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BRIDGING THE GAP BETWEEN THE HUMAN OPERATOR AND THE FAR AWAY TECHNICAL SYSTEM BY MEANS OF PICTORIAL COMPUTER GRAPHICS AND MOBILE DEVICES

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Abstract: This paper presents a highly pictorial and vivid concept for the visualization of dynamic information for the supervisory control of distant technical systems. Elements of technical system are modeled and presented "close to the real appearance". System information like process values are integrated into these elements. Production goals and deviations from the goals are visualized situation-depended to assist and support the operator. Experiments in Asia and Europe showed the advantages of such a pictorial process visualization. *Copyright © 2001 IFAC*

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1. INTRODUCTION

Increasing requirements in respect of quality, economics and ecology, and increasingly efficient and inexpensive automation systems, lead to an increasing level of automation in technical systems. Such complex, dynamic systems are still monitored and controlled by human operators in a control room. Nowadays, modern information, multimedia, and telecommunication technologies enable the monitoring and controlling of such systems from distant control rooms (Buss and Schmidt, 2001). Several processes may be managed centrally from one control room, using computer-aided control systems. Because of the distance between the control room and the technical system and because of the information preparation this requires, usually the operator becomes divorced from the system. The operator loses more and more the feeling of the system.

Computer monitors are used to show a wealth of process information on a very limited area. Operators have to deal with a flood of information. However, identifying the relevant process variables from among the large number of items of data is important if the current situation at any time is to be reliably and rapidly identified (Johannsen, 1993).

The operator can be assisted in this situation by a user interface to the technical system, suitably structured to accommodate human capabilities. The design of human-machine interfaces must be such as to assist the human's processing of information - both in terms of the storage of information and also in action planning and problem solving. The interface has to keep the operator in touch with the process.

2. TELEAUTOMATION

Recent developments in the area of communications technologies enables a real-time communication between an automated technical system and a far away centralized control room. The increasing power of the information technologies breaks into the use of tele-presence and tele-immersion (Buss and Schmidt, 2001). But as the main information channel the visual channel will still persist.

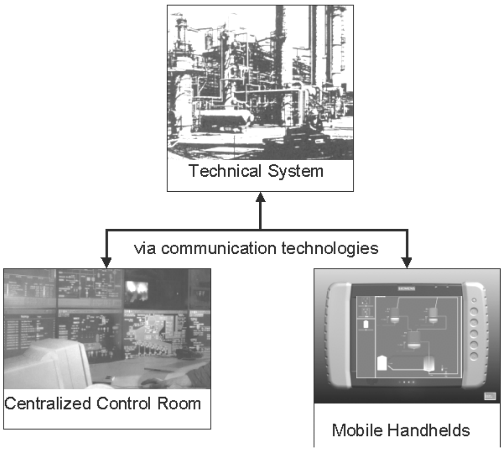


Figure 1: Teleautomation

As a new device Mobile Handhelds will become more important. Such mobile devices become more and more suitable for industrial use – like the SIEMENS Mobic®. Communication standards like wireless LAN or Bluetooth enables the information exchange between the Handheld and the technical system. In the near future the communication technologies will be sophisticated for a safe real-time communication. Figure 1 shows a possible structure of such a network in the field of Teleautomation.

As a consequence the user interface concept has to support the presentation in the control room on PC monitors as well as on Mobile Handhelds – maybe in a simplified version.

3. PRODUCTION GOALS

Different influences have effects on the control of the technical system. For economic reasons enterprises aim

- to optimize the stock regarding procurement, production, and distribution, and
- to optimize the capacity utilization regarding production and distribution.

Additionally the customer order short-dated and expect just-in-time delivery (Obertopp and Fischer, 2001). These influences the control of technical systems (Figure 2).

The production goals are determined by customer order and the availability of material, machines, warehouse capacities etc. These goals are calculated in the superordinate levels ERP and MES.

