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ADVANCED DISPLAY CONCEPTS IN NUCLEAR CONTROL ROOMS

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ABSTRACT

Precursors necessary for the development of a full-scale predictor display/control system have been under development since the mid 1940's. The predictor display itself has been available for use in manual control systems since 1958. However, the nuclear industry has not yet explored the uses and benefits of predictor systems.

The purpose of this paper is to provide information on the application of this technology to the nuclear industry. The possibility of employing a simulation-based control system for nuclear plant systems that currently use conventional auto/manual schemes is discussed. By employing simulation-based systems, a predictor display could be made available to the operator during manual operations, thus facilitating control without outwardly affecting the overall control scheme.

INTRODUCTION

Some operators are better than others in anticipating or predicting future states of control systems. This is directly due to the quality and quantity of prior experience, knowledge, and training in combination with such factors as motivation, cognitive ability, and plant instrumentation and design.

Recent advances in display instrumentation and computer simulation have provided us with the potential for assisting nuclear plant operators to identify and detect anomalous plant trends and conditions before they occur. The purpose of this paper is to provide more information about these new advances with the aim of generating interest and research for applying this technology in nuclear power plant control rooms.

The predictor display is one of the most innovative developments in manual control systems of the past two decades and has been available since 1958. Unfortunately, this type of display is not currently being used in the nuclear power industry, where there is a great need to predict and display process events and system states to plant operators.

Nuclear power personnel who operate sophisticated control systems rely heavily on their subjective ability to predict developing parameter trends based upon what the system is doing presently and what has happened in the prior history of plant parameters. Predictor displays offer the opportunity to extend the operator's capability for maximum control and enhanced diagnostic decisionmaking, particularly in the training environment.

A preliminary review of the literature dealing with predictor display instrumentation [(1), (2), and (3)] provides some hint as to why the nuclear industry has not fully examined the applicability of predictor displays to nuclear process instrumentation. Like the computer, predictor displays have been viewed as a somewhat "sophisticated toy" (4) with an unproven operational track record in nuclear power plants. Despite the sparsity of empirically based operational studies dealing with predictor displays, the few available results lend strong evidence to the conclusion that predictor instruments, in conjunction with valid models, significantly enhance manual control and diagnostic performance in both the training and operational environment (4).

A review of predictor display work yields four reasons why these devices are currently underutilized in the nuclear industry:

1. Plant Specificity--Optimal configuration of predictor systems for one class of nuclear power plants like the PWR (pressurized water reactor) is probably not identical to that required on a BWR (boiling water reactor), HTGR (high temperature gas cooled reactor), LMFBR (liquid metal fast breeder reactor), or CANDU (Canadian natural uranium heavy water reactor). Thus, configurations for predictor display instrumentation must be "tailored" to each individual plant.

2. Vendor Differences--Predictor systems configurations will vary as a function of manufacturer, e.g., Babcox and Wilcox or Westinghouse.

3. Incomplete Systems Understanding—Currently, information regarding all functional relationships among major or important parameters is incomplete; variations in system dynamics and control performance are not completely understood.

4. Vintage Differences—Plant dynamics and idiosyncrasies in procedures and operations vary to a great extent due to plant vintage. For example, a General Electric BWR of 10 years ago is very different from those General Electric BWR's due to come on line in the near future. Predictor displays will have to be fine tuned to reflect these differences in plant vintage.

Manual Control Research

Sheridan (2) presented a brief, interesting history of manual control research. He reported that formal study in the area began about 1900 under the general heading of "psychomotor skills." However, widespread and self-conscious interest in human operator control systems did not occur until rather obvious problems emerged during the operational use of numerous weapon systems employed during World War II. Human- and machine-response lags were of concern because they often resulted in intolerable control errors.

During the latter part of World War II, Tustin (5) applied the theory of linear servomechanisms in an attempt to mathematically model the human operator. Sheridan noted that research on "aided" tracking systems was being conducted. There is apparently some question regarding the development period of another major control system innovation known as "quickening." Sheridan credits Birmingham and Taylor (6) as the developers of that system, while Kelley (3) holds that some investigators have traced research on quickening devices (otherwise known as "command" instruments) back to shortly after World War I. In any event, both "aiding" and "quickening" must be regarded as significant milestones in the development of man-machine control systems.

