An Analytical Alarm Flood Reduction to Reduce Operator's Workload

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Abstract. In the domain of process control, an alarm flood is a situation when there are more alarms generated by the automation system than can be physically addressed by a single operator. To reduce alarm floods an analytical approach, so called AADA (Automatic Alarm Data Analyzer), has been developed to learn these alarm floods by itself. Finally, this behavior can be integrated into process-visualizations which illustrate only the root cause of an abnormal plant state. To increase the operator's awareness during abnormal plant states, a combined approach of the ADDA and the 3D process-visualization is presented in this paper. This approach has to reduce alarm floods and to display the most important information of a plant to the operator during runtime.

Keywords: 3D Visualization, alarm flood reduction.

1 Introduction

Process Control Systems (PCS) are one of the core elements in process control industries, e.g. gas oil refineries or pharmaceutical and chemical plants [1]. The PCS presents the most important information about the process plant to the operator. Beside the observation of process data, operators have to recognize abnormal plant states.

In general, the PCS's visualization is divided into two different parts closely related to each other. Operators get an overview by observing the visualization (see figure 1), which is based on P&ID-diagrams, line diagrams and tables to visualize process data and to show the plant's state based on graphical and textual elements. The graphical elements represent automation device of the plant, e.g. pump, valve, motor, pipelines, the tag information. The most important values to operate the process are visualized related to the elements, e.g. the actual value and the set value of the process. If the conditions for an abnormal plant state come true the graphical elements change the color, e.g. into yellow or red. Changing the color indicates an alert or an alarm (in the following the word notification is used for alarm and alerts), to call operator's awareness. Detailed information about the abnormal plant state is provided when operators have to switch from the process visualization to the alarm

J.A. Jacko (Ed.): Human-Computer Interaction, Part IV, HCII 2011, LNCS 6764, pp. 297–306, 2011.

list. Usually, alarm lists are structured as a table where every standing and unaccepted notification is displayed in one row. Alarm systems ought to support the operator controlling potentially dangerous situations before the Emergency Shutdown System (ESD) is forced to intervene [1].

Thus, operators face two problems: The first one concern that the operator has to handle a vast quantity of notifications and it is difficult to manage those notifications [2]. There are notifications that occur due to causal dependencies between automation devices, e.g. pump, valve and sensor in one manufacturing line. Every automation device may raise a notification that is reported to the operator. Several standing notifications appear in the alarm list. This is one effect for alarm floods. During alarm floods operator just acknowledges the notifications while handling the abnormal situation regarding their process knowledge and experiences. In such a situation operators have not enough time to analyze every notification properly without exceeding the recommended operator response time. Furthermore, there is a risk that operators miss an important alarm [3]. Therefore, the reduction of alarm floods has a high priority when improving alarm systems design [1].

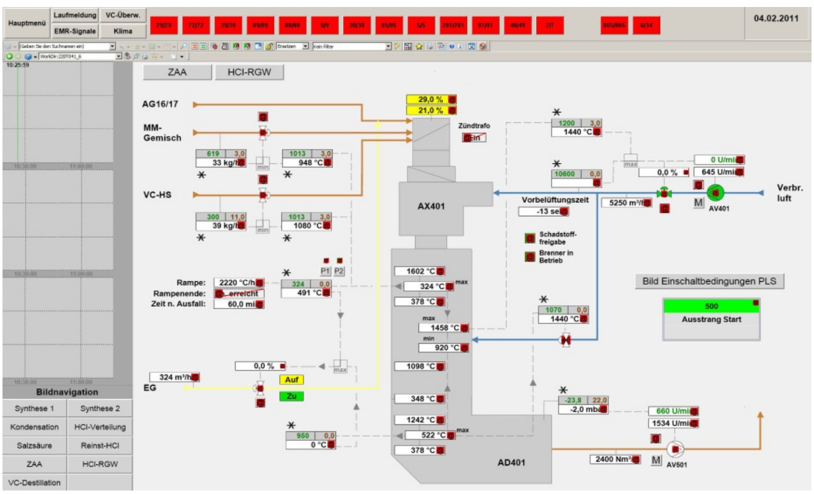

Fig. 1. 2D visualization of a process control plant

The second problem mention concerns the need of switching from the process-visualization to the alarm list to get detailed information about the raised notification. Since the process visualization is based on a graphical display and the alarm list is structured like a table. Hence, the operator loses sight of the process visualization by switching the visualization in order to appraise the alarm list. For instance, the operator is not going to recognize the difference of the actual and the responding set value becoming abnormal. Regarding the alarm list, the spatial information which automation device raised a notification or which one caused the abnormal plant state is lost. In that case, operators have to link information from the alarm list and the process visualization based on their cognitive performance.

