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AWS (WORKSTATION FOR AI·ADVANCED CONTROL)

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ABSTRACT

The system with softfware packages for control system design unifying and encompassing rule based control and conventional control based on numerical models were developed.
Users who are not familiar with control theory, numerical computing, and artificial intelligence (AI) can perform system analysis, control design and development of AI control system without difficulty.

1. INTRODUCTION

Computer aided analysis, simulation and other engineering works are indispensable for the design of control systems that uses artificial intelligence (AI) or advanced contol including fuzzy control. Some supporting softwares for the design and analysis based on control theories are available. However,most of them are specialist oriented and difficult for non specialists to use. Although many expert shells based on AI and fuzzy control are marketed, supporting systems are still only accessories because design methods using these shells have not been established yet.
Consequently, AI and advanced control is not yet practical enough for instrumentation and control engineers. If advanced control tools can be utilized not only by specialists of control theories, computation or AI, but also by instrumentation and control engineers who have knowledge and know-how of domains close to actual operation fields, these tools will be used much more effectively.
On the other hand, workstations have become able to handle large-scale computation and simulation that were handled previously only on general purpose computers or super minicomputers. Thanks to compactness and low cost, workstation have been rapidly popularized, meeting the demand for distributed processing.
In these circumstances, we have developed a software package called "Integrated Control System Design Supporting Software Package". This package integrates conventional control based on numerical models, fuzzy control and rule based control. The package includes various tools arranged easily for use, and therefore will make control engineers or general instrumentation engineers who use this package familiarized with AI and advanced control. Since the design supporting tools can be utilized on a workstation, design work can be performed closely to actual work fields. This will largely benefit process control work. This paper describes the Workstation for AI and Advanced Control, equipped with these software packages (in this paper called AWS). (Fig.1)

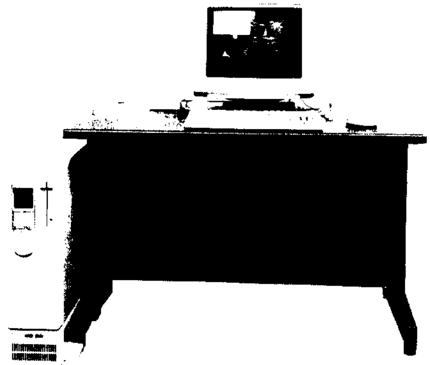

Fig.1 Exterior view of AWS

2. CHARACTERISITICS OF THE AWS

2.1 Integration of AI and Control Theory

The AWS permits the user to handle both conventional control based on numerical models, and fuzzy and rule based control in the same environment (Table 1), and therefore to design AI and optimum control coordinative systems. The AWS makes it possible to incorporate in one system not only qualitative knowledge acquired from experience and intuition, but also quantitative and objective knowiede obtained from statistical analysis and modeling

Function	Item	Methord or form
Data analysis	Deta transform	Linear, normalize, trend, filtering
	Statistical analysis	Histgrum, multiple regression analysis, principal component analysis
	Time series analysis	Correlation function, power spectrum, frequency response
	Identification	Auto-regressive model, approximated transfer function
	Prediction model	Kalman filter, GMDH
Control system design	Optimal control	PID auto tuning, optimal regurator, observer, pole assignment
	Adaptive control	Gain scheduling of two direction
	Decoupling control	Inverse Nyquist array method
	Time delay system	Smith method, process model method
	Frequency response analysis	Bode diagram, Nyquist diagram, phase margin, gain margin
	Root rocus	S-plane, Z-plane
	Transient response simulation	Block diagram, transfer function, state equation
Expert system	Knowledge base	Production rule, criteria frame, network, numerical expression
	Test	Static check
	Simulation	Dynamic simulation
Fuzzy control	Control rule	Fuzzy production rule, membership function
	Optimize	Optimal fuzzy variable
	Simulation	Static and dynamic simulation

Table 1 AWS major function

2.2 On Line Data Processing

The AWS, when forming a network together with an instrumentation system and a computer system, makes it possible to analyze data on line, to conduct calcu-lation and simulation for building AI or performing advanced control, and to transmit obtained control rules and parameters to an implementation system.

