of prediction method class, which may be obtained by the recognizer of prediction method class

in section 4.3.1.
Step5 discern the inputting information and the prediction method class to get the prediction method class suiting for the inputting information.
Step6 judge whether the type of the prediction method obtained in step5 is determinate or fuzzy.
Step7 select the formula and principle of pattern recognition according to the type of prediction method class and the information of prediction model, and obtain candidate prediction model with the recognizer of prediction model class in section 4.3.2.
Step8 get the optimal prediction model suiting for the inputting information. If candidate prediction model obtained in step7 is one, then it is the optimal prediction model; otherwise it may be got by comparing predictive accuracy of several candidate prediction models.

5. Simulation on intelligent prediction system of oilfield development indexes

5.1. Simulation design of system

By using framework and method of proposed in this thesis to improving the system developed in [8], we achieved detail design of improving modules. Main includes fuzzy representation of input information, fuzzy representation of prediction method, design of pattern recognition inference machine including method class and prediction model. Specific procedure may check section 5.1.2 and section 5.2.1 in [16].

5.2. Simulation case

Problem: study the example in [16] using the method presented in this thesis. The procedure to solve the problem is as follows:
Step1 inputted oil reservoir information about time, the average viscosity, the synthetic water cut, the permeability, the monthly oil yield.
Step2 extracted reservoir feature information as the average viscosity A and the synthetic water cut B.
Step3 defined separately the proximity of membership functions that development stage and viscosity belong to prediction method class P_1, P_2, P_3 , and calculated to get their results: $\mu_{P_1}(A) = 0.8758, \mu_{P_2}(A) = 0.2112,, \mu_{P_3}(A) = 0.03, \mu_{P_1}(B) = 0.2434, \mu_{P_2}(B) = 0.6037, \mu_{P_3}(B) = 0.6414$.
Step4 selected synthesis function $M = \frac{1}{2}$, used $\delta_{P_i}(A, B) = M(\mu_{p_i}(A) + \mu_{p_i}(B))$ to calculate separately the synthetic proximity of A,B and prediction method class $\delta_{P_1}(A, B) = 0.5596, \delta_{P_2}(A, B) = 0.40745, \delta_{P_3}(A, B) = 0.3357$.
Step5 got the most matched prediction method class with input information is ordinary prediction method class P_1 by the result in step4 and the maximum membership principle as well as selecting rule in knowledge base.
Step6 determined prediction models P_{13}, P_{14}, P_{15} in ordinary prediction method class P_1 by inputting data information.
Step7 constructed separately the membership functions of prediction model class P_{13}, P_{14}, P_{15} with respect to oil yield or water cut stage and permeability.
Step8 calculated separately the synthetic proximity of relevant factors affecting prediction model class P_{13}, P_{14}, P_{15} in P_1 and prediction model class P_{13}, P_{14}, P_{15}.
Step9 optimal prediction model selected is the decline curve method P_{14} by the maximum membership principle.
The result of obtaining in step 9 is consistent with the method of the practical expert recommending.

6. Conclusion

The prediction of oilfield development indexes is an important and difficult problem that DOF must to be solved. Therefore, our team have being studied its solution since 2008. By using technologies and methods of human-computer interface, the methods and principles of fuzzy processing and pattern recognition, this thesis presented the method of improving intelligent prediction system on oilfield development dynamic index designed by us. The result of simulating illustrates that new designing system may achieve to accurately and efficiently predict dynamic index of oilfield development by automatically selecting predicting model. Especially, the method proposed in this thesis will helpful to design for intelligent prediction system. The future works are to improve the software and the performance of this system by Multi-Agent technology.

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