Even today, there is no solution for alarm flood reduction during run-time of a plant integrated into the process visualization.

In this paper, we present a combined approach of 3D process-visualization and an integrated algorithm to reduce alarms floods. In section two the state of the art for analyzing data is presented and 3D visualization in section three. A new 3D visualization approach with an integrated alarm flood reduction is described in Section four. Finally, the discussion, the conclusion and the future works are presented in the section five respectively in the section six.

2 Learning Plant's Signal-Behavior

In the following the state of the art learning plant's signal-behavior during run-time is described.

For the alarm flood reduction Kurz [4] presents a manual approach to analyze alarm logs. Therefore, he focuses on the top alarms of a plant and tries to find out the main causes and effects between devices and alarms. Results are that five alarms are responsible for 87% of all alarms in one plant section. An analysis of the top 40 alarms in another plant shows that four alarms are the main causes which are responsible for disturbances. Actions to be taken are derived from the analysis to handle alarm floods and realizing the number of alarms being reduced from 1580 down to 440 alarms per day (72%).

Bauer [5] presents an approach for the probabilistic analysis of process data to detect causal relationships of process data generated in case of an error during the run-time of process plants. To classify process data, Bauer uses a decision tree to determine an appropriate calculation method for the analysis. Concerning the classification, the main important criterions for process data are:

- The quantity,
- The oscillation,
- Temporal linear dependency between process data,
- Temporal linear distribution of process data.

Based on the classification-criterions, calculation methods are suggested to select an appropriate calculation method, e.g. next neighborhood, transfer entropy or cross-correlation. The aim is to determine causes and effect's dependencies that are reasons for the faulty behavior of a plant. Bauer shows the causal dependencies by generating a cause-effect map.

To recognize error conditions of a plant, Klein [6] focuses on an automata-based approach to learn the behavior-model during plant's run-time by observing I/O-signals of I/O-Devices in every plant cycle. Therefore, Klein developed a new type of automata called NDAAO (non-deterministic autonomous automata with output) and a parametrizable identification-algorithm. Roth presents model-criterions which are used for the qualitative evaluation of the behavior's complexity (precision of the model) and the model's structure (size of the model). Both are important for an efficient calculation-time to recognizing plant's failure during plant's run-time. Referring to Klein's research, Roth [7] extended the automata approach. Roth has developed failure-indicators to detect differences between the learned set- and failure-behavior. Roth proposes integrating time-aspects in future works.

Process-mining is applied to find structures in unstructured event logs. Current research has focused on extracting a workflow-based process model. Kim [8] presents an FP-tree algorithm (frequent pattern tree) to detect frequent patterns stored in a log file. Before analyzing for frequent patterns it is needed to define a direct causal matrix to serve several purposes. Based on the direct causal matrix Kim is analyzing the log file by using a modified FP-tree for the process discovery. Usually Process-mining faces business-processes and is not established to analyze alarm logs in the domain of process control. Furthermore, this approach is not able to find causalities by itself.

2.1 Automatic Alarm Data Analyzer (AADA)

Regarding our research, we developed the automatic alarm data analyzer (AADA), an algorithm that is to find causal dependent notifications. The AADA analyzes notifications stored in alarm logs. An alarm log contains notifications recorded during the run-time of a plant. The aim of the AADA is to recognize causal dependent notification and generates alarm-sequences based on the alarm logs. Within alarm-sequences are causal dependent notifications to point out the root cause and their effects during an abnormal situation. Furthermore, we adapt the ADDA to except user inputs before the start of an analysis e.g. if the alarm log contains notifications generated by a fast or slow process. Additionally, the user can enter which plant sections have to be analyzed or what kind of notifications (alert, alarm etc.) have to be considered.

However, the alarm log contains notifications from all parts of a plant. Every generated notification is stored in the same alarm log. Depending on the size of a plant, notifications are stored temporal closely but are not dependent. Therefore, notifications generated by several independent plants could have a similar time stamps. By analyzing the alarm log these notifications appears next to each other and may be recognized as an alarm-sequence. This distorts the results of the analysis. Hence, generated sequences have to be verified by plant operators who know the process plant. Nevertheless, most of the alarm-sequences are relevant and are useful to improve the alarm management system to prevent design mistakes.

