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Research on Safety Monitoring and Warning System Based on Information Fusion for Coking Production

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Abstract

Coking production process is very complex, and full of risk factors, toxic and harmful substance, it's a typical high risk industry. In view of the prominent safety hazards and strong interference to safety monitoring in coking production, put forward a kind of safety monitoring and warning system based on information fusion for coking production. To achieve the target that safety condition was monitored accurately and hazardous situation warned reliably, safety information of the monitoring and warning areas was collected by sensor network which include combustible gas sensor, dust sensor, temperature sensor, pressure sensor, flowmeter and IP camera ,and the information fusion model of safety monitoring and warning was established, and then, through the BP neural network and the D-S evidence theory algorithm, various safety information was fused. Actual tests show that it has achieved the goal that monitoring accurately and warning reliably. It is of great significance to ensure the security of coking production.

Keywords*: Coking production; Monitoring and warning system; Information fusion model; BP neural network; D-S evidence fusion*

1. Introduction

Based on the influence of the production process and equipment in the coking production, the process has typical characteristics that high temperature, high pressure, high dust, poisonous and harmful. On the other hand, gas link, dust pollution, fire, poisonous materials link and other major security risk happens frequently, so a reliable monitoring and warning system is essential safeguard. But, because of bad production environment, it has seriously affected the monitor sensor working stability and reliability, so safety monitoring and warning system working under serious threat. According to the characteristics of coking production that production area is large, production is complex, full of risk factors and the monitoring points is scattered, this paper studied safety monitoring and warning system based on information fusion for coking production. By building sensors network, optical fiber information transmission network and safety information fusion processing center that use BP neural network and D-S evidence theory, establish the monitoring and warning system suitable for coking production. Make sure that the safety state of coking production was accurately monitored and reliably warned.

2. Coking Production Process and Characteristics

The coking production system of Neimenggu Zhengneng Chemical Group divided into 14 production areas and 1 coal preparation plant. Each production area includes

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several workshop sections that include coking, gas purification, desulfurization, debenzolization, *etc*. Major equipment include coke oven, gas-liquid separator, blast condensation, electrical tar precipitator, desulfurization tower, debenzolization tower, ammonia tank, tar tank, *etc*. Coal preparation plant has some large equipment like belt conveyor, crusher, *etc*. The main process of coking production is shown in Figure 1.

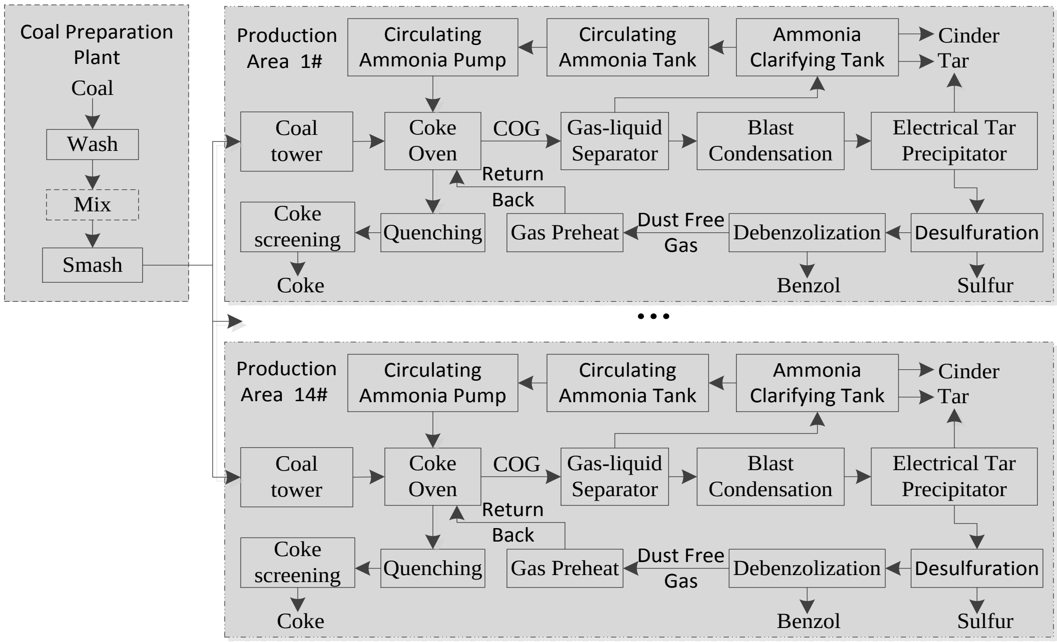

Figure 1. Main Process of Coking Production

From the main process we can know that deep processing of COG is an important link of coal coking production, and it’s a most important part of safety monitoring and warning. There are three issues in the process:

