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INCREASING THE RELEVANCE OF DATA PRESENTED TO THE OPERATORS IN AN ACCELERATOR CONTROL SYSTEM*

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Summary

Relevancy assumes a critical importance in control system operation because of the large amount of information available. The information deluge impacts the following areas: If information is presented at too high a rate or in too large blocks, the operators may not comprehend it. If useless data is often presented in a given display, the operators may ignore all data presented by that display. If the context of the data is not presented, the data may be meaningless to the operators. If the control and display systems are not properly designed, peaks in the message generation rate may choke the system. This paper describes the techniques in use and under development at the Clinton P. Anderson Meson Physics Facility for increasing the relevance of data both for real-time operations and for long-term analysis of accelerator performance. Data sifting and organization for presentation and for compact storage is discussed.

Introduction

There is a long-standing interest in man-machine interaction in the control of the Clinton P. Anderson Meson Physics Facility (LAMPF) at Los Alamos.[1] The control of a large accelerator facility is a complex task. One strives to implement the control system in such a fashion that the control system itself is transparent: Operators "feel" the characteristics of the process being controlled and not the characteristics of the control system. Transparency may be characterized by three R's: responsiveness, reliability, and relevancy. Response to operator requests should not be obviously limited by delays in the control system. Reliability should be high enough that operators are not held up by repairs or continually questioning if the instrumentation is working correctly. Relevant information should be presented or stored. All of these have a human as well as a strictly engineering aspect. This paper focuses on relevancy.

Since part of the operator's task is to cope with unforeseen circumstances that arise at unexpected times, there is a certain inherent vagueness in the design process of making control information relevant.[2] Hence the first word of the title of this paper implies good design is an iterative process in which one learns from trials and tribulations.

At each iteration in this process one may find a stumbling block or an opportunity. Stumbling blocks occur when changes are arbitrarily imposed on the operators. Under these circumstances, many operators are proud that they had a way to do the job before the change, they may resent the change because it forces them to do the job differently, and they may even refuse to use the part of the system incorporating the change. Opportunities occur when the operators are allowed to contribute their ideas in regard to the change and are given some choices as to how the change is made. Under these circumstances, many operators are proud of their contribution to the change, they may accept the change enthusiastically, and they may experience a growth in pride in the control system as a whole.

Other general considerations in display system design are discussed in the literature.[1-4]

Quantity of Information

Control systems incorporating digital computers allow a few men to supervise a large set of equipment. The large amount of on-line and long-term trend information potentially available to the operators has implications for information display rates and for storage requirements.

Information Display Rates

Whether a given display will be comprehensible to an operator often depends more on the degree of structure or pattern apparent in the data than on the amount of data presented. A few unrelated numbers on one line of a character scope display may be less understandable than thousands of data points displayed graphically in an isometric[5,6] or contour[7] plot. Thus organizing the data to make structure more apparent in displays is one tool for dealing with the deluge of information from the control system.

At LAMPF, the computer system saves certain data automatically which are later plotted up for studies of machine stability. In the case of the man that analyzes the long-term performance of the accelerator, if he receives too large a stack of graphs of machine performance every week (or whatever), he is likely to drop the whole bunch unread in the round file. We have found that it is better to send this man only occasional samples of the data obtained, or to send him only the worst-looking or the exceptional cases. (The latter will be discussed further in a section on data conciseness under the part of this paper on quality of information.)

Another aspect of the information deluge comes to the fore when fault conditions occur and a large number of fault messages need to displayed. The display system should be designed so that such peaks in the information rate do not choke the system. At LAMPF, certain warning messages are displayed in cyclic fashion on the top four lines of the character scope at each console. Those messages which indicate fault conditions which may require operator action are also printed on a dedicated printer.

The fast protect system at LAMPF is a hardware system which checks various conditions and shuts off the beams at their source if the conditions are not satisfied. In addition, an interrupt signal is sent to the control computer. Messages identifying these interrupts are handled in a special way. These messages are considered to be so important that they are allowed to pre-empt the space used by the warning messages discussed above. The fast-protect messages are not sent to the printer since some fault conditions produce such a large number of these messages that the system would be seriously overloaded and unresponsive.

Some types of process control systems require operators to acknowledge certain classes of faults.[3] At LAMPF we consider this an unnecessary burden on the

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operators and detrimental to system response; we have avoided this kind of requirement.

In passing, we remark that the importance of information output is hinted at by the fact that the format output program is the busiest program of all the systems and applications programs running on the LAMPF main control computer.

Storage Requirements

Obviously it is practical to store only a small portion of the data potentially available on long-term trends of facility performance. The method employed at LAMPF is to use a series of data scan programs which are called automatically at intervals ranging from seconds to once every eight hours. Each scanner has a list of channels for which data is to be taken. The lists are easy to modify to meet changing requirements. Thus data are stored at sample rates appropriate for the subsystem under study. The scanners store the data on disk files. Graphs produced on a daily basis are plotted directly from the data on disk. For longer term graphs the data may be dumped to magnetic tape for interim storage.