2.3 Interactive Input/Output

In order to utilize a variety of function easily, the the procedure of utilization must be simple without special technical knowledge or operation skills.It is requisite for man-machine interfaces of recent computer systems that operator's native language can be used. The AWS permits to use in the japanese language.
The user can input data or set conditions and get calculation results and messages through tables or descriptive formats,interactively and by selecting function keys.

2.4 Graphic Output

The AWS shows the results of analysis and simulation graphically on the color display, using the multi window function. Graphs can be enlarged or reduced to any dimensions, and two or more graphs can be displayed simultaneously for comparison and evaluation. If necessary, results and screen displays can be printed out through a laser beam printer or a X-Y plotter.
Fig.2 shows an example of interactive input/output and graphs. Set values, graphic output, and system messages can be displayed simultaneously.

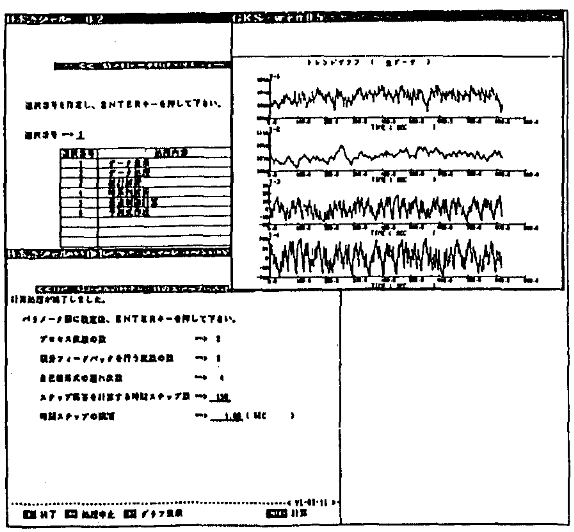

Fig.2 example of interactive input/output and graphs

3. SYSTEM CONFIGURATION

3.1 Hardware Configuration

The hardware is based on the UNIX * Workstation Σstation 230. Table 2 shows its specifications.

3.2 Software Configuration

The software consists of basic softwere for the workstation on which tools are mounted and the control design and AI tools. (Fig.3) These tools are packaged separately by functions and can be selected optionally; packages can be added one after another.

CPU	Processor	68030 (25MHz)
	Floating point operation	68882 (25MHz)
Memory	6 MB~32MB	
Magnetic disk	134MB or 330MB (expandable)	
Floppy disk	1 MB (5 inch)	
Cartridge MT	120MB (option)	
Display	20/16 inch color (256 colors), 1280×1024 dots	
Keyboard	JIS arrangement	
Mouse	3 buttons	
External interface	RS-232C	
	Ethernet*	
	Centronics	
	GP-IB	
Output devices (option)	Laser beam printer A4/B4 240DPI	
	X-Y plotter A3	
	color hard copy	

* : Ethernet is a registered trademark of Fuji Zerox.

Table 2 AWS hardware specifications

Software package for control system design	* option
* SAPL-100UX	Design package on classical control theory
* SAPL-200UX	Design package on modern control theory
SAPL-300UX	Design package on data analysis
* GISTLAX-UX	Gain scheduling of two direction adaptive control system
* FRUITAX-UX	Fuzzy rule information processing tool for advanced control system
* EIXAX-UX	AI tool for process control
* ΦNET-UX	Structuring tool for material flow control system
* COMEX	Compact knowledge based expert system
Basic software	FORTRAN, GKS, GKS driver, LBP driver
SX/A Basics (operating system)	Kernel, library, command, C-language, X-window EMACS

