VISUALIZING MODEL-BASED PREDICTIVE CONTROLLERS

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One common problem with information displays, particularly in process control, is that relevant data is often scattered across several, separate displays that obscure important relationships and fail to show event information. The current displays used for model-based predictive controllers demonstrate several of the problems that this kind of a design can incur. It is hard to get a good sense of the recent, current and near-future status of the controller (situation awareness), and it is difficult to make informed decision when making changes to the controller (putting data into context). This forces users to navigate around a virtual workspace and attempt to compile the data necessary to make an informed conclusion. We have applied several design principles to show how it is possible to re-represent data into hierarchical data layers that support the cognitive tasks of monitoring, diagnosis, and control. This design forms a coherent, coordinated workspace which helps orient users to problems in the controller, with direct navigation to supporting details.

INTRODUCTION

Model-based predictive controllers (MPC) are becoming very popular in petrochemical refineries, as they simultaneously control and optimize large sections of a petrochemical process using a predictive model. However, current visualizations (trend plots and data tables) either don't extract or don't display in a "cognitively compatible" way all that is relevant to users who must supervise and interact with them. We conducted site visits to four refineries, where we interviewed engineers and operators and observed their use of MPC. Several observations were noted with the current design and use of MPC displays:

1) The operators may only look at MPC displays periodically (monitoring/situation awareness issue).
2) The current operating displays for MPC are primarily data tables. Often, these data tables take up several pages, so that an operator must serially scan through them all to "see" the controller (navigation issue; no overview).
3) Operators may change limits periodically, but these changes are not documented or viewable (changes not tracked; difficult to diagnose).
4) Some of the information that is important for diagnosing controller behavior is shown on detail screens that are seldom viewed by operators (navigation issue; difficult to diagnose).

DESIGN PRINCIPLES

Based on these observations, we developed an alternative design based on the following design principles:

Design Principle 1: Create a workspace that supports monitoring, diagnosis, and control.

We split the MPC operating screen into 3 functional areas. The left third of the screen is dedicated to overview information, to support periodic monitoring of the overall health and current status of the controller. The top two-thirds of the remaining screen space is dedicated to diagnostic information, and the remaining area of the screen shows detailed information about a single variable. The general layout of the workspace is shown in Figure 1.

Design Principle 2: Support periodic monitoring of the controller through the design of an overview display.

Our overview display shows three types of information:

1. Current overall status information for the controller. Overall status parameters are shown with standard "label: value" display elements, such as whether the controller is on, off, warming up, handling constraints or optimizing, the name of the model being used, and the time to next update.

