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Industrial image classification using a randomized neural-net ensemble and feedback mechanism

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ABSTRACT

Accurate burning state recognition plays an important role in rotary kiln sintering process control. In order to avoid significant discrepancy between human feedback cognitive mechanisms and traditional open-loop recognition methods, a novel intelligent cognitive model based on a variable granularity simulated feedback mechanism is explored in this paper, where evaluation indexes of cognitive results are established to freely regulate cognitive granularity, and the variable granularity simulated feedback mechanism is constructed to update cognitive features and cognitive rules with different granularities. The proposed cognitive model is applied to improve burning state recognition accuracy. With the initial granularity, a burning state recognition decision information system is developed using extracted flame image features. Random vector functional-linker (RVFL) network ensembles are employed to build the initial burning state recognition rules. By using cognitive errors and granularity transformation rules, a heuristic feedback mechanism is proposed to update the decision information system and recognition rules. The experimental results show that our method is effective and outperforms other open-loop recognition techniques.

1. Introduction

A rotary kiln is widely used in metallurgical, cement, chemical, and environment protection industries. A burning zone temperature is regarded as the controlled variable in most rotary kiln control strategies because of its crucial impact on clinker quality [1]. However, due to the disturbances inside the kiln, there is no accurate analyzer available for this temperature. Recently, the strategy of burning state recognition by flame images has received considerable attention. In [2], it is reported that the temperature field and clinker sintering information are extracted based on image segmentation techniques. Novel segmentation-free burning state recognition approaches are given in [3,4], and the performance is superior to that of the segmentation-based methods.

Most of the recent pattern recognition systems are built based on the open-loop feedback-free model. However, the absence of an evaluation index renders recognition results unauthentic. As the best intelligent perceptron, the human cognitive mechanisms have the characteristics of repeated comparison and inference [5,6]. With the aim of best performance, objects are repeatedly cognized with multi-level features from macro to micro. Granularity aims at the information requirements of different systems [7,8]. The existing recognition systems usually have constant granularity features. It is found that the feature suitability of different objects is distinctive, i.e., simple features with coarse granularity are applicable to some easily recognized objects, whilst complex features with fine granularity are applicable to others. Our aim is to obtain authentic outputs. For these uncertain outputs as indicated by the evaluation system, repeated cognition with variable granularity features should be employed to enhance their reliability. This motivates us to undertake further research in these directions.

On the basis of our previous work in [3], where an open-loop feedback-free model with constant granularity features is utilized to recognize burning states, a novel intelligent cognitive model based on a variable granularity simulated feedback mechanism is proposed in this paper, and the main technical contributions are summarized as follows: (i) exploring an intelligent cognitive model with a variable granularity simulated feedback mechanism to imitate human cognitive mechanisms; (ii) designing the variable granularity simulated feedback mechanism to repeatedly cognize with free granularity features; (iii) defining cognitive errors to build the evaluation index system of the cognitive results; and (iv) applying this intelligent cognitive model to recognize burning states to achieve the optimal feature space and better recognition accuracy. Specifically, firstly, the framework and functions of the intelligent cognitive model are illustrated to provide theoretical support. Secondly, in order to realize the variable granularity simulated feedback cognition, the operation

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mechanism of the intelligent cognitive model is designed, and cognitive errors and granularity transformation rules are defined to provide the numerical calculation model for the evaluation index system of cognitive results. Thirdly, for the application of burning state recognition, after the pre-processing by the compact Gabor filter bank, with the given initial granularity, the local configuration features of the flame image region of interest (ROI) are extracted by the scale invariant feature transform (SIFT) descriptor combined with the "bag of visual words" (BoVW) and latent semantic analysis (LSA) [3]. Then, the RVFL network ensemble is employed to generate the initial recognition rules for the built initial burning state recognition decision information system [9]. Finally, according to the defined cognitive result evaluation index system, heuristic feedback granularity is calculated to update the decision information system and recognition rules to realize the variable granularity feedback cognition from macro to micro. Numerous experiments with comprehensive comparisons are carried out based on flame images of a cement plant No. 2 rotary kiln. Experimental results show the effectiveness and superiority of our intelligent cognitive model compared with the existing methods.

The remainder of this paper is organized as follows. The intelligent cognitive model based on the variable granularity simulated feedback mechanism is constructed in Section 2. The proposed cognitive model for burning state recognition is given in Section 3. To evaluate the performance of our approach, experimental results with comprehensive comparisons and discussions are presented in Section 4. Finally, we conclude this work in the last section.