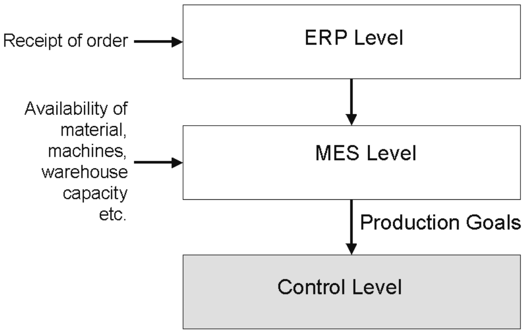


Figure 2: Levels of ERP, MES and Control

Investigations in different domains have shown that operators supervise and control technical systems based on these goals. But usually these goals are not integrated in one user interface. The operator is informed about the goals through different devices (sometimes even as a paper printout).

4. PROCESS CONTROL AND INFORMATION PREPARATION

Because of the high level of automation operators monitor the technical system in the majority of cases. Nevertheless the operator has to interact with the technical system through the user interface. Different steps of these operators' actions can be described in a simplified manner based on different action models of human behavior (e.g. Rasmussen, 1984; Norman, 1986). The operator perceives process information, interprets this information and determines the state of the (sub)process. The operator compares this actual state with the optimal state – the above described production goals. If there is a relevant deviation between the actual state and the production goal the operator determines the actions required. In the final stages the operator plans and carries out the actions required. A user-centered process visualization should support these steps and therefore support the operator.

Integrating the production goals into the user interface for process control result in a consistent interface. An user support should move along – integrating deviations from goals including prioritization into the user interface, offering reasonable actions ,and a task-oriented information preparation.

5. BRIDGING THE GAP BETWEEN OPERATOR AND TECHNICAL SYSTEM

To cover the distance between the operator in a centralized control room and the anywhere placed technical system the user interface has to make the technical system tangible. The power of computer graphics allows the presentation of system information via three-dimensional depictions.

Three-dimensional presentations activate curiosity and fascination. The holistic perception of the virtual emulated, three-dimensional information space is facilitated by the daily experience with real three-dimensional space – with the real world. (Elzer, 2001). Based on this a three-dimensional visualization for process control concept was developed by Beuthel (1997). The concept present a conventional S&C-Diagram as a plane in the three-dimensional space, the process values rise as bars from this plane. Advantages like a higher information density were found.

It is a well known psychological fact that humans process pictorial information faster and more easily than textual information. These differences are described very well by the so-called *multimodale model*. This model describes different memory areas, which in each case are dependent on the modality of the initiating stimulus and possess very different characteristic abilities. The advantages of pictorial information - the so-called *picture superiority effect* - are determined by this (Engelkamp, 1991). This means that it should be advantageous if the process information to support the operator is coded pictorially.

Correct action planning by the operator is based on the mental model. The planning of action steps can be described as a dynamic cognitive simulation of the mental model. As with simulations of mathematical models on computer systems, this cognitive simulation is repeated iteratively, with the initial parameters changed each time, until a satisfactory result is achieved. The process visualization must make available the information necessary for the operator to form a correct mental model, based on system and process identification. In addition, since a mental model is usually characterized by strong symbolism, support for the model should be based on such pictorial visualization (Dutke, 1994).

Following this ideas an ideal process visualization should use pictorial three-dimensional visualization means to bridge the gap between the operator and the technical system.

6. PICTORIAL PROCESS VISUALIZATION

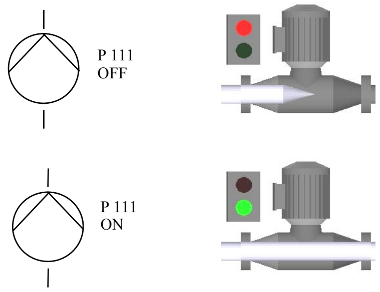
As a pictorial process visualization the Virtual Process Visualization concept was developed to utilize the above mentioned advantages. The Virtual Process Visualization is a concept which deals with the above problems by means of a special visualization technique, derived from modern computer graphics. This type of visualization can be used to show various kinds of relationships (even time-dependencies). The entire process is represented in a highly pictorial and transparent way – and bring the operator back to the technical system.