Prediction Research

Human control operators repetitively perform sequential elementary tasks such as monitoring flow rates and temperature to make certain that there is no difference between a parameter's desired value and the actual value. If a discrepancy is noted, the operator may adjust a control to compensate for the difference in the parameter of interest. During this process of human action followed by system reaction and feedback, the operator is attempting to predict the outcome state of the individual parameter. Without predictive information, the frequency and speed of the operator's corrective actions are greatly limited by his or her abilities plus the timelag of the system in response to his or her actions. As task complexity increases, the introduced timelags contribute to the rise in probable errors of omission or commission.

Research focusing on the degree to which operators employ a cognitive or predictive model in different types of control tasks has been disappointingly limited. Limited evidence on this subject suggests that human operators do not have a cognitive model that predicts first- or higher-order derivatives from compensatory or pursuit displays very well (7). It is, however, systematically documented that an operator's performance improves dramatically when the trajectory history of a controlled element is displayed.

Thus it would appear that the performance of operators typically and dominantly reflects their anticipatory or predictive abilities associated with correctly prescribing what control actions will most quickly and accurately affect the future state of the system being controlled. Assuming this is true, it is unfortunate that the applicability of predictor displays in commercial nuclear power systems has not been addressed. The fact that a relatively inexperienced operator's performance tends to improve with experience and time might suggest that experience is enhancing the operator's ability to anticipate and predict parameter changes independently of training or advancements in conventional control/display hardware.

DEFINITIONS AND CONCEPTS

Predictor Displays

Predictor displays generally employ a fast-time simulation produced by a mathematical model of the system being controlled to present an expected trend plot of system parameters to a control operator via cathode ray tube, or other visual display device. Each predicted parameter is generated by this model, which is time scale accelerated. Plant parameter information is transmitted to the fast-time model via sensing transducers within the actual plant. Taking transducer-generated data, the model reiteratively computes or updates discrete predictions of the actual system's projected future state. In essence, a predictor display can tell an operator what to expect regarding the future state of selected plant parameters as a function of initiated or omitted control actions.

Predictor displays offer a unique control advantage, particularly in the diagnosis and control of developing system trends where the ability to anticipate future system change is advantageous. These advantages have been well documented in submarine collision research. The results of one study showed significantly better operator control with predictor displays than with all other displays tested under identical conditions.

In summary, a "true" predictor instrument predicts the future state of a controlled vehicle or process, i.e., it displays to the operator one or more future states of parameter values of a system, as well as its present state or value. The projected time period in which prediction occurs is variable and contingent on a number of system factors.

Classification

At least two classes of prediction fidelity outlined by Bernotat and Widlok (8) are useful in describing predictor instrument capabilities and applications. Class 1 prediction requires the actual model equation of the controlled system and its derivatives. For example, to predict the future location of an aircraft, the present position, velocity, acceleration, rate of acceleration, etc., would be required. Extrapolating future position is accomplished by using a power series (an infinite series whose terms are successive integral powers of a variable multiplied by constants), typically Taylor's series, which is repetitively computed to provide continuous updating of a predictor display.

Class 1 prediction does not account for the unique response characteristics of a controlled system; extrapolation is based on a purely mathematical computation. Clearly, two vehicles having entirely different response characteristics would respond differently to the same initial conditions. Thus, under Class 1 prediction, the actual controlled system will progressively depart from the predicted trajectory of the process parameters by an amount contingent on its specific response characteristics.

Bernotat and Widlok (8) note that Class 1 prediction is applicable to stabilization and guidance tasks where very short prediction spans can provide useful inputs [e.g., Bernotat and Widlok (9) and Bernotat, Day, and Widlok (10)]. Much of the work here has involved a one-dimensional display showing a single projected endpoint; i.e., the end of the prediction span, although some have dealt with two dimensions, in which the entire predicted trajectory was shown.

Class 2 prediction includes the actual value of the controlled system, its derivatives, and the controlled system's response dynamics. The predictor instrument of this class is a logical and innovative derivation from a concept introduced by Liebolz and Paynter (11). These researchers proposed a computing system with two-time scale for a totally automatic control system; in effect, two computer-simulated models of a vehicle. One was a real-time model that simulated the actual dynamics of the vehicle or process; the other was a fast-time model that extrapolated real-time dynamics, including controls inputs, and predicted future status. Like the command instrument, the concept proposed by Liebolz and Paynter presupposed a precomputed trajectory. Thus, discrepancies between predicted and desired future status could be rapidly and repetitively computed and fed to a high-speed, automatic controller that subsequently eliminates the discrepancies.

