Usability in a New DCS Interface

New Model of Viewing in Operator Displays

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Abstract. The current operating displays of DCS (Distributed Control System) are designed for 2D environments. This limits the full awareness situation of the industrial process, since it is distributed across multiple operator displays and requires the operator to navigate among them. This inspired the idea of creating a single operation DCS display, in a 2.5D/3D environment that allows a full view of the entire manufacturing process. This increases the amount and quality of information that is given to the operator and prevents unnecessary operation navigation between displays.

Keywords: DCS, HCI, 3D, 2.5D, visualization models.

1 Introduction

The DCS (Distributed Control System) is a control device that is primarily used in the continuous process industry. This type of industry is characterized by having a critical production process, in which any failure or shutdown can create dangerous situations for both the environment and for people. Failures in this industry may involve shutdowns of several days, while the start-ups can stay for several days until process stabilization is achieved. 40% of these failures [12] are attributable to errors or failure in operation, which means that the efficiency of operators becomes a critical element of this industry. This requires increasing the quantity and quality of information that is given to the operator and to provide him/her with tools and frameworks that favor the selection of a wise operating decision.

This paper describes an innovative DCS operator interface, which increases the amount and quality of information that is perceived by the operator. This interface showed in a single 2.5D/3D graphic display, shows the contents of a previous set of 2D DCS operating displays. The first paragraph of this paper summarizes the main features of this innovative DCS operator interface. The following section describes the new operator display. The last section relates the experiences of operators that tested this interface.

2 Operator Displays of DCS

Optimal operator interface must provide accurate and complete "situation awareness" in all conditions of the industrial process status (normal, abnormal and emergency).

C. Stephanidis and M. Antona (Eds.): UAHCI/HCII 2013, Part I, LNCS 8009, pp. 87–96, 2013.

This reduces the number of unscheduled shutdowns, minimizes the variability of the process and improves safety.

Currently, operator displays have a 2D format, "Fig. 1", which hinders to access to an accurate situation awareness of the process, since it is not feasible to create a single operating display that contains all information of the industrial process. This requires creating overview displays with the most critical parts of the process and/or forces the operator to navigate through all the displays in the DCS. Both one as another option has advantages and disadvantages, but does not give an answer to the need to view the status of all operating variables, to be monitored in the industrial process.

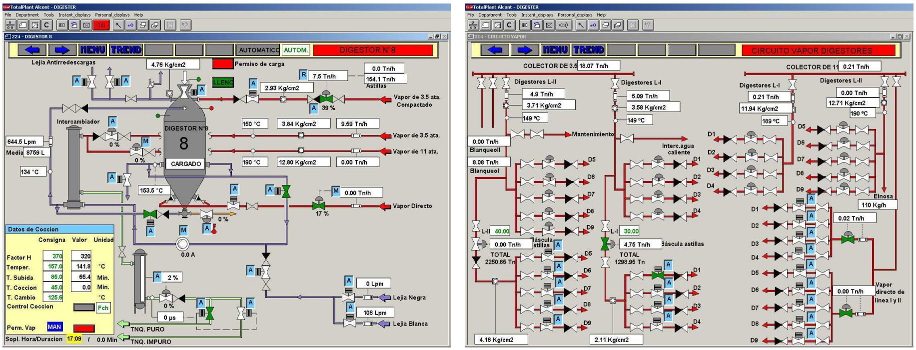

Fig. 1. 2D-Displays of Digester nº 8 and Steam Distribution (DCS of Honeywell TotalPlant)

2.1 Present Operator Displays

The DCS operator interfaces [4] [5] [6] [7] [9] that have been studied so far in the preparation of this paper, they had monitors 2D and also displays charts or diagrams containing process in 2D format. This means that if someone wants to have different views of the process is essential to create new displays. DCS alarms are indicated on the operator displays with a change in the color of the component that generates it and also they are listed in a table sorted by priority and/or areas, which are accessible from different sides of the display. All operating displays show the status of the components using a color code, and some of them allow access to programming manuals, device manuals (valve, motor, etc...), programs of logic blocks, wiring diagrams, piping diagrams or links to other management applications (Maximo, SAP ...). Also all the components allow the operator to select the operating mode (automatic, manual or remote) or to force their input and/or output values. The typical input interface of DCS is the keyboard and mouse, although in some cases, using a touch screen as advanced device, as it supports user defined configurations, which facilitate access and navigation through the operating displays.

Operators typically manage up to fifty DCS operating displays with several thousands of I/O signals associated; so there may be displays or I/O signals that are not accessed by operators, for several working shifts. Sometimes it happens that these components or displays are not serviced until an alarm or warning.