But a re-engineering of an alarm management system is time consuming. Hence, it is an advantage if the generated alarm-sequences, which are verified, could be integrated into the visualization for pre-processing the notification. Pre-processing by means of incoming notifications are analyzed by the AADA during run-time. Meanwhile, the AADA extracts the root cause of a recognized alarm-sequence by suppressing remaining messages concerning one alarm-sequence. Finally, only the root cause of an abnormal situation is indicated in the visualization.

3 3D Process Visualization

To display process data in machine and plant manufacturing 2D visualization is state of the art in process control. Current HMI systems use line diagrams, bar charts and tables to visualize process data or P&ID diagrams for structural information. These visualization elements are available in libraries and can be integrated into the process screen and be connected to process variables in a simple way. In some applications, e.g. tanks or piping are represented in 3D but from the operators' point of view, there is no additional benefit generated by this kind of 3D visualization. Even though 3D visualization is often considered as gimmick, there are different studies that show the benefits of 3D in process control. Beuthel [9] and Hoppe [10] proved the advantages of 3D process data visualizations for coal-fired power plants and electric power grits. They arranged 3D elements (e.g. bar charts) spatially on a 2D structure diagram (CAD, P&ID) to display actual process values. Both studies measured the reaction time and the processing time to handle problem situations in 2D as compared with 3D visualizations. The results showed an advantage for 3D representation.

The general applicableness of 3D process data visualization and their interaction possibilities for process data visualization and data analysis of multidimensional data fields was evaluated by the authors for typical applications of industrial process control [11]. For example a 3D visualization for monitoring temperatures in an ethylene reactor was provided [12] and implemented in the plant's process visualization.

The time consuming development could be a reason for the rarely use of 3D in process control. Each 3D scene has to be programmed step by step. For this reason, we developed a prototype library with 3D objects, so called 3D pattern [13]. These 3D patterns use standard interfaces like OPC or ActiveX and can be integrated in most state-of-the art HMI systems as easy as 2D visualization objects. The library was developed based on real application examples from industry and has been evaluated by experts.

The benefit of 3D in process data visualization was evaluated empirically by the authors by means of the application example of a continuous hydraulic press. 2D visualization, 3D visualization and 3D visualization with interaction of process data as well as different training situations were evaluated comparatively. The results of the experiment showed a significant advantage of 3D with interaction in error detection of complex problem situations [14] [11]. This result corresponds with Wickens' "proximity-Compatibility"- principle (PCP) [15]. This principle states that tasks that require the integration of information, benefit from a perceptual proximity of the display or visualization. The integration of information is necessary in particular for the detection of complex problems. These problems require the combination of three or more process values for the analysis of the system status. At the same time also a minor subjective factor of stress could be proven during the process control in the group of 3D with interaction. The fact that these only could showed in the group 3D with interaction, suggests that interaction with the 3D scene has a substantial influence on the information reception.

4 3D Visualization Combined with Alarm Flood Reduction

4.1 Visualization for Cause-Effect Disturbances

There are two main objectives for the new visualization approach. The first one concerns to the integration of cause-effect dependencies into the visualization. The second one faces the problem to visualize only the root-cause by proper elements.

In contrast to 2D, the 3D visualization offers another dimension to present more information to the operator in contrast to 2D. Concerning Wickens' PCP we use the third dimension to couple the information of process data, notifications and structural information in one process screen.

For the 3D visualization cylinders are used as the basic element shown in figure 2. This element is divided in several parts. The symbol for process control objects (PCO) is placed on top of the graphical element. The PCO-symbol is similar to the standardization ISO 14617 [7] as it is used for 2D process-visualizations. PCO-Symbol is placed on top of the cylinder (1) given in figure 2. The circle around PCO-symbol shows the percentage MTBF-value (2) which represents the maximum operating time of the corresponding automation device.