A current predictor instrument of the Class 2 variety is an example of designing the machine to fit the person, rather than to design (select, train, etc.) the person to fit the machine. While it compensates for man's inherent response lags and relative lack of predictive capability, it also frees man's outstanding perceptual and intellectual capabilities, providing considerable flexibility in using displayed predictive information. Present and future status of a vehicle or process is usually displayed on a cathode ray tube, including the actual extrapolated trajectory from present position to some preselected temporal point. Thus, the instrument uses the information computed by the real- and fast-time models suggested by Liebolz and Paynter and replaces their automatic controller with the human operator.

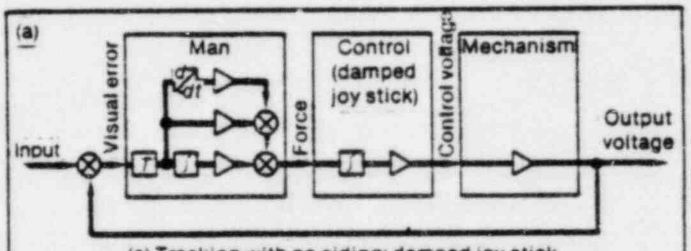
Applications of Class 2 prediction, like those of Class 1, include stabilization and guidance. Because of the greater accuracy of extrapolations that take into account system-response dynamics, Class 2 prediction spans can be much longer. On the other hand, the two-time-scale modeling scheme neither provides perfect extrapolations, nor does it permit prediction spans of unlimited length.

In effect, Class 2 prediction assumes a constant medium for the system under control. For many applications, particularly nuclear power plants, operating environments are not constant. For example, power levels, neutron density, core temperature, primary flow rate, volume, and core liquid levels are continuously interactive and are not constant. Other variables are power demand, grid distribution requirements, and fuel levels. Consider the complex interrelationships between system variables and states as a function of one system parameter change. For example, the open relief valve on the pressurizer at Three Mile Island caused dramatic changes in a number of parameters, including vessel level.

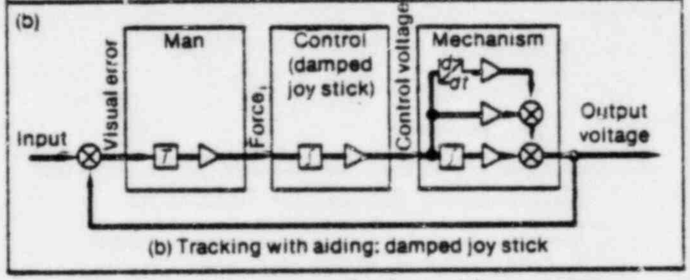
Control Aiding

Aiding is a control method of compensating for the operator's relative inability to obtain predictive information from the display. Its utility is generally limited, however, to systems having constant rates. As the dynamics of a system depart from constancy, the rate component becomes progressively less useful. Since rate must be the primary mode of control in high-inertia systems (aircraft), the amount of aiding that can be practicably included in such systems is severely limited.

Aiding, originally developed for gunnery tracking tasks, will help an operator track a moving target by modifying the control output. Figure 1A shows a blocked diagram of a) an unaided and b) an aided tracking system to illustrate the aiding concept.



(a) Tracking with no aiding: damped joy stick



(b) Tracking with aiding: damped joy stick

Fig. 1A Aided and unaided tracking systems.

Aiding has been found to facilitate operator performance significantly on negligible inertia systems such as electronic forcing functions (12). Further increases in performance levels have been observed with controls having higher-order dynamics, such as acceleration and rate of change of acceleration (13,14). Aiding has a relatively less positive effect on high-inertia systems that have inherent and significant response lags (15). A high-inertia system cannot be displayed instantaneously and it is obvious that its associated controls must be predominantly rate-driven with very small aiding-time constants, for example, 0.1 to 0.15. Larger constants will cause the controlled system to undergo intermittent "jerks," which can be dangerous to both the system and the operator.

Quickening (Command Instruments)

A second method of compensating for the operator's relative inability to obtain derivative or predictive information is termed quickening (6). Although aiding operates directly on the controlled system, quickening methods function only indirectly by providing a simplified display input to the operator, who subsequently responds through a conventional controller.

Quickening devices (command instruments) are not predictor instruments. Although this statement seems valid, a case could be made for stating that a command instrument is a subset within the predictor-instrument family.

Command displays employ a computer that performs integrations, differentiations, and other higher-order computations ordinarily performed by the human operator, often with considerable difficulty and questionable fidelity. In effect, the command display "tells" the operator what kind of control response is required in order to maintain a desired, precomputed trajectory. The operator thus functions as a simple amplifier.