(1) Gas leak, poisoning, fire and explosion was frequently happened during production.
(2) Along with the production process, a lot of dust was made, they have great effect on sensor working condition and performance.
(3) There are so many large equipment, hazards, toxic substances in the production area, it is hardly to achieve the goal that monitoring and warning accurately and reliably only by one type of sensor.

3. Framework of Safety Monitoring and Warning System for Coking Production

The architectural framework of the safety monitoring and warning system for coking production was based on Internet of Thing (IOT) [1], it consists of three parts—information collection subsystem, data transmission subsystem and safety monitoring and warning center. As shown in Figure 2.

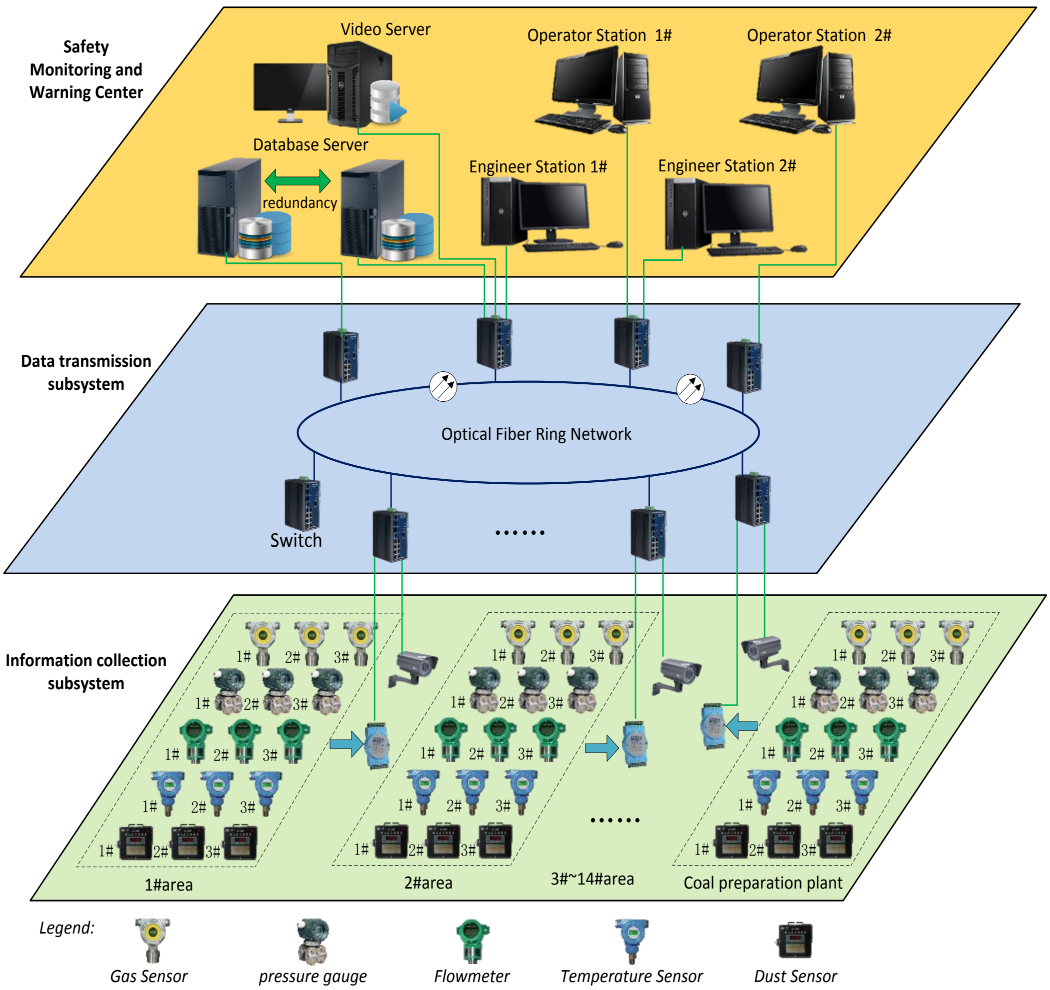

Figure 2. Framework of Safety Monitoring and Warning System for Coal Coking Production