Fig.3 Structure of AWS software

4. CONTROL SYSTEM DESIGN PACKAGES

4.1 Design Package on Classical Control Theory SAPL-100UX

Since the PID control is the base of the controllers even now when digital representation has been popularized, the methods based on the classical control theories are important. Frequency analysis, control design and transient response simulation are performed on the bases of transfer function or block diagrams which represents the control system including the object of the control. Complicated systems which include non-linear elements can be modeled with block diagrams on the screen drawn by the use of a mouse. Fig.4 and 5 show a block diagram prepared as mentioned above and the transient response simulation results from this diagram. On the other hand, standard control models as shown in Fig.6 are available;in most cases, it is sufficient to fill blanks which correspond to symbols in these models.

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* The UNIX operating system was developed by AT&T Bell Laboratories and is licensed from AT&T.

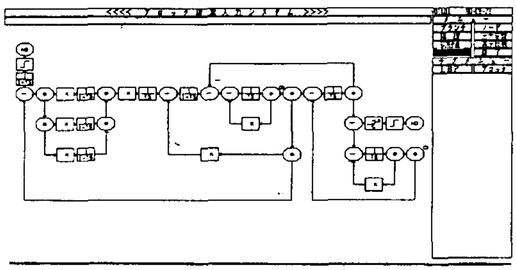


Fig.4 Example of model input using block diagram

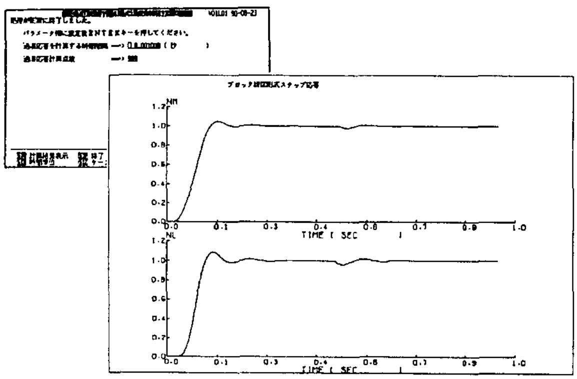
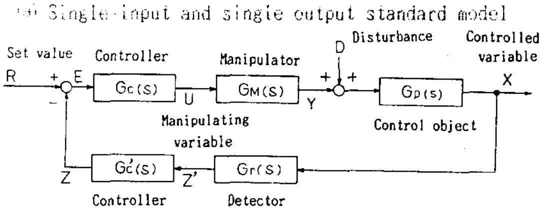


Fig.5 Transient response simulation using block diagram

(a) Single-input and single output standard model



(b) Two inputs and two outputs standard model

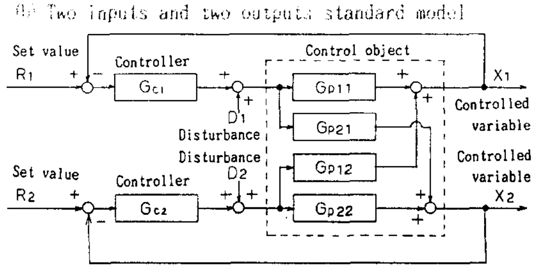


Fig.6 Example of standard model of control system

4.2 Design Package on Modern Control Theory SAPL-200UX

On this package, the control system is represented by multivariable state equations, and optimal control can be achieved by the simultaneous use of the variables or signals available. In this package the user can set up continuous or discrete time state equation, convert model types, check characteristics of the models, design optimal regulators and observers, perform pole assignment and also confirm the controllability of the object by means of simulating the object and optimal control transient response. Design work can be performed with menus in accordance with these procedure flows. Fig.7 shows an example of diagram which displaies pole location by pole assignment for a discrete time system. The display allows the user to recognize easily the poles of the object (O), the poles designated by the user(Δ), and the regulator's ploes according to the calculation(X). Fig.8 shows the result of a transient response simulation of the system after pole assignment.