A command display can be considered a type of predictor instrument since it is used in conjunction with a precomputed parameter history or trajectory which is, by definition, predictable. The display presents the effects of the operator's control actions before they are taken and indicates exactly what to do to achieve a desired future system state. The principal attribute of a predictor instrument is its ability to indicate what to do to achieve a desired future state. Another important similarity between the two displays, though only indirectly related to prediction, is the fact that very little training is required of an operator to perform the control task with considerable accuracy.

Since a computer calculates the exact corrective control response required of an operator, it is clear that a command-display system and a fully automated control system differ only in that the former employs a human operator to perform a simple programmed response that the latter performs by an automatic controller.

The reader who is unfamiliar with command systems might logically question their utility since they employ a human instead of a (perhaps) more reliable automatic controller. In many applications, the automatic controller is preferable. However, in those situations where some deviation from a precomputed (operating) range is desirable but impractical to preprogram because of a large number of contingencies, a command display is the superior system. In such cases, the operator may deviate from the ordered control signal by either over- or under-compensating for the displayed error. In so doing, however, control accuracy will be reduced.

As emphasized by Kelley (3), "A command display does not tell the operator what is happening but instead tells him what to do." For example, if an aircraft maneuver is required to attain a desired altitude, a command display will indicate only a required control response. It will not present system status; e.g., current altitude, rate of change in altitude, etc. Without status information, the operator depends entirely on an error signal and cannot "see" the trajectory or associated characteristics of the controlled system. However, system-status information via supplementary, conventional instruments can be made available in conjunction with command displays. Thus, a control system having command and status instruments has a great deal of flexibility. But such a control system still does not appear to be nearly as flexible as that of the "true" predictor display, which presents both status and ordered information in a single display, and also shows future status by extrapolating present conditions.

Since most nuclear control systems cannot be fully automated, i.e., parameter ranges cannot be completely precomputed, command displays may have limited application in nuclear control rooms.

DESCRIPTION OF PREDICTOR DISPLAYS

Figure 1B shows a block diagram of the Class 2 predictor instrument. The following is a description from Kelley (16), its inventor:

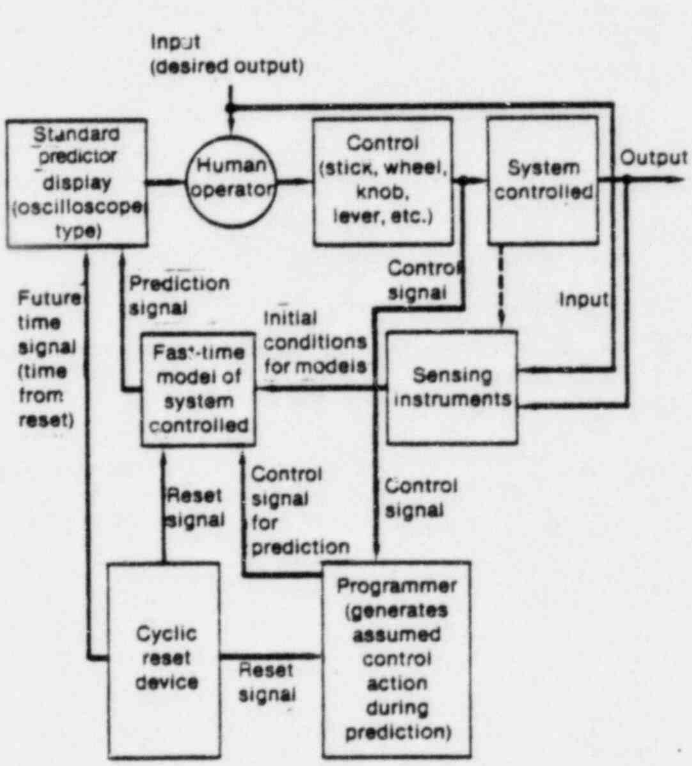


Fig. 1B Manual control system using a standard predictor instrument (Class 2).

> "The heart of the predictor instrument is the fast-time model of the system controlled. This model could be mechanical, electro-mechanical, or electronic, using either anlaog or digital methods. We will suppose the fast-time model is a simulation by means of a repetitive electronic analog computer. Sensing instruments in the real system provide signals which are transduced into D.C. voltages and scaled to equal the voltages representing corresponding quantities in the analog model. In this way, the sensing instruments provide initial conditions for the analog system, conditions which begin each cycle of its operation. If the cyclic resetting device resets 50 times per

> second and the analog operates on a time scale 500 times that of real time, the analog system will represent the period from present time to 10 seconds (actually 9.98 seconds) into the future. The predictor instrument is completed by using a signal from the output of the analog system to operate an indicator. This indicator presents a signal corresponding to all or part of the prediction period.
>
> "The "programmer" is a simple device, which represents the assumed control action of the operator during the prediction period. Since the future consists of a range of possible values of the variable controlled, which are primarily dependent on the control action of the operator, one or a limited number of control actions must be selected and programmed."