3.1. Information Collection Subsystem

The field information was collected by the information collection subsystem, which including air CO content, air dust content, gas flow, pipeline pressure, temperature of important parts and the video image. It was composed by 70 sensors distributed in 14 production areas. In each area, there are five different types of sensor groups, each group contains 3 sensors of same type. The sensors are CO content sensor ESD3000, temperature sensor SWP-ST61, gas flow meter HOMKOM SBL, pressure sensor SWP-GT61 and dust content sensor GCG1000. In this way, field data collected by sensor groups, the reliability of information acquisition was greatly improved. And then information was upload by Ethernet data acquisition module—ADAM-6217. On the other hand, in order to collect the video images of field, the monitoring area is provided with IP camera.

3.2. Information Transmission Subsystem

The information transmission network was based on Ethernet, it build a optical fiber ring network which has the characteristics of large transmission capacity, strong anti-jamming capability, long transmission distance and high reliability. The optical fiber ring network consist 10 switches--Hirschmann MACH4002 48+4G-L3P. Because of the optical fiber ring network, forming a data transmission path with redundancy, when the destruction happened in one part of communication line, it could ensure that the transmission subsystem does not fall into communication paralysis, in order to adapt to the characters of coking production that long distance, large amount of information and strong interference.

3.3. Safety Monitoring and Warning Center

To ensure the high reliability of the safety warning center, the equipment designed with redundancy that include Database Server, engineer station and operator station [2]. Main equipment includes IPC-610H, ThinkServer TS540 and video server DH-DSS7016. Combine with the software and the model for safety state information fusion, the monitoring and warning system could realize some functions like state monitoring, alarm, video monitoring, *etc*.

4. Safety State Information Fusion and the Realization of Monitoring and Warning

4.1. Framework of Safety Monitoring and Warning System's Software

The system's software can be divided into 4 parts, they are data acquisition & safety monitoring module, safe state information fusion module, video monitoring & image characteristic analysis module and database [3-4], the framework was shown in Figure 3.