ASM (Abnormal Situation Management (Consortium)) [1] develops guidelines or recommendations about the best practices that can be applied in the design of the operating displays. The purpose of these displays is to optimize the amount and quality of information in the industrial process, which must assimilate the operator to possess an excellent situation awareness and thus be able to make the best decision [2]. These guidelines were developed to apply only in 2D displays, but many of them could be extrapolated to design 2.5D/3D displays.

2.2 Revolutionary Interfaces

ABB and Interactive Institute of Umea have developed a prototype of a business management tool [10] which facilitates the monitoring of any KPI (Key Process Indicator) of the process. This information, which is showed in a display, is collecting from business management systems or from the industrial control.

This management tool has a monitor with a touch screen, which displays in the 2.5D environment the production building of the production plant and/or industrial equipment. This touch screen facilitates the rotation, displacement, increase or decrease of the scene. An overview of the plant shows only high-level KPIs, but if the operator wishes to view a section of the factory, then emerge new KPI or more specific variables, which are specifically related to that area and that, before, they were not visible in the upper level.

The software was designed to convert the graphic display in a tool that replaces the traditional portfolio. Thus, participants can add comments to the graphical elements in the form of notes, drawings and virtual sticky notes that remain attached to the item and not to a physical position of the display.

This tool was not intended to become a DCS operator interface, since it cannot allow interacting with industrial devices to browse or change their status. However, this software shows the direction that investigations are walking into the human-machine interfaces in industrial management environments and this suggests that the same trend is transferred to the area of the DCS operator interfaces.

3 New 3D/2,5D Operator Display of DCS

It has been created an application that shows a DCS operator display in 2.5D/3D format. The application can show 3D operator display, but can also show operator display in 2.5D format (if the computer does not have 3D peripherals). This operator display, "Fig. 2", replaces a set of 10 DCS displays with 2D format. This set of 10 displays is formed by 1 display of steam distribution display "Fig. 1-right" and by the 9 displays of each of the 9 lines of digesters. The display that represents digester number 8 is shown in "Fig. 1-left". Each line of digestion, "Fig. 3" is composed of a digester, a heat exchanger, a condensate tank, a recirculation pump, some steam valves, some liquor valves and all associated piping. The steam distribution display shows a set of common facilities for all these lines.

Navigation along the graphic scene is made using a 3D-joystick, while the selection of a graphical element is done with the mouse (only 2.5D graphic scene) and/or joystick. Similarly, these peripherals make it easy to spin, pan and zoom the chart of the manufacturing process to achieve visualize the scene from infinite views (front, side, rear, near, far ...).

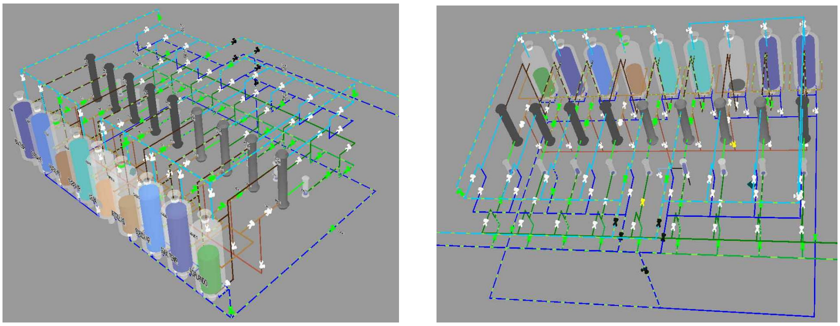

Fig. 2. Oblique and back view of the industrial process

This operating environment also reported the appearance of an alarm or warning, by issuing a voice message with emotion. The issuance of said voice messages with emotion facilitates immediate compression by the operator of the upsets that are occurring; because emotional intensity indicates the criticality of the alarm and the message indicates exactly, which is the component that generated it. The graphic scene also shows, in text, all physical quantities of the process, and the status of all devices and equipment (valves, motors, switches, etc..).

The application includes a dialog window in 2D format and control information on the components of the process, which have been selected with the mouse or 3D-joystick. This window displays in textual format, the status of the selected component and allows its control (change of state), by pressing buttons.

The background color of the graphic scene has been determined to be the gray, because it is recommended for displays, by ASM. The gray color intensifies the difference between the graphical objects and the vacuum, and also allows the use of the operating display in control rooms with different light intensities.