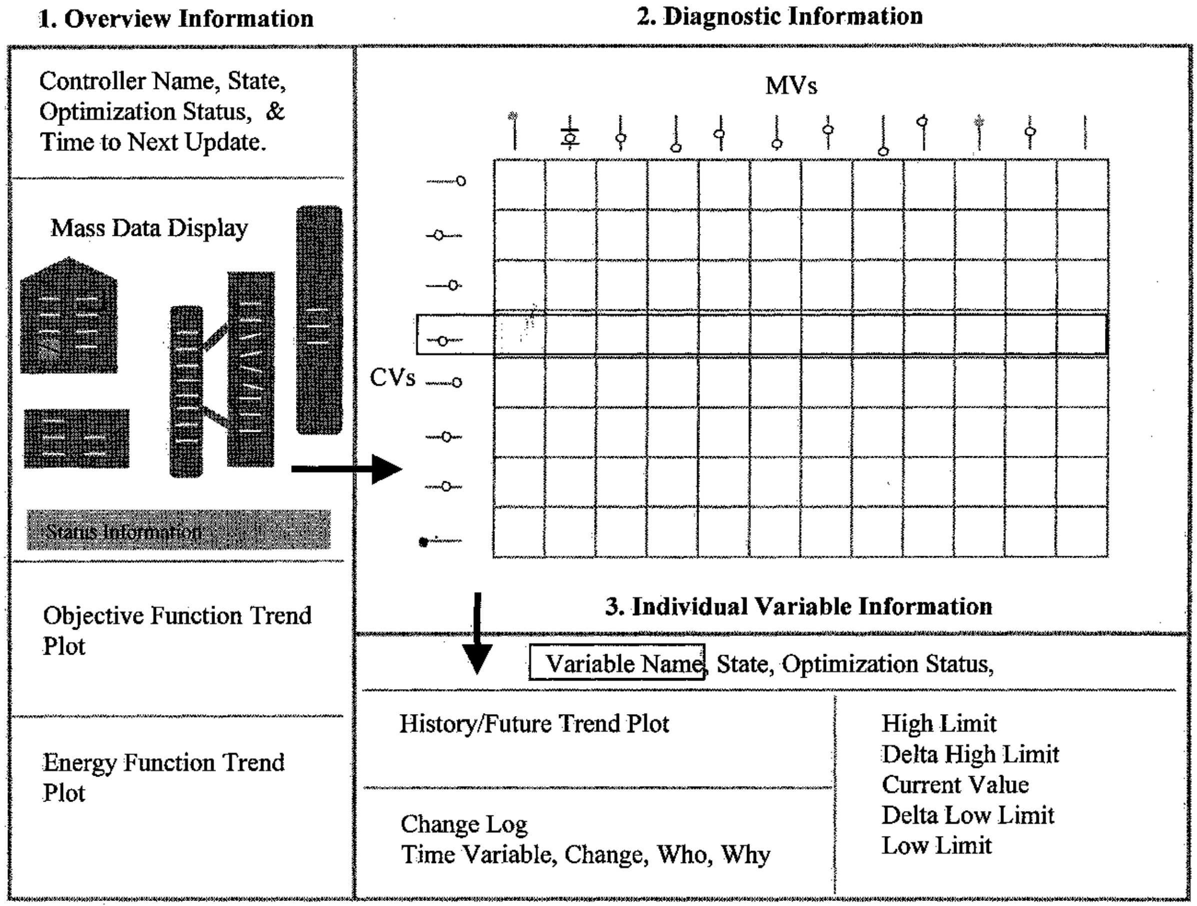

Figure 1. Layout of the redesigned MPC workspace This is a *schematic* representation of the MPC workspace, not the actual display. There is a relationship between the three functional areas of the screen: The Overview on the left hand side of the screen, the more detailed diagnostic information in the top right hand side of the and the detailed, individual variable information shown in the bottom right. A variable selected in one view will be highlighted in the other views.

2. Recent overall trend information. We show two overall trends; one for the value of the objective function contained in the optimization algorithm and one for the "energy" being expended to keep the controlled variables within constraints. Energy is defined as the sum of all the moves made in each control interval. These plots allow a user to see if key overall controller parameters are changing over time. These are shown with standard trend plots, augmented with a background to show whether the current value of the trend falls into "normal" or "abnormal" regions (these regions are defined by the plant engineers).

3. Recent individual variable information. We also represent each of the variables in the controller using a mass data display (Beuthel, Boussoffara, Elzer, Zinser, and TiBen,1995). A mass data display has the advantage of showing several variables simultaneously in a small display space, taking advantage of repetition in form to create a micro/macro display relationship, where detail cumulates into larger coherent structures (Tufte, 1990). Each variable in the controller is represented in the mass data display with an icon that maps four pieces of information onto the icon's features:

1. Recent trend behavior is encoded by the shape of the variable. The variable can be one of seven shapes, what we call "signature trend plots". An algorithm is used to classify the recent behavior of the variable into one of the seven standard first and second-order plots: steady state, ramping up or ramping down, increasing at a decreasing rate, increasing at an increasing rate, decreasing at an increasing rate, or decreasing at a decreasing rate.

2. The variable type and function is encoded into the location of the icon in relationship to the other icons in the mass data display. Variables are grouped according to location in the plant, and a background graphic that encompasses those variables represents the area in which those variables are located (such as the regenerator, reactor, feed preheat section, etc.).

3. The near limits status of the variable is encoded into the line color of the signature trend plot. The line will be black if the variable is within its upper and lower limits, yellow if very near or at a limit, and red if beyond a limit.

4. The status of the variable (normal/abnormal) is encoded into the background shading of the icon. The background of the icon is shaded if the variable is deemed to be in an "abnormal" state (where "abnormal" can be any of several abnormal states defined by the plant engineers).

It is important to note that the operators do not use the mass data display to discern details about the particular variables, but to get an overall sense if things are normal or not. Since the controller tends to push the process to the limits, but keep everything at a fairly steady state, normality is seen as a common pattern of flat, black lines with no backgrounds shaded. It is only when the process is moving or conditions are going out of normal ranges that the pattern begins to break in one or more ways as described above (the trend lines change from being flat to one of the other six shapes, the trend line changes to yellow or red, or the background of the variable highlights). The location of the variable does not serve as a notification, as do the other three mappings, but helps to identify the location of the variable in the process once further investigation is warranted.