Some measurements have indicated that the storage space filled by our data scanners can be reduced by recording data items only if they differ significantly from the data item most recently recorded for that channel. (The time of the measurements would always be recorded so that one may distinguish cases in which no data was taken from cases in which there was no significant change in the data.) When the level of significant change was set at the resolution of the analog data system at LAMPF, it was found that the storage requirement for analog RF subsystem signals was reduced to about half that for the normal recording scheme.

In general, a display device for any measurement should not display a result exceeding the resolution of the measurement. Exceptions to this are sometimes necessary. For example, when the control system is first being checked out, one may want to display data points with an apparent precision beyond that of the measurement itself in order to sort out how much of the displayed result is signal and how much is noise. Once the characteristics of the noise are understood, the display precision can be reduced as appropriate. Reducing display requirements can reduce storage requirements if data packing is feasible.

Quality of Information

In order that data presented to operators be useful, it must be accurate, concise, presented in the proper context, and in a few cases, available at locations other than at the main consoles.

Data Accuracy

Hardware aspects. Someone must be willing to fight for accurate data or the operators will always be fighting against the data to have it make any sense. Inadequate transducers must be replaced, noise and backlash tracked down and reduced to tolerable levels, and calibration procedures worked out and put to use. During accelerator off times, computer programs which exercise the equipment and check its performance can be a real help in diagnosing equipment faults.

As an aside, the author would like to see more checks built into computer hardware to trap faults or errors in data and programs. Possibilities are different formats for instructions, data, and uninitialized data so that these could be detected if they turn up where they don't belong. Provision for significance arithmetic in floating-point calculations would make it possible to put up only a meaningful number of digits on displays and to obtain error bars for graphs more easily.

Software Aspects. Once the data have reached the computer, some software treatment can improve its relevance to some degree. An example at LAMPF occurs in a set-point management program. In determining the values of parameters, the subroutine used averages the results of several data takes, throwing out points which are far from the others in the process.

Another approach is the use of control vectors or orthogonal knobs, which transform sets of data and process them in a fashion to improve the relevance to the operator. For example, instead of dealing with magnet currents (the actual controlled parameters) one may have an algorithm that allows him to adjust local transverse beam positions or angles (virtual parameters) as if his knob was directly connected to one of these.[9-11] Since changing a single magnet current generally changes all positions and angles, it can be seen that the control vector approach has a great advantage in such an application.

Data Conciseness

A standard technique for avoiding useless data is to display only the exceptions to standard conditions. An extension to simple out-of-tolerance checking used at LAMPF tries to reduce the number of messages triggered by a single fault. Fault conditions are organized in an alarm hierarchy. When one of the channels examined by the general accelerator monitor program goes out of tolerance, a check is made to see that some higher level fault, which will be displayed some other way, has not occurred. For example, if the cavity field is low on a module, a message will not be given if either the sector high voltage is off, or a VSWR or an arc fault has occurred.

Another type of exception reporting is to point out cases of uncorrelated behavior in channels which supply redundant or related data. For example, if the field at one end of an accelerator module does not stay proportional to the field at the other end of the module, something is wrong, perhaps a malfunctioning rf detector. (One would certainly like to know if the detector used for amplitude control is dying!) Some of the recent control system changes at LAMPF are aimed at extending the redundant control information available, in order to make correlation checking possible on all accelerator parameters that directly affect beam performance.

One can deal with the distribution of long-term stability data on an exception reporting basis also. At LAMPF, only graphs of performance data that vary unduly or have some key abnormal characteristic are routed to certain requestors. All data are preserved either on graphs or on magnetic tape for six months in case some question comes up that cannot be answered by the graphs that were sent out. Ways to have the computer decide whether important features are present in a set of data and to rank sets of data in order to sort out the worst cases continue to be studied.

Data Context

Relation to Previous Data. Certain displays at the LAMPF control consoles have caused the computer control and display system to be jokingly called the "million dollar strip chart recorder." Strip chart recorders have not been used in the LAMPF control room because they have limited flexibility and no easy way of handling alphanumeric information. But the strip chart points out that a display with memory can serve three simultaneous purposes:

1. It indicates the present state of the variables displayed.

2. It indicates the trends and extremes of variations of these variables, that is, the relation of present to previous data.

3. It can serve as a record of parameter behavior for an extended period of time, such as a full operator shift.

Displays on storage CRT's have been extensively used at LAMPF because they permit data to be presented in context with its previous behavior and with other parameters in a straightforward way. The memory takes no programming to use. In fact, storage tubes have been overused at LAMPF. In a two-month period, long-duration repetitive displays have irreparably burned the phosphor on display tubes at the principal operating position. Other devices are being investigated which would replace the storage display units for shift-length chart-recorder type applications.