An example of predictor display application to a boiling water reactor is shown in Figures 2a, b, c, d. This display concerns itself with control of reactor vessel water level. The use of this display would be directed at startup, shutdown, and low-power operations when manual control is in effect.

The example shown is a trend display with the trending parameter projected. Current parameter value is always displayed at the 0 sec ordinate. Past trends are to the left and future trends to the right. Figure 2a is indicative of a condition in which actual feed flow does not quite match required fuel flow. Figure 2b indicates the manner in which the display would respond if the operator were to grossly overcorrect for the slowly decreasing level in Figure 2a. The undesirability of this control action is immediately obvious and the operator can readjust the controls to obtain a prediction similar to that in Figure 2c. This type of transient will allow an easy transition into a steady state condition such as that in Figure 2d. The dynamics of control in those operating regimens impose several events that will affect vessel water level. These events include the necessity of realigning flow routes, the density changes produced during heatup and cooldown, and the need for maintaining the proper differential pressure between the feed-injection nozzle and the reactor vessel. Added to these events are the effects (both transient and permanent) produced by changes in feed flow and steam flow.

With these compounding effects present, the operator has difficulty in predicting future trends based on past trends and making precise control adjustments. Instead, control must be accomplished by trial and error, i.e., making a control adjustment/waiting for the resulting trend to become evident--readjust the controls--etc. It would be desirable to let the operator "see" what the future effects of the control action are as they are made. Considering the present state of estimation theory and fast-time simulation, this is a realistic statement.

Control Modes

Two fundamental types of control modes can be employed with essentially identical predictor displays, on-line and off-line (17). For on-line control, each control action by the operator is input to both the controlled system and the prediction model and immediately reflected on the predictor display. It can be likened to "trial and error behavior" in fast time with real-time effects. Thus, the operator inputs a continuous series of exploratory control actions, based on the relation of the predicted trajectory to the desired trajectory, eventually reducing the number and magnitude of such actions as the predicted and desired trajectories converge. As noted by Kelley et al. (17), this control mode is not the most efficient for specific applications, such as spacecraft maneuvers for which fuel consumption rates are critical. On the other hand, when time is critical and fuel consumption rates are not particularly important, the on-line mode has advantages over off-line control.

Off-line control is identical to on-line control, except that control actions are directly input to the controlled system until such time that the operator concludes that the results of the "optimal" control action, as reflected on the predictor display, comprise the best of all possible actions attempted. In effect, the operator's control is directly coupled to the predictor display, but only indirectly coupled to his control, via a switching mechanism. Thus, the operator manipulates the control until the predicted trajectory is the desired trajectory and then activates a switch to input the selected control action. Kelley (3) notes that the selected control action may be the operator's most recent manipulation or one that has been placed in storage.

It is evident that off-line control presupposes the luxury of at least a few seconds to explore the potential effects of various control actions. When such time periods of control inactivities are undesireable or dangerous, on-line control is clearly preferable. For many applications, initial control errors and, where relevant, additional fuel consumption attributable to on-line control will probably be of negligible importance.

A third mode of control relevant to the topic of this paper is supervisory control. In this mode, primary control would be automatic. However, a secondary control capability would be available via a human operator and an override control mechanism. Strictly speaking, the entire control system would be on line, while the automatic and manual components would be on-line and off-line modes, respectively.

Two methods of supervisory control are possible, varying in the degree of "pureness" of the off-line component. If the automatic control system malfunctions, manual backup becomes essential. The operator may have little or no time to explore the utility of various control inputs and will thus function in an on-line mode, having only the displayed effects of the last inputs from the automatic controller to use in selecting the first inputs. If the automatic control malfunctions, but time is not critical or if the automatic system functions normally but unanticipated events demand manual override, the operator may function predominantly in the off-line mode.