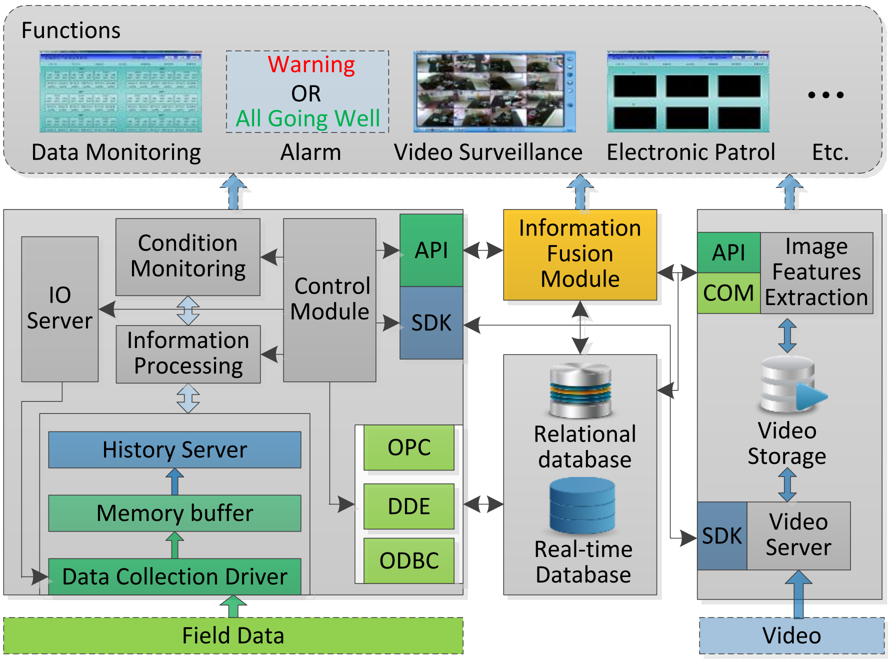

Figure 3. Framework of Safety Monitoring and Warning System Software

With the help of data acquisition driver, the data acquisition & safety monitoring module of safety monitoring and warning system collected the field data. On one hand, the field data was used to production process monitoring; on the other hand, the module and the database achieve docking through the OPC, DDE or ODBC interface, store the data in the database. Video monitoring & image characteristic analysis module's functions are video monitoring and field image feature extraction, and then the field image feature was transmitted into the database and information fusion module [5]. By Software Development Kit (SDK), we could insert video into state monitoring software. In order to realize the multiple information fusion, including field data and field image feature, information fusion module and data acquisition & safety monitoring module, video monitoring & image characteristic analysis module was docked through the API interface. In this way, the system could judge the safe state accurately and warning reliably. Through the security state information fusion, the system could make up the shortcomings of low reliability, under strong interference that bring from traditional monitoring system which consists only one type of sensor, overcome the dust, smoke and other interfering factors on the safety monitoring of the production area. Most importantly, the core of safety information fusion module is the security state information fusion model and information fusion algorithm.

4.2. Safety State Information Fusion Model

In the process of coking production safety monitoring, because of the influence of the site environment, field data are often mixed with a lot of interference information, it has serious impact on safety monitoring system. To solve above problems, safety information model use the method of information fusion based on BP neural network and D-S evidence theory to improve the accuracy and reliability of the system. BP neural network has characteristics of strong fault tolerance ability, adaptive and self-learning, and have advantages in terms of mass data processing. But it also has some shortcomings like "unknown information" mistaken for "unsure information" [6]. While the D-S evidence theory relies on evidence accumulated to narrow assumptions interval, based on multiple accurate judgment and description, refining consistency, eliminate contradictory information, "unsure information" can be processed very well. Through the combination of the two, the system could realize safety monitoring and warning function bitterly [7]. Information fusion model was shown as Figure 4.

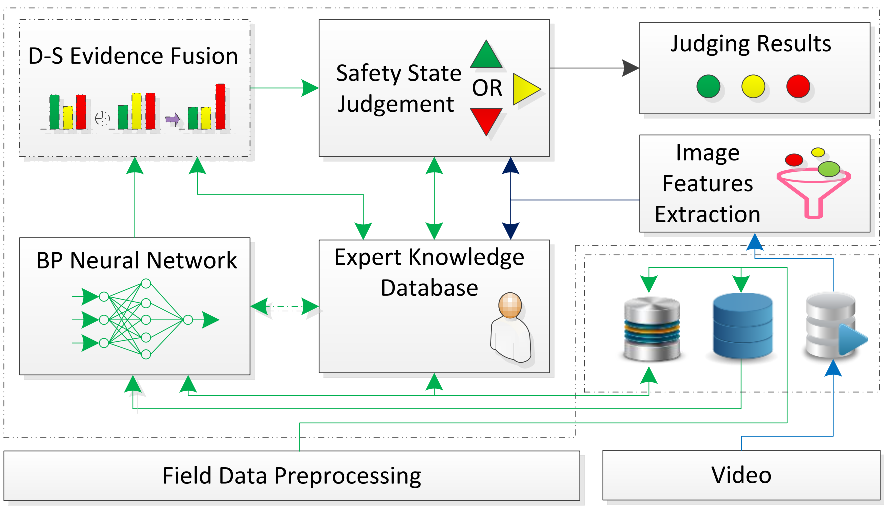

Figure 4. Information Fusion Model of Safety Monitoring and Warning System for Coking Production

When the field data, which is preprocessed, is stored in database, on the one hand, it was used as materials to build the expert knowledge database, which include sensor data features, image features, data relationship, *etc*., and the main function of expert knowledge database was supporting the judgment of safety state. On the other hand, through using the method of BP neural network, together with the expert knowledge, it could construct several of security status evidence. And then, through using D-S evidence fusion algorithm, the information fusion model taking all aspect of evidence into account to fusion analysis. Fusion results combined with expert knowledge and the image feature were analyzed for security state judge, and finally get the security status of the production area accurately.

4.3. BP Neural Network and Security State Evidence

In order to use the algorithm of D-S evidence theory in multiple security state information fusion processing, firstly you need to be able to make many aspects of evidence that fully reflect the field environment [3]. Every aspect of security state information that collected by sensor group was fusion partially by BP neural network, and the results are the evidence that stand for different aspects security information. We could get five groups of independent evidence by BP neural network, they represent for gas content in the field, dust content in the field, temperature of important parts, pipeline pressure and gas flower.