2. Intelligent cognitive model based on the variable granularity simulated feedback mechanism

2.1. Framework and function of the intelligent cognitive model

The intelligent cognitive model renders a cognitive system with humanoid intelligence. Exploring the close-loop control concept, an intelligent cognitive system could be described as a selective and hierarchical information management process from coarse to fine, which possesses the human cognitive characteristics of repeated comparison and inference. The humanoid intelligent cognitive model should realize the following goals: (i) represent the object characteristics with various granularity features; (ii) describe the human cognitive process at various granularity levels; (iii) imitate the human cognitive mode by the granularity regulation mechanism; and (iv) realize the interaction and repeated cognition between various granularities by the cognitive result evaluation mechanism.

The proposed intelligent cognitive model is shown in Fig. 1. A three-layered structure comprising a training layer, cognitive layer, and feedback layer is used in this model. The framework and function of each layer are summarized as follows:

(i) The training layer consists of pre-processing, feature modeling, and classifier design. Based on the calculated granularity from the feedback layer, cognitive knowledge is represented and cognitive rules are built with the given granularity, which provides the feature domain granulation rules and cognitive matching template for the testing dataset in the cognitive layer.
(ii) The cognitive layer consists of pre-processing, feature extraction, classification cognition, and cognitive error analysis. Based on the feature space and classifier built in the training layer, the cognitive results of the testing dataset are evaluated with the given granularity, which provides the heuristic feedback information for the granularity calculation in the feedback layer.
(iii) The feedback layer consists of granularity calculation. Before the first cognition, the initial granularity of the training layer is given by the feedback layer. Once the intelligent cognitive model runs, the heuristic feedback information is inferred by the cognitive result evaluation index system of the cognitive layer, and the granularity of the next cognition is calculated to update the built feature domain granulation rules and cognitive matching template.

2.2. Operation mechanism of the intelligent cognitive model

The intelligent cognitive model realizes the repeated interaction between cognitive knowledge representation and the feedback cognitive process at different granularity levels.

(i) *Operation mechanism of the training layer*: For the training dataset, the following steps are implemented based on the given granularity from the feedback layer: (a) pre-process the training dataset to remove possible noises; (b) form the training dataset cognitive decision information system by the extracted features; (c) divide and map the training feature space domain to represent the cognitive knowledge, and build the compact feature space with sufficient cognitive information by entropy evaluation indexes; and (d) design the classifier to build the cognitive matching template.
(ii) *Operation mechanism of the cognitive layer*: For the testing dataset, the following steps are implemented based on the training layer operation mechanism: (a) extract the testing dataset features based on the cognitive knowledge representation of the training dataset; (b) obtain the testing dataset cognitive results based on the built matching template; and (c) evaluate the cognitive results to obtain the heuristic feedback knowledge to guide the granularity calculation of the feedback layer. The evaluation rules are listed as follows: Firstly, the testing dataset is coarsely compared with the training dataset of the same testing dataset cognitive class, i.e., sample layer comparison. If the comparison results meet the threshold, then the present cognitive results are regarded as final outputs.

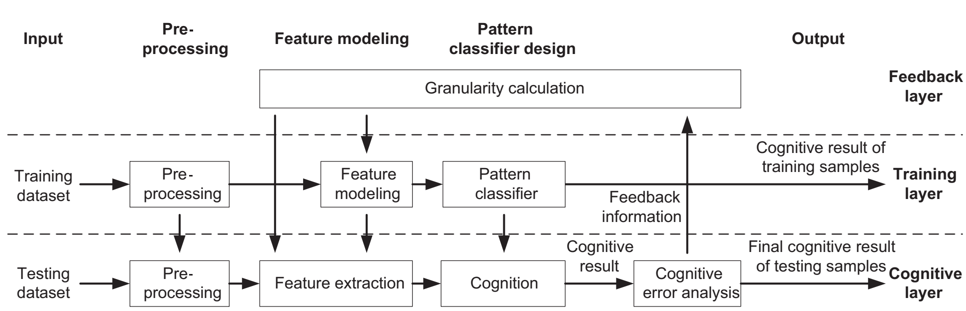

Fig. 1. Variable granularity simulated feedback mechanism-based intelligent cognitive model.