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Research article

A method to remove chattering alarms using median filters

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A B S T R A C T

Chattering alarms are the most found nuisance alarms that will probably reduce the usability and result in a confidence crisis of alarm systems for industrial plants. This paper addresses the chattering alarm reduction using median filters. Two rules are formulated to design the window size of median filters. If the alarm probability is estimated using process data, one rule is based on the probability of alarms to satisfy some requirements on the false alarm rate, or missed alarm rate. If there are only historical alarm data available, the other rule is based on percentage reduction of chattering alarms using alarm duration distribution. Experimental results for industrial cases testify that the proposed method is effective.

1. Introduction

Alarm systems form the essential part of the operator interfaces in large modern industrial facilities such as chemical plants, power stations and oil refineries. An alarm indicates potential problems, and directs the operator's attention towards plant conditions requiring immediate assessment or corrective action. Therefore, alarm systems play an important role in preventing, controlling and mitigating the effects of abnormal situations [1,2].

According to EEMUA [1], every alarm presented to an operator should be useful and an operator should not receive more than six alarms per hour during normal operation of a plant. However, this is the rare case in practice. Alarm variables, on the one hand, are very easily implemented in modern industrial plants that are usually equipped with computerized monitoring systems such as distributed control systems and supervisory control and data acquisition systems. Generally the more alarm variables are configured, the more safety is deemed to be improved. Therefore, the number of configured alarm variables has increased exponentially [3], and there are tens, hundreds or even thousands of alarms raised per hour. As a result, many existing industrial alarm systems have far too many alarms to be handled by plant operators. Performance metrics of existing industrial alarm systems are summarized in Table 1 [4], which are based on a study of 39 industrial plants ranging from oil and gas, petrochemical, power and other industries. The benchmarks in EEMUA [1] are provided for reference. Obviously, the actual alarm rates in the various industries exceed the recommended number of alarms in the EEMUA [1] benchmarks.

Alarms can be classified into nuisance alarms and correct alarms. A nuisance alarm is one that does not require a specific action or response from operators [1,4]. An alternative definition of a nuisance alarm is an alarm that annunciates excessively, unnecessarily, or does not return to normal after the correct response is taken [2]. Hence, nuisance alarms are the ones that do not affect the process, even if these alarms are ignored by operators. A correct alarm is the one that requires operators to pay attention or to take action in prompt manner [4].

However, according to industrial surveys provided by Rothenberg [4] and Bransby and Jenkinson [5], a majority of alarms that operators of industrial plants received are nuisance alarms. Therefore, nuisance alarms considerably weaken the usability of alarm systems, and often lead to a confidence crisis of alarm systems.

Chattering alarms, which are caused by noise or disturbance, are the most found nuisance alarms and may account for 70% of alarm occurrences [3]. A chattering alarm is an alarm that is activated and cleared many times within a short time period. Rothenberg [4] defines chattering alarms as the ones that activate ten or more times within 1 min, and alarms repeating more than three or more times in 1 min are chattering alarms in the ISA standard [2].

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Table 1
Cross-industry activation study.

	EEMUA	Oil & Gas	PetroChem	Power	Other
Average alarms per day	144	1200	1500	2000	900
Peak alarms per 10 min	10	50	100	65	35
Average alarms per 10 min	1	6	9	8	5

Because different types of process variables have different time scales in terms of variation dynamics, there is not a unanimous definition for chattering alarms in the literature. In this context, considering the sampling period of process variables and generalizing the rule of thumb from the ISA standard [2], for a process variable with the sampling period T, chattering alarms are defined as alarms that repeat more than three times in the duration of sixty times of the sampling period T.