Graphical components must have a geometry format in 3 dimensions to be inserted into a graphic scene in 3 dimensions. However, all standard symbols [11] to identify a component are designed to be used in 2D representations. This requires some new designs of 3D graphical symbols, to allocate to the process components, so that can be used in a graphic scene to represent a real industrial process. It was decided that these new 3D graphical symbols must be generated by the axial revolution of the graphic representation of the symbol of the 2D component; since this allows them to be recognized or identified in a very simple manner, from any spatial position in which locate the operator. Similarly, the creation of these new symbols from an axial resolution of 2D symbols enables projection onto a 2D plane, which exactly reproduces the original 2D symbol. Occasionally, the axial revolution of the representation of a 2D symbol does not generate a 3D geometric figure, resembling the 2D symbol. This requires creating a new 3D symbol, from some geometric transformation of 2D symbol or by a new reference model for that component.

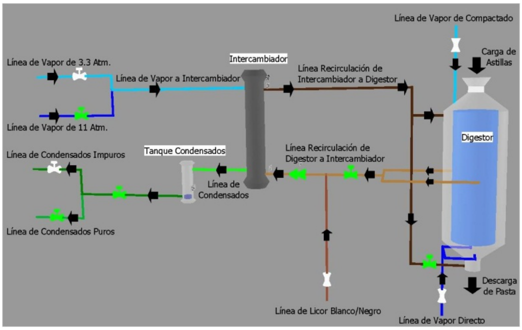

Fig. 3. View of one of the lines of the industrial process

The digester comprises a geometric revolution of a container with transparent color, which contains inside a cylinder of variable height, which indicates the charge level of the digester. The color of this cylinder indicates the state of digester: empty, loading chips and/or bleach, temperature rising, baking, puffing, etc.

Vertical heat exchanger is represented by a vertical cylinder with two flanges at the upper end and the lower end. This figure has a solid color of dark hue, and it has no operational status that is relevant to know.

The condensate tank is represented by a vertical cylinder with two flanges at the upper end and the lower end, but it contains within itself a cylinder with variable height. The height of this cylinder indicates the level of condensate in the tank, while its color indicates if it is in a steady state of operation or alarm / warning.

The 3D symbol of a valve is generated by the axial revolution of the normalized 2D representation of a valve symbol. The 3D symbol comprises the valve body and the handle thereof. The body is represented by a geometrical figure comprises two circular truncated cones, faced by their smaller radios and joined by a cylinder whereas the handle resembles a rectangular parallelepiped, which is connected to the body via a cylinder .

The axial revolution of normalized symbol of a 2D pump generates a sphere or a cylinder with a triangular prism inside. None of these geometric figures are easily identifiable with a pump 2D symbol and also cylindrically shaped figure has different visual appearance depending on the place where the operator observes it. The normalized symbol of a 2D pump is formed by a circle, within an equilateral triangle, where the vertex indicates the flow direction. Finally, it was decided that the 3D geometrical figure that represent a pump must be constituted by a set of two circular cones in series, where the two vertices indicate the direction of fluid flowing through the pump.

The red color is only used to signal an alarm condition, the yellow color is used to display a warning status and the violet is identified with a state of uncertainty component. The green and white colors are used to indicate different states of operation in which there is a physical component of the industrial process. Green indicates that a pump is running / active or a valve is open. The white warns that a pump is stopped /halted or that a valve is closed.

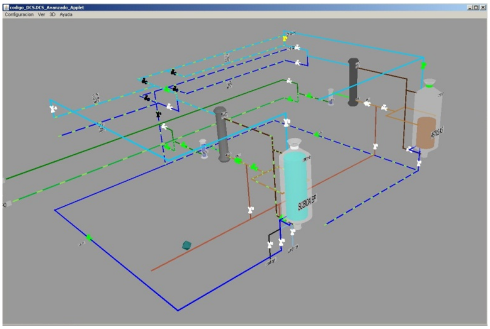

Fig. 4. Partial view of the industrial process

The pipelines have different colors depending on the transporting fluid inside them, while a change in a physical characteristic of fluid is noticed by a variation in its color tone. Blue indicates that the pipeline carrying steam; the green line denotes that contains condensates and the brown color shows that the pipeline is carrying bleach. The variation of the blue color tone denotes a change in vapor pressure, for example dark blue color indicates that the pipeline transports high pressure steam and light blue color containing low pressure steam. The graphic representation of the pipeline has an animation to symbolize the flow of the carrying liquid. The design of animation imposed the creation of a sequence of bright color geometries, alternating in a synchronized manner to give the appearance of movement. This sequence is assigned a frequency of 0.1 seconds for projecting an optimal illusion of movement.