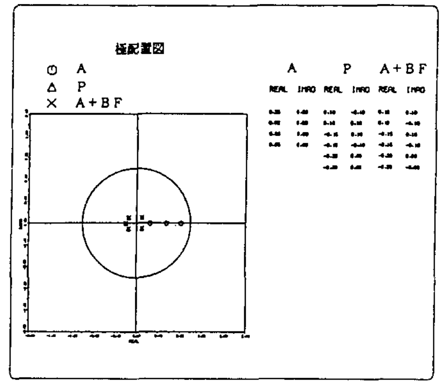


Fig.7 Pole location diagram

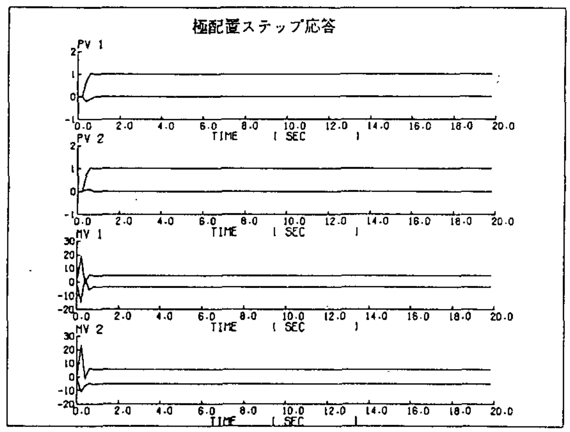


Fig.8 Result of transient response simulation in system after pole assignment

4.3 Desing Package on Data Analysis SAPL-300UX

On this package, data analysis, modeling and designing of control systems are performed, using time-series data. After manipulation, display, filtering or other pretreatment of time series data, modeling is performed by means of statistical analysis, time-series analysis and prediction model. As a dynamic model used for control of single input and single output system, approximated transfer functions are identified based on the control area from step response or impulse response data. For a multi input and multi output system, auto regressive model is identified by Akaike's method. For approximated transfer functions, optimal PID parameters are obtained by auto tuning. For auto-regressive model, feedback gains are obtained by the optimal regulator theory. Transient respons simulation is performed to evaluate obtained control parameters. In cases of optimal regulators, feedback gains are determined by adjusting the weights to obtain desirable control respons. Fig.9 shows these flows.

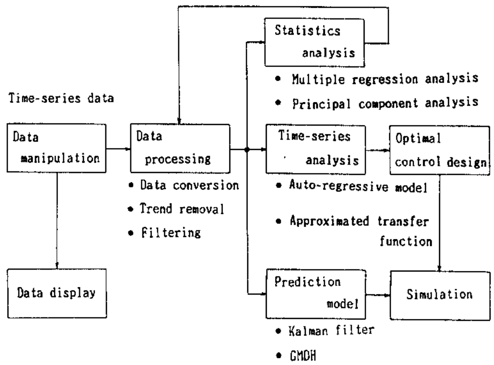


Fig.9 Flow of data analysis and control system design

4.4 Gain Scheduling of two direction adaptive control system GISTLAX-UX

This tool classifies process characteristic changes into (1) quick changes due to non linear characteristics of the process, and (2) slow changes by the lapse of time, and adapts control parameters to both directions. The system has PID parameters as gain scheduling curves, corresponding to indexes (e.g. magnitude of load, opening of a valve) called adaptive indexes for nonlinear characteristics.

In order to prepare a gain scheduling curve, a process model is identified from control response data, corresponding specific adaptive indexes, and optimal PID parameters are calculated. From PID parameters corresponding to several adaptive indexes, a gain scheduling curve as an approximate curve is decided using the least square method. For changes by the lapse of time, the gain scheduling curve is revised by replacing old PID parameters with new parameters.

Fig.10 shows the composition of the GISTLAX-UX.