Part of this visualization concept are the *Virtual Process Elements* (Wittenberg, 1997; 1998; 1999; 2001a; 2001b; 2001c):

6.1 Virtual Process Elements

The individual process units are implemented as so-called *Virtual Process Elements*. Based on a typical member of the group of items concerned, a visual object is developed.

All these graphical objects have been developed to give a consistent presentation of information and consistent interactions. In accordance with the idea of direct manipulation, operators interact directly with the process items. This visualization concept is expected to be efficient, with the process variables and the relationships between process items being visualized. Spatial variables - such as fill-up levels and flows - are shown directly, others are coded using color and shape.



a) The pump symbol in DIN 28004, Part 3 b) Virtual process element: *pump*

Figure 3: Pump-symbol

Figure 3 shows the conventional DIN symbol for a pump and the corresponding Virtual Process Element.

As mentioned above the production goals are very important for the control strategies of the operator. For this reason a *State and Goal Visualization* is integrated into this visualization concept:

6.2 State and Goal Visualization

Subtasks are defined as appropriate for each higher level function, and are associated with appropriate production goals. Each task is associated with a specific view, which includes the process items, the process variables and the relationships between them. A higher level overview of the process shows the states of the system and the subtasks. The view of each subtask shows the achievement of its production goals, the necessary process values, and the statuses of the process items.

Because pictorial methods cannot be used to represent purely quantitative data, the process values are presented qualitatively. Threshold values and setpoints facilitate the identification of current process conditions and the production goals. In the concept presented in this paper, the threshold values and setpoints are only displayed when the associated process values or process items are in abnormal states. This limits the volume of information to the essential minimum.

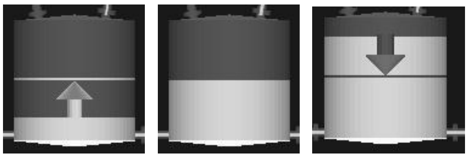


Figure 4: Visualization of the actual and desired fill-up level (L) (left: actual L lower than desired L; center: actual L = desired L; right: actual L higher than desired L)

As an example figure 4 shows the visualization of the fill-up level in a reservoir. A small line represents the target value (50%). This line is visible only if there is a deviation from the target value. The arrows show the direction of the necessary level change. Like the "goal-line" these arrows are only visible in unsatisfying conditions.

Additionally the degree of the goal fulfillment is represented in the form of colored columns ("goal-columns"). The direction of the columns displays whether a goal is fulfilled or still in the range of tolerance or whether a warning or an alarm is present (see Figure 5).

The operator can plan the order of the necessary interventions on the basis the column lengths and the coloring. Additionally early activities are easily possible for the prevention of unwanted (and maybe dangerous) system states.

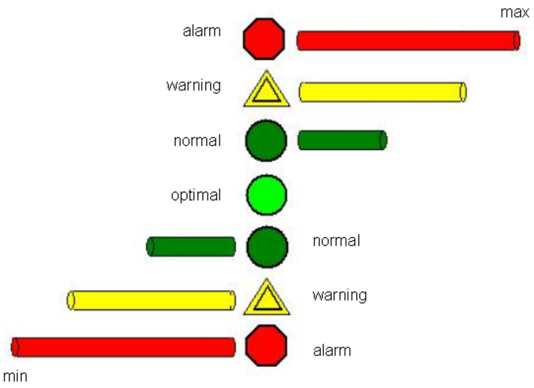


Figure 5: "Goal-columns"

If the bar is on the left-hand side (which is usually associated with a negative deviation) the process variable is too low. The state is indicted by color changes from green (optimal) through yellow (warning) to red (alarm). In addition, the usual symbols (e.g. a warning triangle) are displayed. The use of color and shape coding simplifies identification of the current (sub-)system state. On the basis of the column length the operator can detect, how far the goals are achieved. The goal columns are presented with the belonging process elements inside the so-called "goal-monitor" (see figure 6 for an example).

