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An approach to combining related notifications in large-scale building management systems with a rehabilitation facility case study

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A R T I C L E I N F O

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A B S T R A C T

ICT advances have enabled the incorporation of multiple devices that monitor various aspects of the environment into building management (BM) systems. The data from these devices is used to detect multiple abnormal situations, which require the awareness of system users and/or timely response. However, the number of abnormal situations is usually large, and delivering all of the associated notifications is overwhelming for users, rather than helping them to interpret the ongoing status of the environment. This work proposes a novel approach for combining ongoing notifications in the monitoring systems by their types, priorities, locations, and receivers. The approach is based on formal classification of possible alarms and runtime analysis of ongoing notifications with the aim of reducing repeating information pieces delivered as part of multiple notifications. The paper provides details of combination principles of notifications and applies them to real data from a rehabilitation facility. The results show a reduction in the users' information load of approximately 42% of the peak number of ongoing notifications. It is expected that the proposed approach will improve situation awareness in the managed facilities – enabling better and faster decisions on the ongoing status of the environment.

1. Introduction

Present day control and monitoring systems can be equipped with a wide range of heterogeneous devices capable of monitoring various aspects of the environment, the process of interest, and even the health and mental state of system users. This fact is especially evident in building management (BM) systems, where advancements in information and communications technology (ICT) have enabled the first steps toward integration of various building subsystems which have dramatically increased BM system capabilities along with the diversity of devices [1,2]. The number and diversity of devices, in turn, allow detection of multiple abnormal situations, which should, in principle, improve situation awareness and help the users to make correct and timely decisions. However, the number of notifications associated with abnormal situations is usually large and instead of helping the users to interpret the ongoing status of the environment, this can overwhelm a user's cognitive capacities and create situations where important information is unnoticeable or even lost. The result of this intensive information flow is reduced system safety due to an increased number of user errors. This fact is more studied in the domain of process industry, where downtimes and safety issues are costly and require close attention. For example, many sources report a range of 30–90% of all system failures as operator errors [3–5], while stating that the cost of such events is around 3–8% of plant capacity [6]. This problem is also relevant in other domains of control and monitoring systems, such as building management, where the number of data points can be in the tens of thousands, and facility operators must be assisted in order to easily locate the problem and provide a timely response to it [7–9]. There is therefore a great need to improve the situation awareness of the users of these systems by reducing the information load delivered to system users in the form of notifications.

The research community has addressed the problem of intensive information flows from several perspectives. One of the approaches is to enable delivery of the right information at the right time to the right person through context-aware systems [10]. The general idea behind context-aware systems is the introduction of an additional layer in the system architecture that is responsible for interpreting ongoing situations and inferring the most appropriate information for each user of the system in the ongoing context [11–13]. The concept of context-awareness is adopted in various domains ranging from industrial applications to building management and healthcare monitoring systems with the focus to either 1) appropriately react to the inferred situations of the environment, as in [11,14,15], or 2) conveniently present information to the user, as in [16–19]. While context-aware systems deal

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with the delivery of the correct information and improvement of user awareness of what is happening in the surrounding environment, they are not originally concerned with reducing information intensity to the user. A set of techniques exists, which are closely related to this topic, called alarm management. Alarm management is more commonly known and more formally described in process industry; it comprises the set of techniques, tools, standards, and procedures, with the goal of improving the effectiveness of alarm systems [20]. Recent research has proposed new algorithms for reducing information load, which comes in the form of nuisance and false alarms [21–23], number of alarm floods [24,25], wrong prioritization of alarms [26], and presenting large amounts of similar data to the users [27]. These works are usually based on analysis of alarm logs and related data, which results in detection of badly designed alarms and recommendations for reconfiguring alarms in the control and monitoring system.

This work proposes an approach for combining related notifications in the BM systems with the aim of reducing information load to the users. The approach covers the design and runtime phases of notification management. The design phase enables clear classification and correct priority assignment between alarms. The runtime phase implements combination principles to reduce information load to the users at system runtime. The combination principles relate ongoing notifications by type, priority, location, and notification receiver. The main objective is to reduce the number of notifications that have repeated information pieces. The runtime notification analysis is a major advantage of this approach in comparison to most of the existing solutions, which use log data for alarm analysis and are not able to address user needs during system operation.