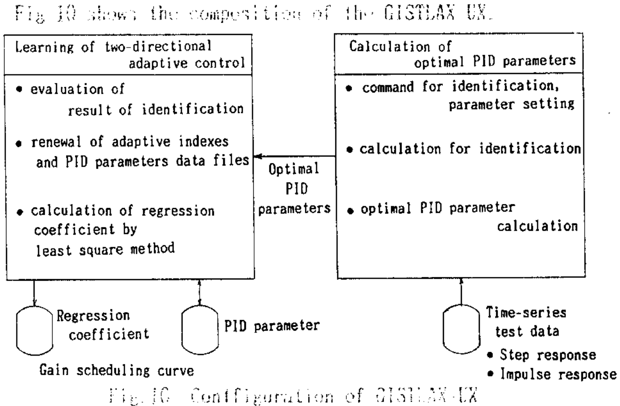


Fig.10 Configuration of GISTLAX-UX

4.5 Fuzzy rule information processing tool for advanced control system FRUITAX-UX

Fuzzy control is a control method that realizes flexible and highly adaptive operation on computer using a lot of fuzzy information. Effort are made to apply fuzzy control to such fields where operations are difficult to automate and so they are carried out by operators' intuition and experience.

This tool, packaging the building support section of the fuzzy control system FRUITAX which is widely used, permits the users to design, confirm and evaluate fuzzy control systems easily (Fig.11). The FRUITAX-UX, displaying the process of fuzzy inference, makes it possible to check how control rules work and how inference is made. Fig.12 shows an example of inference state display.

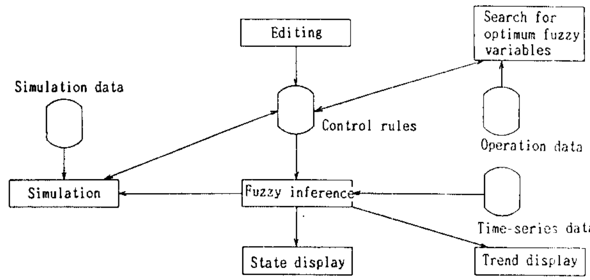


Fig.11 Configuration of FRUITAX-UX

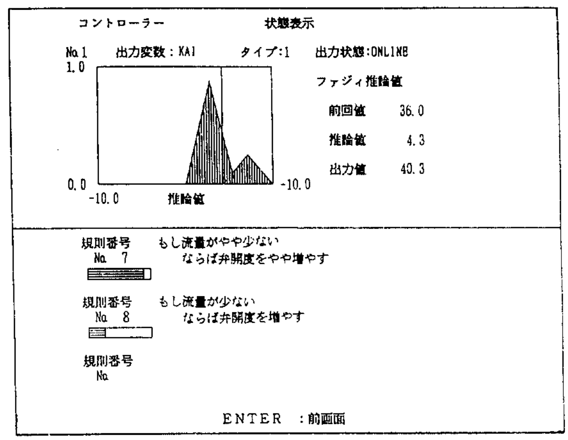


Fig.12 Example of inference state display

4.6 AI tool for process control EIXAX-UX

This package is composed of the support section of the EIXAX which is an expert system building tool. The EIXAX has been developed for automatic process operation by use of AI, paying attention to that the operater conduct process operation on the bases of rules and numerical formulas. The rules and formulas are stored as knowledge base, and the automatic operation is carried out by use of inference engine. Fig.13 shows the knowledge representation on the EIXAX-UX. As shown in Fig.14, the EIXAX-UX supports knowledge engineering work, through editing, checking and testing the knowledge base as well as AI control simulation.