Design Principle 3: Support direct navigation from the overview display to more details.

Since the overview display is designed primarily to alert operators to a problem, we must allow the operator to get more details about a particular variable that warrants further investigation. We support navigation from the mass data display to more detailed information in two ways. The first is by a mouse-over action, which will cause a status bar just below the mass data display to show the name of the variable and any abnormality information that has been detected. Second, the user can single click on the variable's icon in the mass data display, and the details about that variable will be shown in the Individual Variable window to the right of the overview pane (area 3 of our workspace shown in Figure 1) and any other information about that variable that is shown in the Diagnosis pane (i.e., in area 2 in Figure 1) will be highlighted as well.

Design Principle 4: Use representation aiding to map domain properties onto corresponding graphical elements.

We already described how we applied this principle when describing the mass data display above. We also applied this principle in the design of two other representations of variable information. One of these will be described here. We designed a "bubble gauge" that shows the current value of a variable in relation to its limits and optimization parameters. Each variable is shown on a fixed length scale, normalized to the maximum allowable range for that variable (as defined by plant engineers). This scale is represented by a fixed length line on either a vertical or horizontal axis. Perpendicular to the primary axis, we show the user-set high and low limits with a perpendicular black line, the current value of the variable with a small hollow circle, and the target optimization value (if set) with a light gray X. Thus, we can map the following onto one small graphic: highest allowable value, lowest allowable value, current high limit, current low limit, current value, and current optimization value. Further, by showing all of these in a scaled graphical representation, the user can see how close the current value is to the other parameters that have been set and easily see if the variable has been "clamped" (where the current high and low limit constrain the variable to a much smaller region than allowed).

Design Principle 5: Use consistent color coding throughout the display to represent the same thing.

We use the black/yellow/red color coding consistently throughout all of our displays and graphic representations to represent 'within range', 'at limits', and 'outside of limits' respectively. Whether it be the iconic representation in the Mass Data Display, the circle used in the bubble gauge, or the trend line in an individual trend plot, we use this coloring throughout the workspace to provide a consistent representation of the variable's status.

Design Principle 6: Show variable information relative to limits.

We already described how we applied this principle in the design of the bubble gauge. We describe now how we use this principle in the design of the trend plot. When a variable is selected in the overview or diagnostic display, the control display will show a historical and predictive trend for that variable. *This trend plot also shows the limits that were in effect on the same graph.* This is a simple concept but one that is rarely, if ever seen on actual trend displays in use in process control. This allows the operators to analyze how the variable has behaved in relationship to its limits and to see when those limits have been changed and the effect of those changes on the variable's performance. This is important contextual information that is lost when this information is not plotted.

Design Principle 7: Show important context information when the user changes a limit, including past operator changes.

By dedicating the bottom right third of the screen to single variable information, we can automatically show all the details necessary to assist the operator in making informed limit changes. We show the recent and predicted trends relative to limits, the maximum allowable range as defined by plant engineers, and a historical log of changes made to that limit by other operators. This log is yoked to the trend plot, such that clicking on the log will scroll the trend to that time and vice versa.

DISCUSSION

One common problem with information displays, particularly in process control, is that relevant data is often scattered across several, separate displays that obscure important relationships and fail to show event information. The current MPC displays demonstrate several of the problems that this kind of a design can incur. It is hard to get a good sense of the recent, current and near-future status of the controller (situation awareness), and it is difficult to make informed decision when making changes to the controller (putting data into context). This forces users to navigate around a virtual workspace and attempt to compile the data necessary to make an informed conclusion. Woods has called this the problem of "design for data availability" rather than "design for information extraction" (Woods, 1995). We have applied several design principles to show how it is possible to re-represent data into hierarchical data layers that support the cognitive tasks of monitoring, diagnosis, and control, and to design a coherent, coordinated workspace which helps orient users to problems in the controller (helping them to know when to move from a monitoring stage to a diagnostic stage in working with the controller), with direct navigation to supporting details.

The Elucidator work completed to date represents a cognitive engineering approach to a pertinent problem in petrochemical refining. Our forthcoming evaluations will provide a measure of the effectiveness of this solution and insight into the use of cognitive engineering and representation design in applied settings.

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