The graphic scene is contained in a window, with several menus or tabs, which are used to select the different options for modifying the graphic scene. The application allows viewing and/or hiding the individual lines or pooled lines or digesters common line to all digesters "Figure 6", then this allows the operator to focus his/her attention exclusively on a limited set of lines. The animation of the pipelines is enabled / disabled on a menu option, and its activation is highly desirable in simulation tasks or learning the process, as it shows the flow of the various materials involved in the manufacturing process. However, it could be dangerous to have enabled animation pipelines in the routine process control; because the operator could become saturated with the vast amount of visual information that is given. This could cause the operator to relax focusing on key aspects of their work of process control and it can cause malfunction or accident of unpredictable consequences.

Some components or circuit sections should show numerical data or messages to the operator; because a color code provides a very limited amount of information. This requires labels to show process information, "Fig. 5", to report the status of the digester or the various physical quantities, which are used to keep the process within its limits. For example, the pump has a label with its electric consumption; steam pipelines show a pressure indication that transport fluid; liquor pipelines have an indication of flow and the temperature of the bleach flowing into them; and finally each process area has a label with an indication of its name or designation.

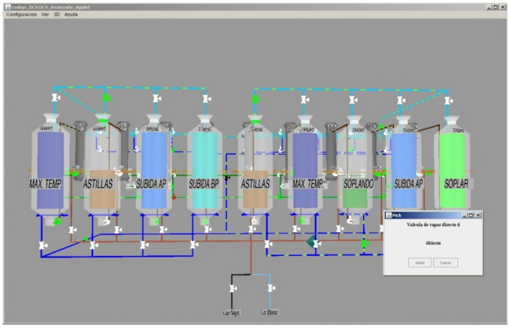

Fig. 5. Frontal view of the industrial process, with the commands window

The moment when an alarm or warning arises from a component, the operator cannot concentrate on visualizing the color change of the component; so it is advisable to give an audible message to notify the operator that exists a circumstance that requires his/her attention. Therefore, whenever a component goes into alarm or warning is issued a recorded message, including the name of the component and unambiguous critical condition (alarm or warning) that is. Also, the menu has a tab that permits the operator to enable or disable such alarm or warning messages. This option is very useful in cases arising in a lot alarms or warnings (e.g.: when starting the process). This suggests that it would be desirable to disable the broadcast of these messages, not to stun the operator with a large amount of sound emissions, which would generate a very noisy environment; the noise can completely decentralize him/her from their control work of the production process.

The graphic scene, showing the industrial process, has several options that facilitate viewing from other points of view. This implies that the graphic scene can be moved to any position, rotated about any axis or modified in size (zoom). These options allow the operator to navigate inside the process, to focus on specific areas of the same. This facilitates the visualization of the process from other locations and achieves that no area of the process remains hidden or distorted by other element that is in front of it. Therefore, the scene can be viewed, "Fig. 4" from the bottom, rear oblique, enlarged etc. The operator performs these operations with assistance of a mouse or a 3D-joystick. The 3D-joystick is the only peripheral device that can be used to interact with 3D scenes shown, since the graphics card prevents the use of the mouse. Similarly, a menu option or button joystick let you repositioning the graphic scene in its original position and thus facilitate this task for the operator.

Components (digesters, valves and pumps) of the industrial process can be selected, so that their information is displayed in a small command window "Fig. 5". This window provides more detailed component information, including its full name and the operating state it has got. Also, this window can also be used to change the state of the component, since this option was excluded on the application requirements. Component selection is done with the mouse pointer or by an advanced pointer. The advanced pointer needs to touch or cross a component to do this choice, while the mouse selects the first component that is located at the same depth coordinate. The advanced pointer is shown on screen with the geometrical figure of an octahedral and its movement is controlled via keyboard or 3D-joystick. This advanced pointer it is only available when viewing 3D scenes.

3.1 3D Visualization

The stereoscopic-3D view is achieved by obtaining two images of the graphic scene, which correspond to the images that are to be fetched by the left and right eyes of the user. The left eye image is obtained by directly capturing 2.5D image of the industrial process, but the right eye image is created by a rotation of 7° of the previous image. The hardware used for 3D visualization includes a 3D graphics card from Nvidia [8], a 120Hz 3D monitor and 3D glasses IR synchronized. The 3D scene cannot permit displaying the mouse pointer, so it is necessary to create a 3D pointer controlled by a 3D-joystick. This joystick is the only peripheral that can be used to rotate or move the graphic scene, as well as to move the 3D-pointer, which lets you select the components of the process. The frame rate of the 3D display is 2 seconds, which is within the permitted operating range from the ASM.