This part of the visualization concept shows the optimal state and information about any necessary action, it assists the operator in performing his task, and it includes the production goals for a dynamic adaptation of the (economic) conditions.

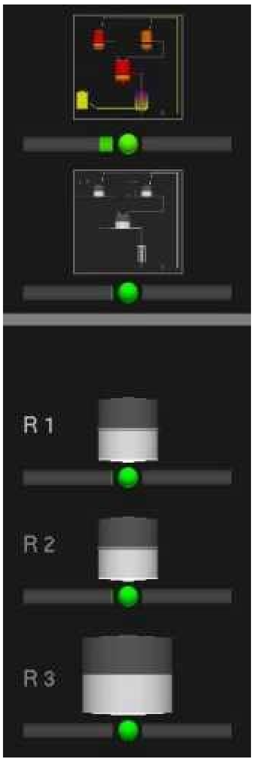


Figure 6: "Goal-monitor"

6.2 Experiments

In experiments, this visualization method was compared to and evaluated with conventional topological interfaces. These experiments were intended to verify the hypothesis that this visualization is more descriptive, thus making it easier to comprehend the actual process state. The first experiments used a distillation column as an exemplary application. The subjects (German graduate students) had to keep the process in an optimal state although different malfunctions occurred. After each scenario the students had to fill out questionnaires about the scenario, the malfunctions and their subjective impressions. With the questionnaires aspects like general design, navigation, support of the operator performing the tasks, presenting the states and target value etc. were investigated. The Man-Whitney-U test were carried out on the results using the software tool SPSS and showed significant advantages of the Virtual Process Visualization method (Kistner, 1999; Wittenberg, 2001a, 2002).

The second experiment using a central heating application was designed as a 2x2 matrix. The subjects (Japanese graduate students) were split into in two groups. Each group started with a different interface. After the first stage of the experiment, the type of interface was changed for the second stage. Each stage contained five different scenarios, i.e. different initial values and a different desired temperature in the apartment block. The dependent variables were the mean errors of the temperature of the apartment block, the fill-up levels in the reservoirs, the time to respond to malfunctions and the number of undetected malfunctions. 30 different sets of variables were recorded. The variables were analyzed with the software tool STATISTICA. As expected, differences were found in the time to respond to malfunctions, the number of undetected malfunctions and in the mean error of the apartment block. An ANOVA was carried out, and showed that all these results are significant (Wittenberg, 2001c, 2002).

The significant good results in both test series (also in Japan and in Germany) gives a hint for the advantages of pictorial visualizations in an intercultural background.

7. OUTLOOK

Modern automation systems lead to an increasing degree of automation. The operator becomes more and more an observer. Further development is necessary to support the operator's diagnosis in case of abnormal situations Also help- and support-systems should developed for such complex applications. There is also a need for different user-group-dependent views (operator's view, maintenance view, manger's view etc.) on the technical system through the process visualization. Following the user-centered usability engineering life-cycle (Epstein et al., 2001) SIEMENS Corporate Technology develops such user-centered solutions for the above mentioned problems.

Figure 7: Early design study of a GUI for mobile Applications using the SIEMENS SimPad® (Penzkofer, 2002)

As an example figure 7 shows an early design study of a graphical user interface for the supervisory control of industrial production processes (Penzkofer, 2002). Next steps are the development and implementation of a prototype and the evaluation with usability testing. Basis of this prototype is a design pattern concept which will be developed at SIEMENS Corporate Technology (Wittenberg et. al., 2002).

In addition to control rooms such mobile device can supply the operator with the necessary information at every locations - depending on the task. On site interaction is now possible - the operator is back in the process – the gap is bridged.

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