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# Comprehensive alarm information processing technology with application in petrochemical plant

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During the abnormal plant conditions, too much information is produced due to momentary plant excursions above alarm limits. This flood of information impedes correct interpretation and correction of plant conditions by the operator. Existing techniques for the design of alarm systems mostly have weak ability to handle complex hazard scenarios and increase the probability of larger safety issues. In this paper, a comprehensive alarm information processing (AIP) technology is introduced, called multi-round alarm management system (MRAMS), including several processing strategies: AIP based on single sensor, AIP based on sensor group, root cause diagnosis based on Bayesian network, sensor fault judgment method and false alarm inhibition method. In case studies, both simulation experiment and pilot application on a real petrochemical plant are presented. Results indicate the MRAMS is helpful in improving the accuracy of correctly diagnosing the root causes and hence avoiding false and redundant alarms. By adopting this new technology, the safe and reliable operation of the plant can be achieved, and the economic loss brought by improper alarms can be reduced.



## 1. Introduction

With the increasing complexity and high integration of industrial processes, alarm floods caused by correlated process variables are becoming a major concerned safety issue (Wang et al., 2015). In complex process system risks can emerge including intractable risks that are not the resultant of the combination of active failures and latent conditions. That means even when all components of a system function correctly, their interaction needs not be compatible, and disaster can still occur as safety is an emergent system property (Pasman et al., 2013). Therefore the alarm information processing (AIP) technology is of paramount importance to the process safety management that enables the operators to quickly and correctly diagnose the root causes of the abnormal situation and provide suitable corrective actions. AIP technology has attracted growing attention in the past. As a sustainable development theme is pursued by modern process industries, the demand for an advanced, safer, and more effective AIP technology is desired.

Modern process systems are usually equipped with distributed control systems (DCSs) to ensure safe operation and high product quality. Typically within a DCS, an alarm system is installed and maintained. In the alarm system, high/low and/or high–high/low–low alarms are often configured for important process variables so that operators can maintain variables within their defined operating limits, i.e., alarm thresholds, to achieve best operation performance. When a variable moves beyond the defined operating limit, an alarm is triggered and the operators are notified that there might be an abnormal event happening. Generally alarm thresholds are carefully determined during the commissioning of plants. Alarms with poorly assigned thresholds frequently result in false alarms and missed alarms.

Out of all the alarms, only one or two are the root alarms. The rest are merely “effect” alarms or “phantom” alarms (Leung and Romagnoli, 1999). “Effect” alarms are due to the interactions between process variables. This undesired situation is called an “alarm flood”. In such situations, the operator might not be able to fulfill his required tasks to keep the plant within safe operation limits and to find the root cause of the disturbance. Takeda et al. (2014) investigated a logical and systematic alarm system design method for first alarm alternative signals, by using modules to investigate the sets of alarm sensors and the alarm limits setting for first alarm alternative signals to distinguish the fault origin. The completeness of fault propagation for a branch of the cause-effect

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model as the plant model was explained. Zhu et al. (2014) proposed a strategy to control alarm floods for chemical process transitions. To generate useful alarms in fault situations, an artificial immune system based on dynamic time warping (DTW) is used for fault detection and diagnosis. Chao and Liu (2004) proposed an alarm management framework for automated network fault identification, in which the concepts of redundant/ringleader alarms and innocent network elements were also introduced into the framework to obtain an effective diagnosis. Adhitya et al. (2014) paid attention to the human aspect during the developing of various methods and tools for better alarm management. The time of occurrence of critical alarms before they were actually triggered was predicted. Brooks et al. (2004) proposed a new mathematical treatment of alarms that considered them as multi-variable interactions between process variables to calculate values for alarm limits. This had resulted in substantial reductions in false alarms, and also unified alarm management, process control and product quality control into a single mathematical framework. Some literature (Yang et al., 2012; Schleburg et al., 2013) focused on the problem of multivariate alarm analysis and rationalization which is complex and important in the area of smart alarm management due to the interrelationships between variables. Other research works such as managing alarm floods by improving the interface of alarm systems were reported (Laberge et al., 2014).

Existing techniques for the design of alarm systems mostly have weak ability to handle complex hazard scenarios in which fault interdependencies make alarm floods more serious and increase the probability of larger safety issues. An effective AIP technology is desired for a safe and effective operation of a process plant. In this paper a comprehensive AIP technology, named Multi-round Alarm Management System (MRAMS) is proposed. It involves several AIP strategies to be carried out step by step in-depth, in order to reduce false, missed and redundant alarms. Both simulation experiment and actual application on petrochemical plant are presented to validate and evaluate the effectiveness of the proposed technology.