The BP neural network adopts three-layer structure. The numbers of hidden layer nodes was determined referring to the formula (1) [8].

$$l = \sqrt{m+n} + a \quad (1)$$

While, m is represent for the number of input layer nodes, n is represent for the Number of output layer nodes, a is adjustable variables, it needs to be determined according to the requirements of the learning rate and the error of the neural network. The input of BP neural network was feature vector (I_1, I_2, I_3), and I_1, I_2, I_3 represent for information feature that collected by 3 sensors of the same type. The output of the BP neural network was feature vector composited by credibility of security level of the monitoring and warning area: $\{m(A_1), m(A_2), m(A_3)\}$, $m(A_i) \in [0,1]$, security level division was "A_1 =Normal", A_2 =Attention ", "A_3 =Dangerous". There are five different types of BP neural network; each of the inputs was representing for one type of security information. Using the methods of partial fusion, we could get 5 aspects evidence [4]. The structure of BP neural network was shown as Figure 5.

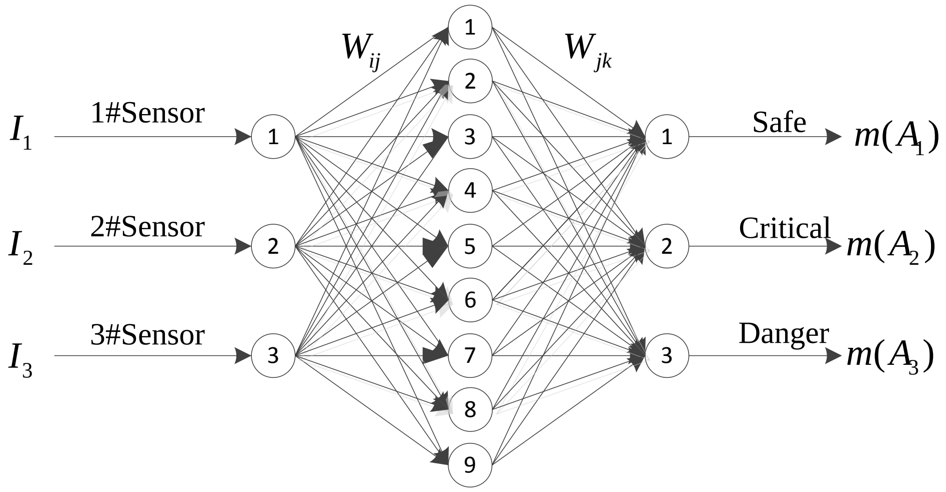

Figure 5. Structure of BP Neural Network for Information Fusion Model

As shown in the picture, through experiments can know when a=6, that is to say, when have 9 hidden nodes, the training error and the training time of BP neural networks to get the best. The initial connection weights was choose randomly from $[-1,1]$,The hidden layer function selects the double tangent function-$f(x)=\frac{e^x-e^{-x}}{e^x+e^{-x}}$,the output layer function selects the Sigmoid function--$f(x)=1/(1+e^{-x})$. Duo to the form of the function, it has different influence on the BP neural network's convergence speed and error, so the function is modified to $f(x)=1/(1+e^{-k(x+\sigma)})$, improve the adaptability of the neural network through regulation of the slope k and offset parameters σ ,speed up the network convergence.

In view of 5 kinds of security state information, 150 sets of pretreated field data were selected as the sample, the 5 different types of BP neural network was trained and tested by MATLAB software, set the target error σ=0.001. Take the BP network of gas content for instance, the result was shown as Figure 6.