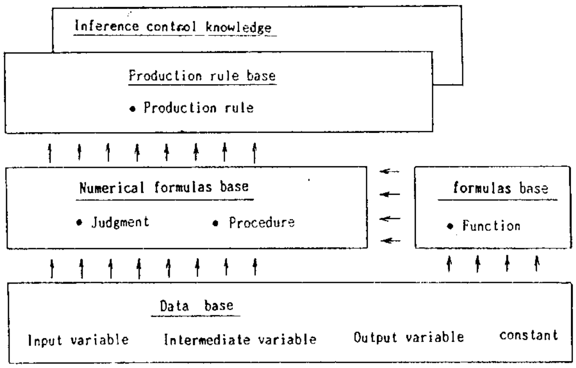


Fig.13 Knowledge representation on EIXAX

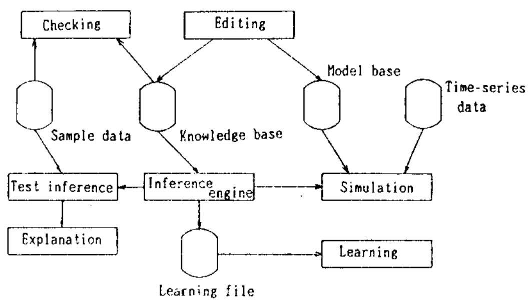


Fig.14 Configuration of EIXAX-UX

4.7 Structuring tool for material flow control system ΦNET-UX

This package supports the building of material flow control systems in the field of factory automation(FA). Equipment conditions in a material flow system is modeled in a network form while operating conditions are represented by rules which is suitable for dynamic knowledge representation. Combining two types of knowledge that are different in nature, knowledge base can be represented in easier expression. Fig.15 shows the composition of the ΦNET-UX.

Network type knowledge is prepared by the definition of place and state transition, and setting their connections in a table form. Equipment specification and control/operation plan are simulated and case study is repeated to determine an optimal system. Since the knowledge base for the simulation and that for the on-line control are identical in construction, the former as it is can be used as the knowledge base for the latter.

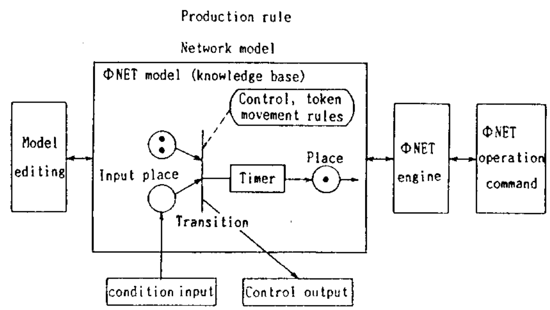


Fig15. Configuration of ΦNET-UX

4.8 Compact knowledge based expert system COMEX

The COMEX has been used on personal computers and minicomputers as an expert system building tool in the field of selective (diagnostic) type problem. Selective type problem is to select correctly and quickly from many hypothesis a solution that is most suitable to given conditions. It is a typical selective type ploblem to locate the most probably cause from stored possible causes of a trouble, or to select a part that is most suitable to design conditions.

The COMEX consists of a knowldge editor, an inference engine, a control utility program, and a interface library. The knowledge expression is based on "criteria logic", which permits to express easily the knowledge used for selective type problem.

5. APPLICATION TO PROCESS CONTROL

Table 3 and Table 4 show major fields of applications and major systems to which the AWS is applied respectively. The most characteristic and effective application to the field of process control is composed by network connection. Through the network, on-line data is taken from an operating plant control system. Analysis, modeling, and control design, knowledge base composition and simulation are conducted on the AWS. then obtained information for control is transfered to a controller or a control computer. In the field of process control it is normally impossible to induce practical numerical models only by physical rules. It is effective to analyze process data and to model based on the result of the analysis. In case of building an expert system or a fuzzy control system, it is difficult to incorporate skilled operators'knowledge and experience into knowledge base immediately. Therefore, it is a normal procedure to prepare a prototype at first, then to add and modify control rules. In both cases, the AWS can be used efficiently The AWS, connected with the process on line, permits to take process data. design control system. prepare control rules, perform confirmation and evaluation of them through simulation, and immediately revise control parameters and control rules of the actual control system. The AWS, when connected constantly with a control system not only under adjustment but also after that, makes the system flexible to changes in the process. The AWS can be used as an effective tool today when high efficiency, high quality and flexibility in production equipments are demanded. Fig.16 shows an example of the system configuration. In this system the AWS applied to a chemical process control. This system is operated as follows. Process data are transmitted to the AWS through the A50 control computer. On the AWS, the received data are analyzed and modeling is performed. Combining the model and fuzzy control, control rules are prepared. Then they are confirmed by simulation. The control rules thus evaluated are sent to the A50, and real time fuzzy control is started. Simultaneously with the real time fuzzy control, the control rules are stored and modeling and engineering work is continued on the AWS for the version up of the control rules so as to complete the fuzzy control system. The fuzzy control system permits to stabilize the production and to save the labor on a process which was difficult to automate.