The BWR Water-Level Control System

In the water-level control example, we assumed that the operator performed all control actions manually, but manual control is valid only for a limited set of plant conditions. For this reason, the supervisory-control system is the one most applicable to the BWR water-level control mechanism. A supervisory control system will allow control of vessel inventory through the entire range of normal plant conditions (see Figure 3). It is also similar

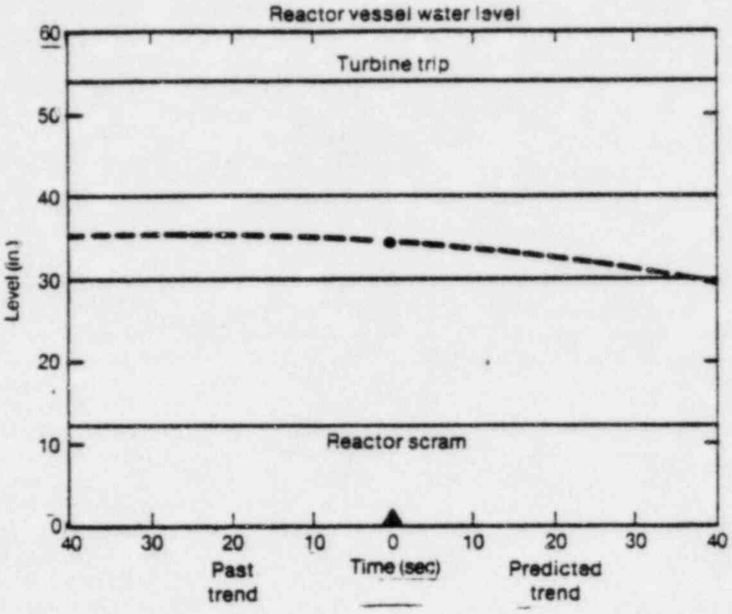


Fig. 2a

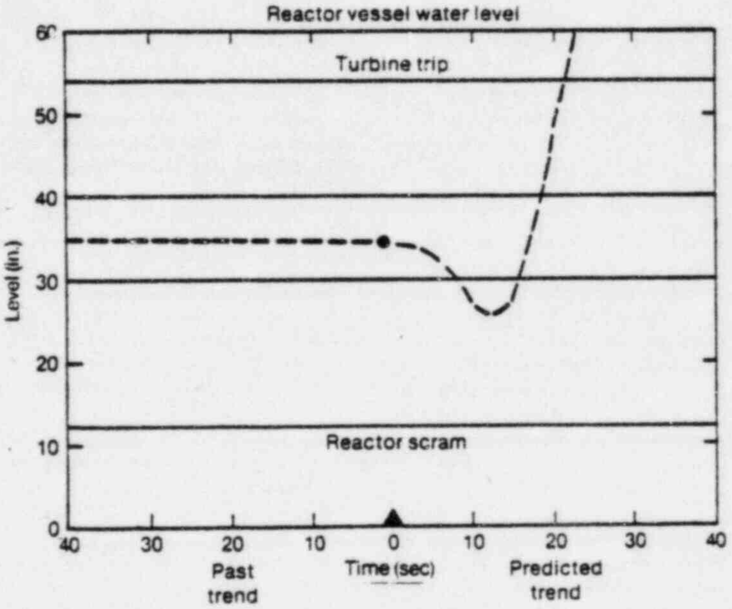


Fig. 2b

Predictive display of the water level for a BWR reactor vessel.