Another way of displaying analog data in context is to display the most recent N points on a scope with vector capabilities.[12]

A device for quasi-real time displays in seven colors has also been developed.[13] The device, named chromonitor by its developers, uses a memory block of 512 words for each of the 16 possible traces to be displayed in oscilloscope-like fashion.

Meaningful Labels. We now shift our emphasis to the sense of context being that which is known or familiar to the operator. In general, operators prefer natural language descriptions, abbreviations or mnemonics in place of number designators or codes. The choice between either having the operator learn the language of the machine or programming the machine to use the language of the operator is not as clear-cut as some of the display design literature might imply.[3] In control system design, there is a spectrum of reasonable solutions corresponding to the spectrum of frequency of use of the displays involved. For a display of RF system status that is in almost continuous use, a highly abbreviated and color-coded display is natural and appropriate. On the other hand, for a beam current monitor calibration program that is rarely used more than once or twice per month, the displays need to describe clearly any actions required by the operator. Abbreviations are to be avoided here.

The appropriate degree of abbreviation also depends on the degree of familiarity of an operator with the system being controlled. An operator who is new on the job may prefer displays based on diagrams of parts of the accelerator and displays with few abbreviations. As his knowledge of the accelerator grows, his preference will probably shift toward highly coded and compact displays for frequently used functions.

Whether programs are designated by number or by name, one must designate exactly which program is wanted when calling a program into use. Two types of devices that aid the operator here are the programmable button panel[14] and the touch panel.[15,16] In the button panel, the panel senses which of several plastic cards have been inserted and thus furnishes the computer the information necessary to determine which program is desired when a button is pushed. The cards also carry labels for the buttons for the benefit of the operator. The touch panel overlays a character scope; the label changing is done by the display system. Touch-panel systems seem to lend themselves to the creation of program directories, which can be a convenience.

Standardization. Standard formats for selections or for values which may be changed on a display simplify life for the operator. One approach to standardization for programs that run infrequently enough that one does not have to squeeze every milligram of efficiency out of them is to use a general subroutine to handle operator interaction. One such subroutine in use at LAMPF allows the programmer to merely call the subroutine specifying the variables to be affected, which simplifies coding for him. (Format specifications are entered on a disk file using an interactive program.) The subroutine displays the current values of the variable plus explanatory text on the character scope, waits for the operator to change any values he wishes or make a selection, then acknowledges any new values and posts an indicator to tell the operator that his action is not required until further notice. The display is color-coded to prompt the operator as to which action is required.

Parameter Sets Saved. When an operator demands a program, it is often convenient if the program has saved the input parameters last used and displays these when asking the operator for the new input conditions. Thus the operator does not have to respecify all parameters when only a few are to be changed. When using a keyboard and character scope, one generally overtypes the old value with the new. Thus displaying the old parameters can give the operator an example of the input format and position required for the parameters that he does wish to change.

For some programs at LAMPF, it has been found advantageous to save multiple sets of parameters. When using these programs, one can go back to one's own favorite set of parameters or go to a set of parameters appropriate to the task at hand by merely specifying the parameter set number. Each set number has a corresponding user-specified label which identifies the task in natural language. A definition option allows the operator to change parameters within a set if necessary.

Eliminating Distractions. Two areas over which the display designer has some control and in which he can aid the operator are: (1) keeping displays simple and to the point, and (2) arranging the displayed material compactly. It has been found at LAMPF that the area used by a program on a character scope should usually take only one or two lines. (Each line can display 40 characters.) Besides conserving the space used on the scope, this tends to focus the operator's attention on the particular operation in progress - he doesn't have to search through a lot of inactive items to deal with the active ones.

Having the displays for a particular program appear in a limited region on the console is also an aid to the operator.[3] If the operator has to keep looking back and forth between separated parts of the console, unnecessary delay and irritation may result. This concept of visual compactness is definitely not intended to imply that figures and text should be packed in displays without spaces for legibility!

Remote Availability

For some equipment adjustments, it is advantageous to be able to ship data from the normal operating position to some remote location. One way to do this is to have provision for converting some displays to TV format and sending the information to remote locations via closed-circuit TV. At least one accelerator facility makes available a portable mini-console which can be plugged in at the controlled equipment interface units.[17] More permanent remote consoles are used in connection with particular experimental beam lines. Care should be taken in designing such remote consoles to limit the remote control capability so that operators at the different positions will not be working at cross purposes.

A system for remotely displaying the current operational beam status at LAMPF for the benefit of the experimenters is now being designed. Hopefully, the system will reduce the number of telephone inquiries received by the accelerator operators.

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