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Alarm clustering analysis and ACO based multi-variable alarms thresholds optimization in chemical processes

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ABSTRACT

In chemical process, excessive alarms, high false alarm rate (FAR), and high missed alarm rate (MAR) generated by unreasonable setting to variable alarm thresholds are the main causes of affecting operation stability and device safety. In this paper, a clustering analysis based method was proposed to optimize the variable alarm thresholds. Variables are first clustered into groups using standardized Euclidean distance before variable weights are given by entropy weight method. Second, the probability density functions of the variables are fitted with process data under normal and abnormal conditions. An objective function about the FAR, MAR, and average alarm delay (AAD) is then established with variable weight and alarm delay. Finally, the objective function is optimized to find the optimal alarm thresholds using ant colony optimization (ACO) method. Case study of an industrial atmospheric-vacuum crude distillation shows that the proposed method can effectively reduce FAR and MAR.

1. Introduction

Alarm thresholds of the measurable variables in chemical process need to be set properly by alarm management system to keep the safety and the stability of the chemical production process. Alarms are activated when the process values of variables exceed their alarm threshold, so reasonable alarm threshold setting is of vital importance for the whole production process. Too high thresholds lead to some significant alarms lost and increase the potential danger of device involved. In contrast, too low thresholds yield too many invalid alarms and interfere with the operator's attention on the important alarms.

In practice, many false alarms, high false alarm rate (FAR), and high missed alarm rate (MAR) arise in chemical processes (Foong et al., 2009; Izadi et al., 2009a,b). They are mainly caused by the ineffective management of alarm system and unreasonable variable threshold setting. According to the statistics of EEMUA, the alarm number that an operator can effectively handle is about 150 per day (one alarm every 10 min), with a maximum number of about 300 per day (one alarm every 5 min) (EEMUA, 2007).

There have appeared many optimization methods for setting process variable threshold in chemical process. For example, in terms of FAR and MAR, Verdier et al. (2008) improved the change detection algorithm CUSUM to obtain adaptive alarm threshold with constant FAR in process. Izadi et al. (2009a,b) presented a framework about the best filter based on FAR, MAR, time delay, and deadband. Chen (2010) developed two-stage control limits of Q and T^2 statistics in multivariate statistical process to reduce FAR according to Bernoulli's data distribution. Naghoosi et al. (2011) proposed an objective function about FAR and MAR, and estimated the best thresholds by minimizing the objective function via the relationship between alarm deadband and threshold. Zang and Li (2014) proposed a multidimensional kernel density estimation approach to optimize threshold via an objective function about FAR and MAR. Han et al. (2016) proposed a multi-variable alarm threshold optimization method to reduce alarms by combining FAR and MAR with correlation coefficient. These methods have been improved by intelligent algorithms in the last decade. For example, Mezache and Slitani (2007) used fuzzy neural network and genetic algorithm to estimate threshold. Burgess et al. (2009) constructed a dataset-based model to analyze alarm frequency with various alarm limits of heart rate and respiratory rate. Jiang (2010) established online and offline models to optimize alarm threshold. Yang et al. (2010) determined optimal threshold in line with the difference of correlations between the process data and alarm data. Kondaveeti et al.