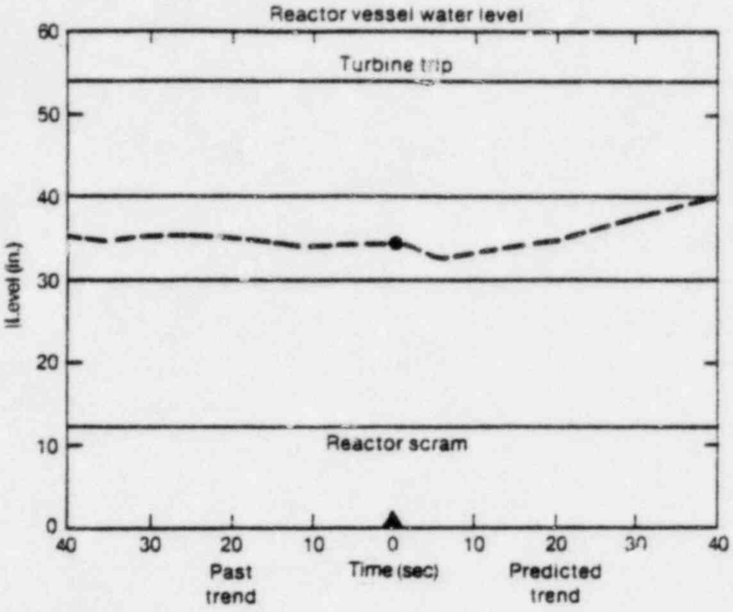


Fig. 2c

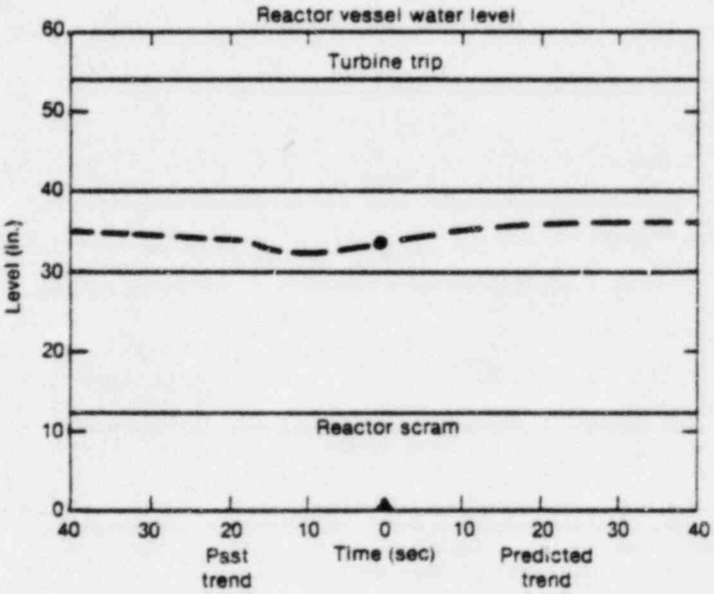


Fig. 2d

(continued)

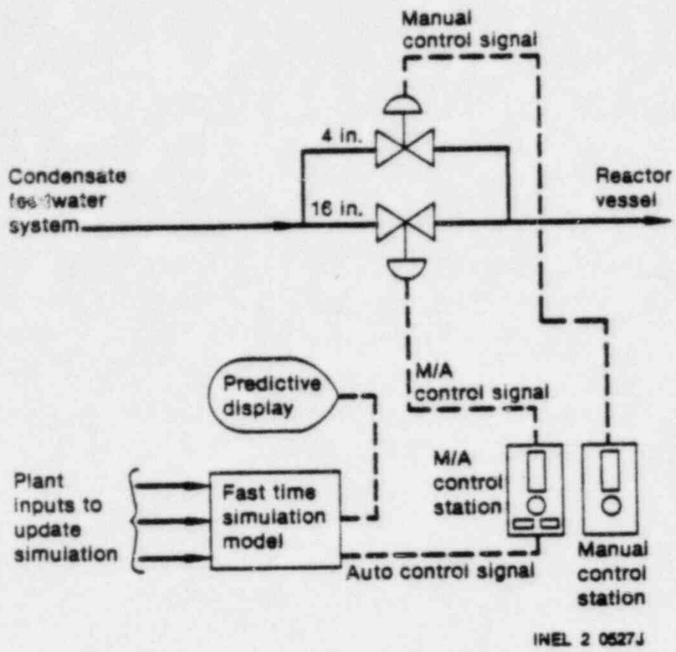


Fig. 3 Conceptual arrangement of a simulation-driven, supervisory-control system.

to existing analog control systems, with the exception of the predictive feature in the control system.

The major difference that the operator would find with the predictive system as opposed to a conventional analog control system would be the presence of a predictive display. The difference in the automatic control mode would be almost unnoticeable to the operator, the major change being that the automatic control signal is generated by a simulation model rather than a conventional analog controller. However, in a manual control situation, the presence of the predictor display would greatly improve the operator's performance for both the off-line and on-line modes.

APPLICATIONS AND PREDICTION DISPLAY RESEARCH

Since its initial appearance (1), the predictor instrument has been proposed for use in a wide variety of control systems, either for primary, secondary, or backup control. Kelley, for example, suggested that it would be ideally suited for submarine depth control. It has been proposed that it be used to provide aircraft pilots with predicted takeoff points and last, safe-stop points. A number of investigators envisioned a need for predicted path information for controlling lunar robot vehicles and for guiding spacecraft in reentry tasks; e.g., Cohen (18), Kelley (19), and Austin and Ryken (20). Fogarty [cited in (21)] indicated that a predictor display would facilitate a range safety officer's task by providing additional information about missile flights and impact points. Price, Honsberger, and Erenta (22) proposed the use of a predictor display instrument for a variety of manual control and flight management functions in connection with the Supersonic Transport.