4 Operators Experiences with 3D Environments

The application was tested by DCS console operators of the Digesters Department of company "ENCE" in Pontevedra (Spain), as well as Technical Engineering Department of the same company [13]. This company has installed a DCS "Honeywell-TotalPlant" with 2D displays, where each operator is responsible for operating multiple monitors, which shows various operator displays.

It is observed that the application shows an exceptional quantity and quality of information available to visual range of operators, because one 3D display shows the same information as 10 old DCS 2D displays [15]. This prevents the operator have to navigating through all displays; whilst he ignores what it is happening in a display, because he/she is watching another one. The graphical process has a visual representation that is more natural and intuitive for the user, as it has a great similarity to the real process.

The symbols and colors used in the 3D graphic scene are immediately recognized by DCS operators, since the symbols used to represent 3D components are an evolution of 2D designs proposed by international standards. This graphic scene transforms hundreds of status signals from the physical devices (valves, pumps, etc...) in visual information based in colors. Previously, this information was displayed in numerical and textual format.

Lines or pipelines that are used to connect the components of the process are shown with up to 5 colors. It avoids the use of extreme tones (dark and light) because it is impossible to distinguish one color from another one 3D environments.

The font size decreases as a function of the depth, so the text can be negligible dimensions and unreadable. The width of the lines is a difficult parameter to use to report the importance of the flow, since the dimensions of the objects are reduced as they are at the bottom of the image. The flow of information depends on position of graphic scene because it can be rotate in any direction. E.g., the back views have inverted the ideal process flows (left to right).

Also, the use of different colors in the representation of 2.5D and 3D figures, showed in the graphic scene, they cannot strictly be considered incompatible with the principle of usability in computer systems. This is because the "risks evaluation" of the workplace of a display operator indicates that this position cannot be played by people with color blindness or with some other visual or physical impairment. This evaluation would also be applied to electricians, as an electrician with color blindness would not be able to perform their work properly, and he/she cannot differentiate all colors wires of a bundle cable.

It is observed that the operator requires less mental effort to comprehend the complete state of the industrial process. This allows to assert that the operating display meets the key concepts of usability, as it is very "user friendly" and very "easy to learn". This is reflected in the fact as how the operator “feels” all displayed components of the graphic scene.

It is appreciated, that operators and users need an adjustment period to the new 3D environment, and that they initially are surprised to the original format of the process. Also, some people aged more than 55 years or visually impaired are unable to view images in 3D and show that they continue viewing images in 2D, but some young people are extremely receptive to these 3D images. The user's position, the distance to the monitor and the phase angle of each eye images strongly influence the perception of the 3D image by the operator, because the presentation is designed so that it is centered in front of the screen at a distance of 60 cm.

The update rate of the process variables is 2 seconds and the speed of 3D rendering images is also 2 seconds. This implies that rendering speed 3D animations renders every 2-4 seconds; while the velocity in the 2.5D environment is 0.1 seconds. However, 3D operators are satisfied with this slowdown, as they believe that there is a great 2.5D point cloud on screen, it generates a lot of noise in the information in the image.

It is found that 3D images are not suitable as a user interface for some tasks or essential job functions of operation, and that those should be shown on 2D displays. Next, we list the features of the DCS interfaces, which are not adapted (at the moment), to 3D environments:

- Control charts and/or process variables are more understandable in 2D/2.5D format
- Windows command and a process component should be shown on a 2D display, as they have textual, graphical and command buttons.
- 3D navigation is done with a 3D-joystick that has a 3D pointer associated.
- The data entry in dialog box (passwords, numbers…) must be programmed in 2D.
- Windows scrolling menus or menus of 2.5D program should not be used in 3D.
- The block diagrams of control logic of DCS are very complex to follow and understand in 2.5D/3D.
- The help documentation about the process should be displayed in a 2D text format.
- Operator helper applications have to run on auxiliary 2D displays.
- Control rooms with several operators in 3D environments create problems of viewing to contiguous positions operators.

5 Conclusions

We present a new concept of DCS operator interface, dramatically increasing the amount and quality of information processing, an operator has available. This new environment brings together in a single operation 2.5D or 3D display equivalent to 10 old DCS 2D displays. Also, the use of peripherals 3D allows the rotation or displacement of the graphical process, facilitating its analysis from various positions and angles (front, rear, lateral, oblique, interior, etc.).

Similarly, it is found that there are some operating functions, which are hardly transferable to 3D environments. Finally, we note that some design methods for 2D displays are forbidden in 3D environments, so we are working to adapt them to the new environment, but trying to preserve their essence.

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