The rest of the paper is organized as follows. In Section 2, the principles of the MRAMS are presented. Five integrated AIP strategies in MRAMS with their respective functions are illustrated in Section 3 with detailed computational procedures. Then simulation experiment and field application are demonstrated to show its effectiveness respectively in Section 4 and Section 5. Comparison with traditional alarm system in DCS is also presented followed by concluding remarks in Section 6.

## 2. Principles of the multi-round alarm management system

Process systems are usually equipped with a system of online monitoring, so any deviation of variable will be transmitted to the control center in real time, with the help of which operators can understand the current state of system clearly and take appropriate actions. However because of sensor fault, abnormal information transmission, personnel misoperation, etc., alarm floods (or redundant alarms), missed alarms and false alarms generally exist over a long period. Some reasons are analyzed as Table 1.

**Table 1**
Some reasons about alarm problems.

| Problems | Reasons |
|---|---|
| Alarm floods (redundant alarms) | Variables vibrate around the alarm thresholds.<br>Cascading faults and common cause faults happen. |
| Missed or false alarms | The power supply of the sensor is depleted.<br>External environment changes or it depredates gradually (Loss-of-function).<br>Potential hazard or hidden failure. |

MRAMS is designed integrating five processing strategies: AIP based on single sensor, AIP based on sensor group, root cause diagnosis based on Bayesian network, sensor fault judgment method and false alarm inhibition method. The functions of each strategy are shown in Fig. 1.

The MRAMS can be carried into execution as Fig. 2, in which the detailed processes are stated as follows:

Step I: Given that a sensor function group $G$ is composed of $N$ sensors, represented by $G = \{S_1, S_2, \ldots, S_N\}$ (the determination of a function group will be explained in Section 3.5), for each sensor $S_i$ in the $G$, "sensor fault judgment method" is applied first to isolate the alarms from the invalid sensors. Further maintenance will be carried out to repair.

Step II: If sensor $S_i$ is considered as normal (fault-free), "false alarm inhibition method" is applied to determine whether the original alarm from sensor $S_i$ needs inhibition. By this strategy if the alarm is judged as a false alarm, the sensor $S_i$ will get an inhibition mark, and there will be no alarm signal displaying on the monitoring system on the present moment.

Step III: If sensor $S_i$ is considered as normal (fault-free), "AIP based on single sensor" is applied to handle the situation that the variable monitored by sensor $S_i$ vibrates around the alarm threshold. Such redundant alarms can be eliminated.

Step IV: "Root-cause diagnosis based on Bayesian network" as the most important step in MRAMS is further applied to discover the root causes of the original alarm, which helps operators to quickly take the most reasonable measures. It also can be used to reduce redundant and missed alarms.

Step V: In order to pay much attention of the incipient faults or potential safety hazards when relevant variable values deviate from normal ranges but haven't exceeded their thresholds yet, "AIP based on sensor group" is applied to set off an early warning alarm for such situation. This strategy can help operator to carry out proactive and predictive maintenance in advance before accident eventually happens.

## 3. Main processing strategies in MRAMS

### 3.1. Step I: sensor fault judgment method

Sensor fault, also known as instrument failure, refers to the significant deviation between the measured variable and the real value. A sensor usually consists of a sensing device, converter, signal processing unit, and the communication interface. Any part of above component is likely to fail, so the deviation between the actual output signal of the sensor and the actual variable value (nominal value) will be found beyond the allowable range. In the proposed strategy, the faults as complete failure or bias can be detected, and the alarms from the invalid sensors have to be isolated.

In a period of time $T$, if the variable value continues to be close to zero or exceed a reasonable range (eg. the design load), the corresponding sensor can be judged as malfunction. Its observable cannot be used for alarm management. Further check and replace of the sensor will be carried out as soon as possible. The work flow is shown in Fig. 3.

It should be noticed that, if more accurate diagnosis of sensor is expected, method such as principal component analysis (PCA) can be used to perform sensor fault judgment in depth. The Hotelling $T^2$ and squared prediction error (SPE or $Q$) from the PCA are often used for fault diagnosis. For a more detailed review of the PCA based sensor fault diagnosis reference, please see, e.g. Jackson (1991),