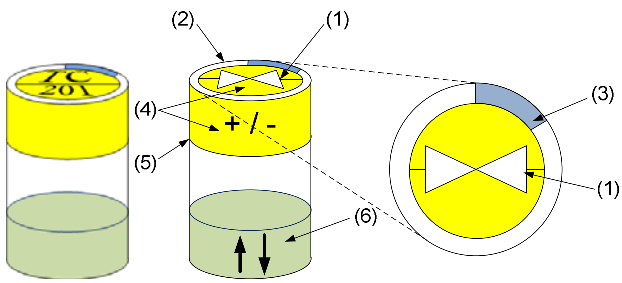

Fig. 2. 3D-PCO (valve) with process-, MTBF-value and alarm/warning

Concerning the colored part of the MTBF-circle (3), it represents the actual operating time of the device. In case those devices exceed the maximum operating time the MTBF-circle is fully colored (3). The MTBF-value is determined as the predicted elapsed time between inherent failures of a system during operation. Moreover, the MTBF-value is important for safety critical systems. The MTBF-circle tells the operator whether a malfunction of an automation device could be the cause of an abnormal plant or not, e.g. incorrect set up of values. The MTBF-circle is also useful to notifying the operator by disclosing necessary forthcoming maintenance, to prevent plant breakdowns. Often, the automation devices' MTBF-value is defined in the data sheet of the manufacturer and can be integrated into the visualization by calculating and counting the expected time for a failure of the responsible automation devices. However, the combination of the MTBF-value and the related alert/alarm helps the operator to better assess the abnormal situation.

When certain conditions creating notifications comes true, the upper part of the 3D-PCO starts blinking changing between white and the corresponding color for alert or alarm (4). To indicate an alarm high or an alarm low a plus "+" or respectively "-" placed on the upper part of the 3D-PCO. In case that the alert/alarm causing condition has gone and the operator did not acknowledge the notification, the blinking stops but the color is still displayed. The color disappears as soon as the operator acknowledges the notification.

Hence, if an abnormal situation occurs and an alarm/alert is illustrated the operator might click on the corresponding 3D-PCO to get detailed information about that notification. A faceplate like in common process control systems is illustrated and the common faceplate including the alarm sequence list is displayed. Thus, the faceplate supports operators assess abnormal situations.

Another important type of values to operate a plant are process values. The difference between the actual and the set value is displayed in the lower part of the 3D-PCOs (6). The arrow indicates whether the process value is ascending or descending. For an ascending process value, the arrowhead points from bottom to top while a descending one is displayed by the arrow pointing from top to bottom.

Concerning the 3D-PCO, the difference between the actual and set value is displayed. The maximum displayed difference (5) is determined as the maximal strength of the device concerning the value-differences. The maximal strength of all devices is defined as the technical system by Lauber [17]. The technical system is determined as the whole technical equipment realizing the process control. In case that the difference reaches the maximum value (5) the automation device could be damaged. If there is no difference between the process values the height of the process bar is zero, thus, part (6) is empty.

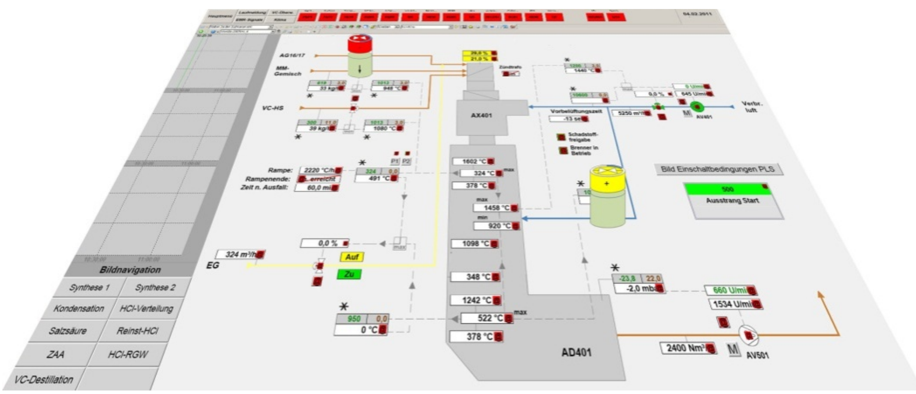

Fig. 3. 3D-PCO (valve) with process-, MTBF-value and alarm/warning

To change the focus within the visualization the operator can interact with it. By zooming in and out, the operator focuses on a plant section in the visualization, e.g. to have a proper view on the MTBF-value or the change process values of the PCOs. Due to the height of the 3D-PCOs, other graphical or textual elements could be placed behind other ones. Hence, operators have to rotate the visualization to avoid covering elements they wants to focus on. By using the bird’s eye perspective the PCO placed on the visualization looks like the commonly applied 2D visualization but is additionally including the MTBF-circle around the PCOs.

4.2 Integrating Alarm-Sequences Generated by the AADA

The alarm sequences, generated by the AADA, contain causal dependent notifications. The first notification in each sequence corresponds to the root cause of an abnormal situation. Remaining notifications in an alarm sequence are effects of the root cause. To call operator’s attention on the main problem in abnormal situations, pointing out the root cause of disturbances is necessary. Furthermore, to increase transparency and legibility of the 3D visualization, it is recommended to avoid placing a 3D-PCO on every existing PCO in the visualization. Integrating the alarm sequences into the visualization resolves these problems during run-time of process plants by suppressing the remaining notifications an just showing the most important notifications on the visualization. Furthermore, based on the alarm sequences, alarm floods can be reduced in the same way.