Other potential applications include controlling nuclear power plants, docking large seagoing vessels, controlling complex aircraft maneuvers such as terrain-following, depicting relative position of aircraft and targets with land-based observers in missile test and evaluation of air combat monitoring, VTOL (vertical takeoff and landing aircraft) and helicopter hovering, and landing an aircraft aboard unstable platforms; i.e., aircraft carriers.

Spacecraft Systems

McCoy and Frost (23, 24) and Mano and Ulbrich (25) have shown that use of predictor display facilitates operator performance in an orbital rendezvous task. Each study also demonstrated that less fuel was consumed with the off-line mode than with the on-line mode. McCoy and Frost (24) also noted that naive subjects were able to perform the rendezvous task with essentially no training whatsoever.

More accurate attitude control and less fuel expenditure were similarly found by Besco (25, 26) in a three-axis spacecraft control task. In this investigation, test pilots corrected rapidly changing thrust disturbances more precisely with predictor displays than with the best alternative displays.

Oceangoing Vessels

Oceangoing ships, particularly large tankers, have exceedingly long response lags. Maneuvers such as docking must be performed at relatively slow speeds. Predictor displays can minimize the effects of such response lags and permit greater maneuvering speeds. Predictor displays have been applied to oceangoing vessels (Kelley (27). In one of the first laboratory tests of the predictor display, Kelley found it provided excellent depth control of a simulated high-speed submarine.

Four types of displays in a submarine maneuvering task were evaluated, including symbolic, contact analog, quickening, and predictor displays. Although the researchers found no differences of tracking error between displays, the predictor display was significantly superior to the others in a subtask that involved the avoidance of a homing torpedo.

PROBLEMS AND RECOMMENDED RESEARCH

Despite the potential of the predictor display and the fact that it has been in existence since 1958, the quantity and the depth of the accumulated research associated with it has been minimal. No comprehensive set of studies has yet evaluated the application of the predictor display to a nuclear instrumentation system. Nor has a series of interrelated, multivariable experiments been conducted to derive optimum predictor display configurations. Perhaps some of the experiments conducted initially might best be described as demonstrations. On the other hand, the overall findings and implications are impressive; viz., that predictor displays usually outperform conventional displays for a number of different control tasks. Nevertheless, much work is needed before the display can be thoroughly understood and its operational applications are firmly established.

Training and Operational Use

The most important question to be answered is the ultimate worth of the predictor display for training and operational use. Kelley (1,27) has noted that with the use of a predictor display, novice operators of fairly complex control systems can become relatively expert within a rather short time. To advance the state of the art, it appears inescapable that predictor instruments should be incorporated into the many trainers and simulators at nuclear power plants. The software should be written in a manner that could easily be modified to accommodate plant changes and updates.

Kelley, Mitchell, Wargo, and Prosin (28) contend that:

> "Manual control is a function of the operator's information acquisition and processing, prediction, and motor skills. Further, it has been indicated that each of these component skills contributes to, or is the result of, the prediction process. Manual control is primarily a cognitive skill and as such, learning to control is principally a matter of developing an internal predictive model of the system to be controlled."

They hold that the predictor display aids in the development of an internal predictive model by providing the operator with immediate and clear feedback about the ultimate effects of control actions. It would then follow that as learning progresses, the utility of the predictor display would diminish. If this theory is true, the real potential of predictor displays lies in the training environment, rather than in the operational setting and future experiments.

It is anticipated that future research will find predictor displays that will remain superior over conventional displays for very complex control tasks that cannot be fully mastered by operators even with extensive experience. On the other hand, it is possible that predictor displays will also be superior for simpler control tasks under stressful conditions. This suggestion follows from the known relation between error rate and stress. Predictor displays provide extremely simplified information to operators and tell them more about the future status of the system rather than what to do. It would not be surprising to find the operator's performace under stress to be less affected when using predictor displays than when employing conventional displays.

CONCLUSIONS

The sophistication of advanced control and display technologies are, unfortunately, not used for nuclear power plant applications. As a result, operators alone bear much of the control responsibility there. It seems evident then that more advanced display and control technology should be transferred to the nuclear industry to augment the operator's capability and enhance plant safety.

One major and promising innovation is the predictor display. Seventeen years of research on this instrument have yielded almost unequivocal findings—that the predictor display greatly facilitates human performance on a wide array of complex control tasks (4). The next step is to examine the applicability of this technique to nuclear control rooms.

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