The rest of the paper is organized as follows. Section 2 presents background and related work, with the focus on alarm management techniques and practices. Section 3 contains detailed description of the proposed principles for defining related notifications in the monitoring systems, with illustrative examples from the domain of building management. Section 4 gives details of the tools implemented to support the proposed principles of combining related notifications and describes the use case chosen for study. Section 5 presents the results of applying the proposed principles to the case study of a rehabilitation facility. Finally, Section 6 concludes the paper and gives directions for future work.

2. Background and related works

2.1. Notification types in monitoring systems

Monitoring systems produce notifications of various types and priorities. The difference between notification types depends on the domain of the particular monitoring system. For example, process industry is a highly automated domain with systems having a large number of process variables to control and monitor. The safety of such systems, however, critically depends on the operator's proficiency and his/her responses during abnormal situations. This domain is therefore well supported by alarm management standards and recommendations including EEMUA-191 (2007) Alarm Systems: A Guide to Design, Management, and Procurement, ANSI/ISA-18.2 (2009) Management of Alarm Systems for the Process Industries and its IEC 62682:2014 extension [28,29]. The ANSI/ISA-18.2 (2009) clearly defines four types of notifications: alarms, alerts, prompts, and messages. The alarms and alerts are used to inform about abnormal situations. The difference between them is in the required actions for the operator: alarm requires the response of the operator (action to improve situation), while alert requires only operator awareness of the abnormal condition (e.g., to pay closer attention, to check up other variables) [30].

Building management is less critical in a sense of downtime costs and incident consequences, therefore this domain is less supported by standards and recommendations [9]. The nature of abnormal situations is also quite different. In the process industry, everything is connected to the automated process, with numerous parameters to control and monitor; in building management, abnormal situations are quite independent in the sense that they usually happen in self-substantive units, such as apartments and buildings. The responses to abnormal situations also have differences: in the process industry, the response is supposed to be a well-defined process of actions in response to the ongoing condition whereas in building management, the responses are less procedural and the operators usually follow short instructions on how to react to certain types of high-priority event. In addition, the operators of such systems are the users, who have other roles and are often only required to have an awareness of what is happening in the environment, rather than to immediately act upon a situation. The difference between alarms and alerts in BM systems is thereby less critical in comparison to process industries; therefore, this paper does not distinguish between them – all notifications indicating abnormal conditions are referred to as alarms. This generalization does not significantly alter the meaning of alarms from process industry; however, it will enable the consideration of all possible abnormal situations and their related notifications in building management systems.

2.2. Alarm management approaches

Abnormal situations in the large-scale monitoring systems create intensive information flows. This problem is relevant in many domains of control and monitoring systems, but it is most studied in the process industry, where it is addressed through a series of practices called alarm management. Alarm management practices aim to increase the effectiveness of alarm systems in a plant; they can include a set of procedures ranging from identification and elimination of badly designed alarms to operator training on how to respond to alarms [31–33].

The research community has proposed numerous ways to improve operator effectiveness in relation to different aspects of alarm management in process industries. One of these approaches is to improve visualization tools, which aid the detection of badly designed alarms causing alarm floods (the condition where the rate of alarms is higher than the rate of the operator's comprehension of them [34]) and/or alarm chatter (the condition of certain alarms in which they activate and deactivate excessively [21]). For example, high-density alarm plot (HDAP) charts, alarm similarity color map (ASCM), and an index of alarm chatter are proposed in [21,34] with the following experimental studies showing their effectiveness in the detection of badly designed alarms [35]. Another way is to use plant data to predict equipment failures and improve operation set points, thus reducing the number of plant shutdowns and alarms [36]. While this is a promising approach for improving the work of plants, it usually requires high computational power to enable this approach at near real time. Finally, there are a number of works that attempt to analyze the similarity of alarms and their causes to offer a potential reduction in information load to the operators of the control and monitoring systems. Examples of such works include the proposal of new algorithms for detection of similar alarms [22,25], sequences of alarms [37], correlated alarms [38], and the same causes of alarms [39]. The common approach in these works is 1) to analyze available alarm log data and/or related information such as plant and system topology, 2) to detect problems in control and monitoring systems from an alarm management point of view, and, 3) to produce suggestions for improving alarm polices in a particular system.

While identification and possible elimination of badly designed alarms based on alarm logs is an important practice for improving alarm systems—and, thereby, user awareness—the related notifications in building management systems are not always a problem of alarm design, but rather a consequence of the possibility of having multiple, seemingly unconnected, triggers at the same time. For example, the warnings about an opened entrance door and low indoor temperature are two separate types of notifications, which can happen independently in different locations; however, when two of these conditions are met in one location, they might be related, due to the cold