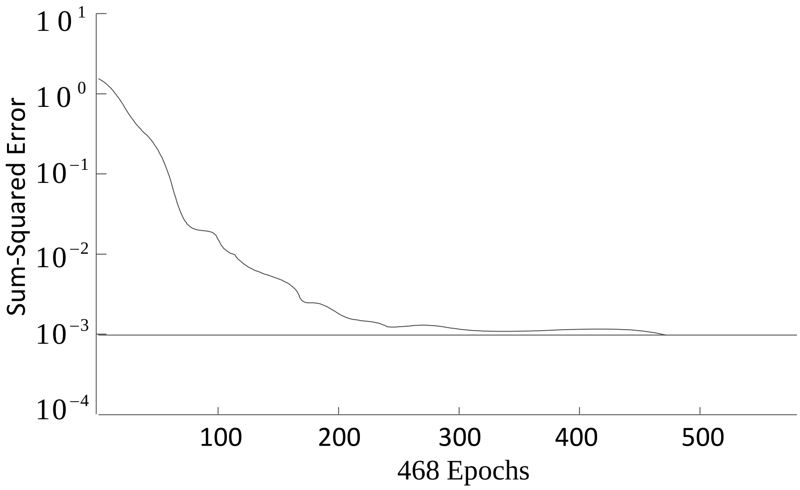

Figure 6. Simulation Results of Error Convergence of BP Neural Network

As can be seen from Figure 6, after 468 times of training, errors meet the requirements.

4.4. D-S Evidence Fusion Algorithm of Security State Information

After got the 5 types of evidence by BP neural network, it is need to using D-S evidence theory algorithm on evidence fusion, to achieve the goal of comprehensive consideration and accurate judgment [9].

According to the division of security state level, built the framework of security state judgment $\Theta=\{A_1,A_2,A_3\}$ .The event " A_1 =Normal", A_2 =Attention", " A_3 =Dangerous". Define the basic dependability distribution function m on 2^Θ m satisfying the condition:

$$\Theta=\{A_1,A_2,A_3\} \tag{2}$$

$$\sum_{A_i\subset\Theta} m(A_i)=1 \tag{3}$$

Among them, $m(A_i)$ is represents for the degree of the evidence m to support the event A_i occurs. Called basic credibility distribution value. Evidence that obtained through BP neural network were recorded as $m_1(A_i)$=gas content, $m_2(A_i)$=temperature of important parts, $m_3(A_i)$=pipeline flower, $m_4(A_i)$=pipeline pressure, $m_5(A_i)$=dust content, $i=1,2,3$. And then, evidence fusion. First, calculate the normalized constant K.

$$K = \sum_{A_p \cap A_q \cap A_u \cap A_q \cap A_u \neq \Phi} m_1(A_p) \cdot m_2(A_q) \cdot m_3(A_u) \cdot m_4(A_m) \cdot m_5(A_n) \tag{4}$$

Among them, A_p, A_q, A_u, A_m, A_n represents for security state of the framework of security state judgment. That is $A_p, A_q, A_u, A_m, A_n \subset \Theta$, the calculation formula for fusion is：

$$M_{end}(A_i) = m_1(A_i) \oplus m_2(A_i) \oplus m_3(A_i) \oplus m_4(A_i) \oplus m_5(A_i)$$

$$= \frac{1}{K} \sum_{A_p \cap A_q \cap A_u \cap A_q \cap A_u \neq A_i} m_1(A_p) \cdot m_2(A_q) \cdot m_3(A_u) \cdot m_4(A_m) \cdot m_5(A_n) \tag{5}$$

"$\oplus$" is represents for the calculation of the basic credibility distribution value [10], $M_{end}(A_i)$ is represents for the final credibility distribution of security state A_i.

The MATLAB are used for the modeling and simulation of the information fusion model. Extracting 6 sets of field data in 1# area, process the data with the trained BP neural network, got 5 types of independent evidences, including m1: gas content in the environment, m2: temperature of important parts, m3: pipeline flower, m4: pipeline pressure, m5: dust content in the environment and S: image feature support degree. When the result $M_{end}(A_i)$ is above 0.6, we think of the fusion result judgment of security state is reliable, that is, the event the system judged has occurred. The simulation result was shown as Figure 7.