Clearly, eliminating the chattering alarms can improve the efficiency of an alarm system. Consequently, how to reduce chattering alarms has recently been receiving much attention among engineers and researchers. EEMUA [1] and ISA [2] suggest that some methods be used in practice, such as, filters, deadbands, delay timers, and shelving, to remove chattering alarms. Izadi et al. [6] presented a procedure based on the Receiver Operating Characteristic (ROC) framework to design optimal filters, deadbands, delay timers by considering two major trade-offs between the false alarm rate and missed alarm rate, and between latency and accuracy. Hugo [7] proposed an adaptive alarm deaband method to reduce the number of chattering alarms via an ARIMA model based on process variable measurement. Naghoosi et al. [8] studied the relation between alarm deadbands and optimal alarm limits, and estimated the optimal threshold with respect to the deadband and history of the process variable. In order to quantify the degree of chattering, Kondaveeti et al. [9,10] defined a chattering index based on the run lengths of alarms, and Naghoosi et al. [11] developed a method to estimate the chattering index based on the statistical properties of the process variable as well as alarm parameters, and derived an alarm chattering formula for alarm deadbands to aid in optimal design. Wang and Chen [12] revised the chattering index and proposed an online method to detect the repeating alarms due to oscillation and exploited two mechanisms to reduce the number of chattering alarms. To overcome the drawbacks of the above-mentioned chattering indexes, Wang and Chen [13] formulated two rules to detect chattering and repeating alarms using alarm durations and intervals, and proposed an online approach to remove chattering alarms, using three performance indices, namely, the false alarm rate (FAR), missed alarm rate (MAR) and averaged alarm delay. An efficient design strategy was provided to select an appropriate delay timer using the historical alarm data [14].

Median filters are nonlinear digital filtering techniques and have been widely used to remove noises in the field of signal processing [15]. Median filters outperform linear filters in environments where the assumed statistics deviate from Gaussian models and are possibly contaminated with outliers [16]. A method to remove chattering alarms using median filters is proposed in this paper. Two rules to design the window size for median filters are formulated. If the past samples of the process variable in the normal and abnormal conditions are available, according to the maximum probability of alarms in $60T$ (T is the sampling period), a window size is chosen for a median filter to satisfy the requirements on FAR, or MAR. If only alarm data is available, according to the cumulative distribution function of alarm duration distribution, a window size is chosen to satisfy the reduction percentage of alarms. The advantages of the proposed graphic design method are its simplicity and ease in implementation, which are desirable for field engineer.

The rest of this paper is arranged as follows: Section 2 introduces some preliminaries for the paper. Section 3 gives a brief introduction to median filters and discusses its performance. Section 4 addresses the design steps of median filters using process data, and presents the simulated results. Section 5 gives a design method based on alarm data, and presents the design example. Finally, some concluding remarks are given in Section 6.

2. Preliminaries

This section introduces some terminology used later in the paper.

An abnormal situation is defined as an event disturbing a process that requires the operators to intervene to supplement the control system. This definition specifically is used to distinguish among normal, abnormal and emergency situations from the perspective of console operations [1,2].

Assume a process variable $x(t)$ has a probability distribution function (PDF) $p(x)$ at normal situation, a PDF $q(x)$ at abnormal situation, and the high-alarm trip point x_{tp} is shown in Fig. 1, then the definition of the FAR and MAR are [6]:

$$FAR = \int_{x_{tp}}^{\infty} p(x)dx \tag{1}$$

$$MAR = \int_{-\infty}^{x_{tp}} q(x)dx \tag{2}$$

A chattering index ψ is an index to measure chattering alarms, which is presented by Kondaveeti et al. [9,10] based on run length distributions:

$$\psi = \sum_{r\in N} P_r \frac{1}{r} \tag{3}$$

where r is a run length, which is the time difference between two consecutive alarms on the same tag. P_r represents the probability and $P_r = n_r \Big/ \sum_{r\in N} n_r$, $\forall\, r\in N$, where $n_r$represents the alarm count

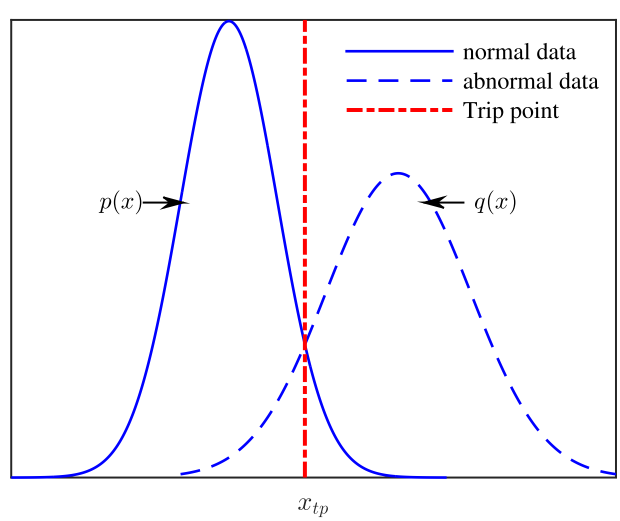

Fig. 1. Probability density functions of normal and abnormal data and high-alarm trip point.