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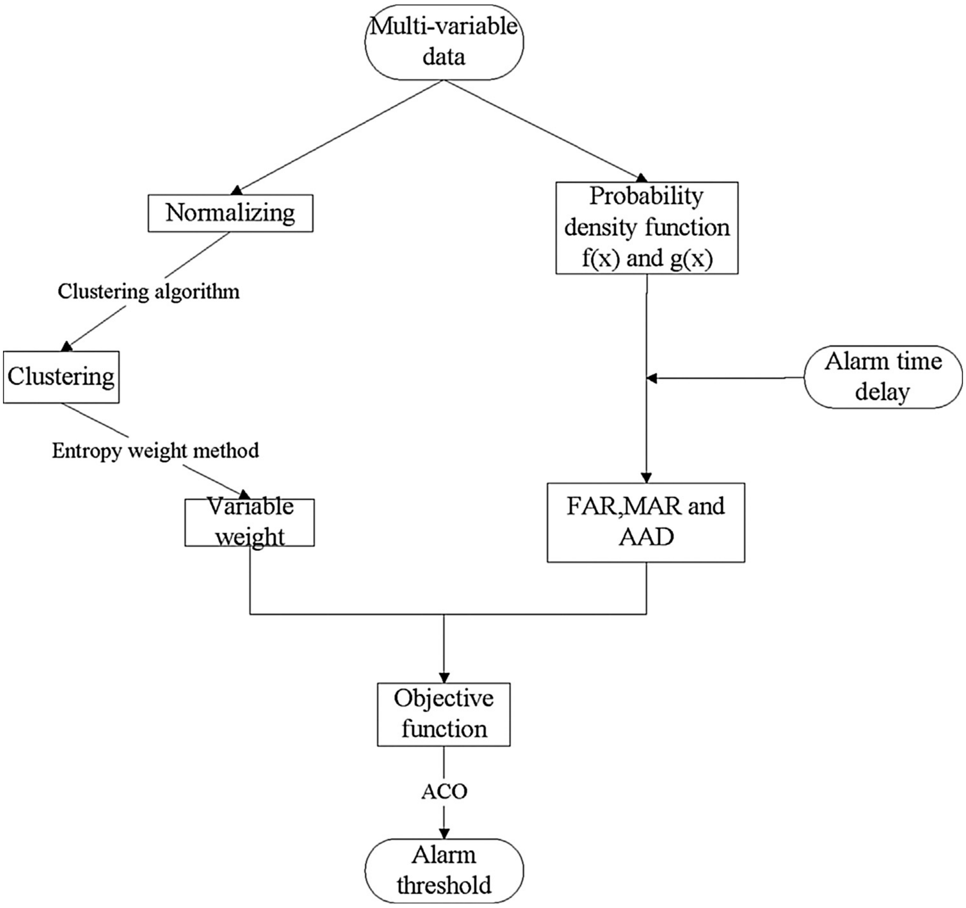

Fig. 1 – Flow chart of alarm threshold optimization scheme.

(2011) reduced the number of harmful alarms in process by using the Markov chain model and choosing appropriate delay time. Zhou et al. (2011) used an auto-associative neural network (AANN) technique to explore environment-tolerant capacity and set alarming threshold to reduce the uncertainty in AANN-based structural damage alarming system. Zhao and Zhu (2012) proposed a data filter based automatic alarm suppression strategy to deal with repeated alarms. Liu et al. (2012) used a kernel density estimation method to assess the state of process alarm based on historical data and numerical optimization method. Wang and Chen (2013) proposed an online method to promptly detect the chattering alarms caused by oscillation and to effectively reduce the number of chattering alarms. Jablonski et al. (2013) proposed a methodology for automatic threshold calculation in a large monitoring system by modeling probability distribution functions. Van Wynsberge et al. (2013) statistically defined relevant alarm threshold in monitoring environmental variables. Şimşek and İç (2014) presented a multi-response based simulation–optimization method to improve the performance of an alarm monitoring center. Combining alarm similarity analysis and process causality analysis, Wang et al. (2015) identified the consequential alarms based on their evolution paths. Abdou et al. (2015) optimized alarm thresholds in OS-CFAR system by using simulated annealing algorithm. Wang et al. (2016) provided an overview of industrial alarm systems, including main causes for alarm overloading, current research status, and open problems from engineering. For above methods, variables are not clustered and grouped when their thresholds are optimized. For a high dimension of variables, the number of alarms in process increase significantly with increasing number of measurable variables. Many false alarms resulting from trivial disturbances will confuse the attention of operators in the central control room, leading to some important alarms missed consequently. Thus, a dimension reduction is of great significance for alarm optimization.

This paper proposed a clustering algorithm and entropy weight based threshold optimization method using standardized Euclidean distance. The proposal clusters multiple variables and calculates their weights with an objective function about FAR, MAR, and average alarm delay (AAD). Ant colony optimization (ACO) method is used to optimize the objective function to obtain variable threshold. Our proposal could not only cluster multiple variables, but also reduce unnecessary alarms. Compared with traditional methods, this method can effectively reduce the rate of false alarm and missed alarm to guarantee the safe operation of plants, avoid excessive invalid alarms, and reduce operation load. The following section will outline the detailed optimum design process of alarm threshold, followed by an industrial atmospheric-vacuum crude distillation case study.

2. Optimum design of alarm threshold

2.1. *Alarm threshold optimization scheme*

Fig. 1 depicts the optimization algorithm on alarm threshold. First, based on normalized multi-variable data, the sum of standardized Euclidean distance between one variable and all other variables is calculated and normalized to cluster variables into groups and obtain variable weights. Then, an objective function about the FAR, MAR and AAD is established following fitting of probability density functions. The obtained weight is combined with FAR with regard to the potential safety hazard generated by increasing MAR. Finally, the objective function is optimized using ACO method to obtain optimal alarm threshold.

2.2. *Efficiency index of alarm system*

FAR, MAR, and AAD are three common efficiency indices of alarm systems. FAR represents the probability of a variable lying in normal state when its value goes beyond its threshold.