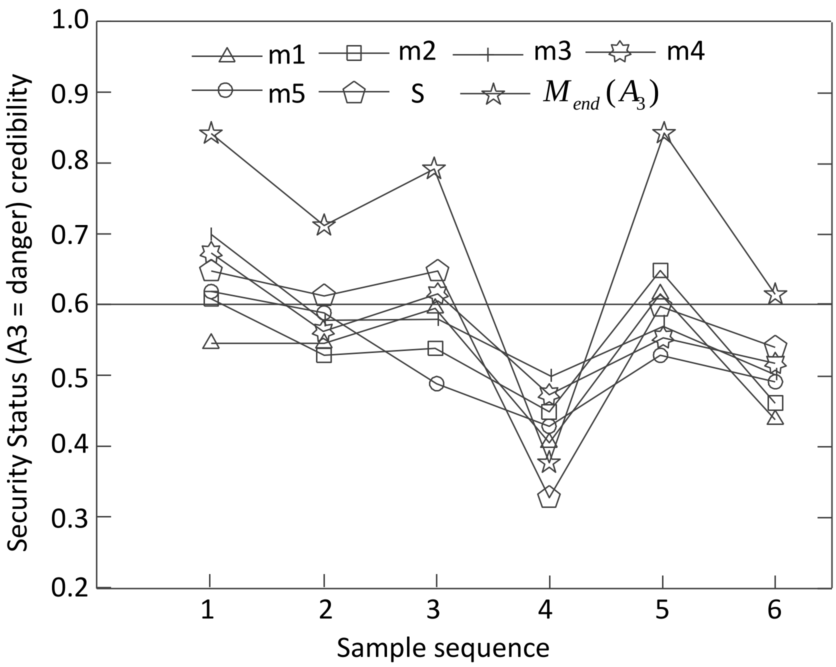

Figure 7. MATLAB Simulation Result of Safety Information Fusion Model

As is shown in Figure 7, compared the judgment results obtained by fusion of 5 aspects information and the determination results of single sensor information can be seen that the information fusion model improved the reliability of monitoring and warning greatly. By using BP neural network and D-S evidence fusion algorithm to judge the current safety status is more reliable. Simulation results show that information fusion model based on BP neural network and the D-S evidence fusion algorithm is suitable for the coking production safety monitoring and warning.

5. Results and Analysis of the Application of Monitoring and Warning System

When the system was put into operation, select 3 set of field operation data from the historical records of 1# area including gas content in the environment, temperature of important parts, pipeline flower, pipeline pressure, dust content in the environment image feature support degree and monitoring and warning results. The result was shown as Table 1.

Table 1. The Field Operation Data Records

Items		Security status classification A1	A2	A3	Data analysis results	System analysis results
1	m1	0. 50	0. 49	0. 10	A1	**A1**
	m2	0. 44	0. 44	0. 12	UN	
	m3	0. 51	0. 31	0. 18	A1	
	m4	0. 45	0. 4	0. 15	UN	
	m5	0. 32	0. 55	0. 13	A2	
	M	0. 62	0. 37	0. 01	**A1**	
	S	0. 62	0. 33	0. 05	A1	
2	m1	0. 02	0. 60	0. 38	A2	**A2**
	m2	0. 01	0. 52	0. 47	A2	
	m3	0. 05	0. 49	0. 46	UN	
	m4	0. 04	0. 51	0. 45	A2	
	m5	0. 06	0. 45	0. 49	UN	
	M	0. 00	0. 65	0. 35	**A2**	
	S	0. 00	0. 55	0. 48	A2	
3	m1	0. 13	0. 40	0. 47	UN	**A3**
	m2	0. 25	0. 29	0. 46	UN	
	m3	0. 14	0. 35	0. 51	A3	
	m4	0. 05	0. 36	0. 59	A3	
	m5	0. 09	0. 35	0. 56	A3	
	M	0. 03	0. 26	0. 71	**A3**	
	S	0. 10	0. 13	0. 77	A3	

As shown in Table 1, the field data was processed by the BP neural network, and m1, m2, m3, m4, m5 and S represent for gas content in the environment, temperature of important parts, pipeline flower, pipeline pressure, dust content in the environment and image feature support degree. M represents for $M_{end}(A_i)$, and UN was short for “unknown security state”. Field operation data record analysis shows that, by multi- information fusion, actual operation results are consistent with the simulation results, it improved the reliability of security state monitoring and warning greatly. The system together with image feature auxiliary analysis, ensure the accuracy of safe state judgment through information fusion.

6. Conclusion

Based on information fusion of coking production safety monitoring and warning has been put into operation, the actual operation results show that the system has the following advantages:

(1) According to the characteristics of the coking production, the system use the sensor groups to collect field information including gas content in environment, temperature of important parts, pipeline flower, pipeline pressure, dust content and field video, build the model of security state information fusion based on BP neural network and D-S evidence theory, achieve the goal that improving the reliability of security state judgment and danger warning effectively.

(2) Monitoring and warning system based on information fusion for coking production is of great significance to ensure the security of coke production. It has wide application in other related safety monitoring field.

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