Field	Purposes	Packages
Process control	Control system design/building, adjustment, data analysis	SAPL-UX GISTLAX-UX FRUITAX-UX EIXAX-UX COMEX
Mechatronics, Machine control	Control system design/analysis, stability analysis, vibration analysis, design of the control object	SAPL-UX
FA system	Material flow control system design Material flow planning	ΦNET-UX COMEX
Education	Education/training for control theories and techniques	All packages

Table 3 AWS application fields and purposes

Objective systems	Applied methods
Cement kiln optimal control	Auto-regression, fuzzy control
Automatic energy control and operation of iron works	Statistical analysis, expert control
Chemical injection control for water treatment plant	Statistical analysis, fuzzy control
Iron works gas mixing control	Noninteracting control
Converter exhaust gas recovery control	Adaptive control, optimal control
Robot drive control	Adaptive control, simulation
Cultivation process control	Fuzzy control
Waterworks demand prediction	Kalman filter
Aluminum coil transfer crane control	Petri net, expert control

Table 4 Example of application systems

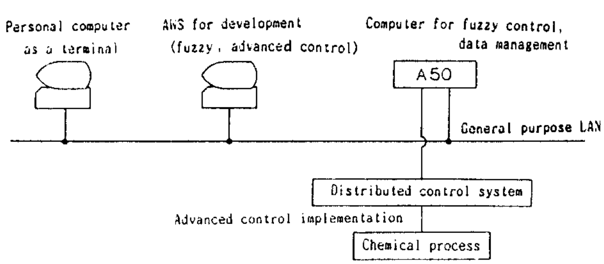


Fig16. Example of system configuration for chemical process

6. CONCLUSION

We have made it possible to utilize expert system building tools and advanced control design supporting systems on a workstation. These tools and supporting systems which were used only by specialists, can now be easily used by ordinary engineers. We expect that the AWS will expand the application of AI and advanced control to more fields. The AWS permits users to see the results of application even though they are not familiar with control theory research and computing methods. The users are required only to understand "what can be done" and "how to use it". This would be meaningful from the viewpoint of education and for the industries that are now suffering from shortage of software and control engineers. It is important that the utilization of these tools should shift from the computers for research and development to terminals directly connected with actual plants. The effect of the AWS will be remarkable in the field of process control where engineering work based on actual measurements is essential.

The authors would like to list our future tasks including expectations:

(1) Design methods for AI and fuzzy control must be established. Knowledge acquisition, which is bottlenecking the development of AI/fuzzy control systems, should further be studied. Theories about the stability of these control systems should be developed.

(2) AI inference time must be shorter. As a method for high speed AI inference, compiler type AI tools which develop knowledge base into source programs will be effective.

(3) Control system design itself must be systematized as expert systems. In case of control-theory-based system design, judgment and evaluation of outcome are difficult even though design methods established. If the trial of building control theory type design systems on expert systems succeed, the application of advanced control will further expand.

(4) Robust control, particularly design methods based on the H^{∞} optimal control theory should be incorporated in an easy to understand form.

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