The moment, when an abnormal situation occurs, the AADA algorithm starts analyzing the incoming notifications. If an alarm sequence is recognized the AADA sends an event to the 3D visualization to trigger the 3D-PCO of the root cause. In case that there are notifications not recognized by the AADA as a part of an alarm sequence, the AADA designate the incoming notification as unrecognized. The 3D visualization will indicate every notification by a single 3D-PCO.

5 Discussion

The 3D visualization has been evaluated by experts of one of the global players in the chemical industry.

Concerning the evaluation, it has been pointed out some promising results. Visualizing the operation time (MTBF-value) of automations device could be very interesting for operators. Generally, the operation time is only available for asset management, especially for safety critical devices. The number of safety critical systems is not negligible. Depending on the process plants, the number of safety critical devices is between 15% and 70% in relation to the overall applied automation devices. Nowadays, operation times are not integrated into plant's visualizations but they might be an advantage. Operators are given information to assume whether an abnormal situation is based on malfunctions of automation devices or on other reasons. Furthermore, operators are able to anticipate abnormal behavior by considering the operating times of the 3D-PCOs. In fact, the pollution of automation devices might influence their operation time, e.g. when they come into contact with chemical materials, such as acid, base, fire, etc. In that case, the illustrated operation times may differ from the expected one.

The expert's evaluation points out that the actual deviation of process values relating to their set values is often more important than the actual process value of an automation device itself.. Furthermore, the illustration points out when the maximum of the allowed deviation is reached. Hence, illustrating the deviation of process values might call operator's attention rather than display actual values.

Alarm floods are problems in several process plants. The AADA itself have been used to analyze alarm logs recorded by five different process plants. Most of the frequent alarm sequences are significant but some alarm sequences are coincidental in the results. Hence, the alarm sequences have to be reviewed to apply the alarm sequences into the run-time visualization. Due to the fact that the AADA analyzes incoming notifications and interferes with the process visualizations, it is important that there is no erroneous alarm sequences integrated into the visualization

Another point is concerning the system integration of the alarm-sequences into the visualization. Regarding the expert's statement, it is important that the calculation time for analyzing incoming notifications do not have to influence the overall process, the speed of the visualization and the data transmission speed of networks.

6 Conclusion and Future Works

Concerning call operators' attention and for alarm flood reduction during the run-time of plant, a new 3D visualization with interaction is presented in this paper. The visualization is based on P&ID diagrams. The 3D visualization includes cylindrical process control objects (3D-POC), which are divided into a MTBF-value part, an alert/alarm part and a process value part. Hence, operators have the most important information in sight. Regarding the interaction, the operators are able to zoom in and to rotate the visualization. Therefore, the operators can focus on selected process sections or uncover process sections that are placed behind 3D-elements.

For alarm flood reduction alarm sequences are integrated into the visualization. The alarm sequences are found by an automatic alarm data analyzer (AADA) algorithm which analyzes alarms and alerts stored in alarm logs. These alarm sequences contain causal dependent alarms and alerts whereby the first alarm or alert of a sequence represents the root cause. By integrating these alarm sequences into the 3D visualization and suppressing the remaining notifications during the run-time of a plant, only the root cause is display to the operator.

Future works will focus on how to enhance the analysis based on AADA algorithm to avoid improving the alarm sequences by a plant operator. The benefit will be an AADA finding more significant alarm sequences without investigating the sequences by a plant operator.

Furthermore, we will implement the combined approach of 3D visualization and alarm sequences into the visualization of a plant-demonstrator. The aim is to measure the automation network to compare the transmission time by using the new visualization approach related to the common process control visualization.

Thereafter, we will implement the 3D approach into the visualization of a plant simulation. The plant simulation is based on real processes of plants and is used for the education of operators in the chemical industry.

Additionally, we will design an experimental environment for the empirical evaluation. Primary, a preliminary experiment with students will carried out. Thereafter, we will realize the main empirical evaluation. We expect that the planned empirical evaluation will point out that the 3D alarm visualization approach achieves better results compared to 2D. Operators will be able to recognize a complex problem quicker in contrast to the traditional 2D visualization and the alarm list approach.

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