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AI SYSTEM FOR INSTRUMENTATION AND CONTROL

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1 FOREWORD

Digitalization of the measurement and control field is advancing and distributed digital instrumentation systems and the superminicomputer are being introduced. The shift to FA, PA, and other sophisticated automation systems and the tackling of advanced control are also progressing.

Recent advances in artificial intelligence advocated by the artificial intelligence (AI) research process are advancing the development of AI systems that use knowledge engineering.

The development and practicalization of AI systems has become indispensable in improving automation technology and advanced control technology in the measurement and control field.

The present trend of AI system development in the measurement and control field and examples of its application in the process control field are introduced.

2 TREND OF AUTOMATION TECHNOLOGY FOR MEASUREMENT AND CONTROL

The introduction of the distributed instrumentation control system to process control is advancing and advanced control which cannot be implemented with conventional measurement and control systems is being practicalized.

In the advance toward advanced control, the development of AI systems based on knowledge engineering is thriving through the growth of knowledge engineering, accumulation of intellectual resources, advance of computer systems, and other technical assistance and the human respect, economical and social structure changes, and other social demands, and the increase in practical systems and AI systems are being introduced into many fields.

Even in the measurement and control field, the importance of AI system practicalization to improve engineering efficiency and operation reliability, promote automation and unmanned operation, improve software development and maintenance efficiency, and lighten the intellectual work load is increasing.

Development of measurement and control field problem oriented AI tools and development of an AI system to accumulate and expand an application record were promoted to cope with such AI system introduction and development trends.

Table 1 outlines the AI tools developed up to here and summarizes their features, etc. The AI tools are described in detail in paragraph 3. The main points of each AI tool are given below.

FRUITAX (Fuzzy Rule Information Processing Tool for Advanced Control System) is a general-purpose fuzzy control system based on fuzzy reasoning and is not seen anywhere else. It is suitable for automatic operation. Dedicated boards are developed to speed up fuzzy operation and reduce the size so that it can be used easily.

EIXAX (Effective Industrial Application Aimed Expert Shell for Advance Control System) is a realtime process control AI system. Automatic operation and control of steel, chemical, water treatment, and other plants can be optimized.

ΦNET (Factory Automation Intelligent Network Control System) is an expandable and flexible AI system for material flow management in FA. It is suitable for implementing a multi-type small lot production line sophisticated FMS and total FA system.

COMEX (Compact Knowledge Based Expert System) is an AI system not limited to the measurement and control field, but suitable for various diagnoses and counseling. It has a knowledge base, which is a special feature in know-how arrangement and systemization. There are many examples of its introduction in facility diagnosis, trouble diagnosis, and other consultant type diagnosis applications.

3 AI SYSTEM FOR AUTOMATION OF MEASUREMENT AND CONTROL AND APPLICATION EXAMPLES

3.1 FRUITAX

In process control, there are many fields where a mathematical model cannot be made of and fields where computer control cannot be used, even with recent control systems, such as modern control and optimal control,

Table 1 Fuji AI tools and their comparison

AI tool name	Outline	Features	Expression of knowledge	Inference method	Periodic control action	Application example
FRUITAX (Fuzzy control)	Fuzzy reasoning applied expert system implementation tool	Rule implementation by probability statistics (rule definition of intuition and experience) Supports the inspection function by simulation. Grade of certainty of fuzziness	Fuzzy membership function type Control rules type	Small scale Fuzzy inference	Yes Period: Several tens of seconds	Chemicals addition control, water quality control Cement
EIXAX (Mathematic model and rule base)	Process automatic operation expert system building tool	Plant operation control oriented Real time expert system FORTRAN used	Production rule Simple frame Mathematical model	Small scale Forward inference	Period: Several tens of seconds	Optimum operation of energy center system Optimum industrial power plant operation
ΦNET (Material flow)	AI tool for material flow automation	Material flow control automation Material flow plan check by simulation Simulation and control parallel use	Production rule Network model (petri-net)	Simple Rule processing linked to node and branch representation	Period: Second	Assembly line control Slab carrying line control
COMEX (General-purpose diagnosis)	Diagnosis type expert system implementation tool	Compact system configuration Practicalization is easy (Installation in personal computer possible)	Criteria frame	Simple Forward inference Backward inference	According to operating environment	Turbine diagnosis Transfer diagnosis Train operation control support system

by reason that the mathematic model is too complex. However, even in these fields, process control cannot depend only on a skilled operator for the following reasons:

(1) Decrease of skilled operators
(2) Social demands for higher reliability and labor saving by automation

FRUITAX introduced this time is an AI system for control automation that displays its effect especially in control fields where the use of conventional control methods is difficult. It was developed and commercialized by Fuji Electric as a general-purpose fuzzy control system for process control based on cooperative research with the Tokyo Industrial College.

FRUITAX consists of a fuzzy controller, which performs plant control, and a support system, which can be used in preparation and verification of the control rules, etc. used by the fuzzy controller.

The features of FRUITAX are:

(1) A large effect and stable operation can be realized in fields where operation variations are large.
(2) The same operation as a skilled operator is possible by giving the so-called "intuition and experience" of a skilled operator as control rules.
(3) For state values which are difficult to measure with plant state measuring instruments (for example, judgement of plant state by flame, etc.), the operator's judgement can be input from the keyboard and used in control, together with the measured value.
(4) Control output can be obtained as the result of overall judgement of many conditions by reasoning based on fuzzy set theory.
(5) The control rules can be changed during plant operation and the effect of the change can be checked by display screen by on-line simulation function. Actual operation in accordance with the modified rules can be performed immediately, as required.
(6) Since application of the control rules and reasoning process are graphically displayed on a display screen, the reasoning state can be monitored and improvements of control precision can be easily handled by checking the control state during actual operations.
(7) Since the control rules and membership function are independent from the inference mechanism, it is easy to add and modify control rules and membership functions. Therefore, know-how related to control of the objective plant can be input as control rules and membership functions at the part where FRUITAX was introduced.
(8) As control rules can be defined by not only hearing from a skilled operator and specialist but also by statistical processing of the operation data, the operating state can be accurately reflected in fuzzy control.
(9) Since a support system on a general purpose computer is available, fuzzy control system design and verification can be performed by simulation before actual operation.
(10) There is a stand-alone type by microcomputer and embedded type in a process control computer system. The type matched to the scale and use of the objective application can be selected.

The FRUITAX functions and architecture are shown in *Fig. 1*. FRUITAX is the first system that put fuzzy control to practical case in prechlorine addition control and activated sludge control at a water purification plant and waste

Fig. 1 FRUITAX functions and architecture

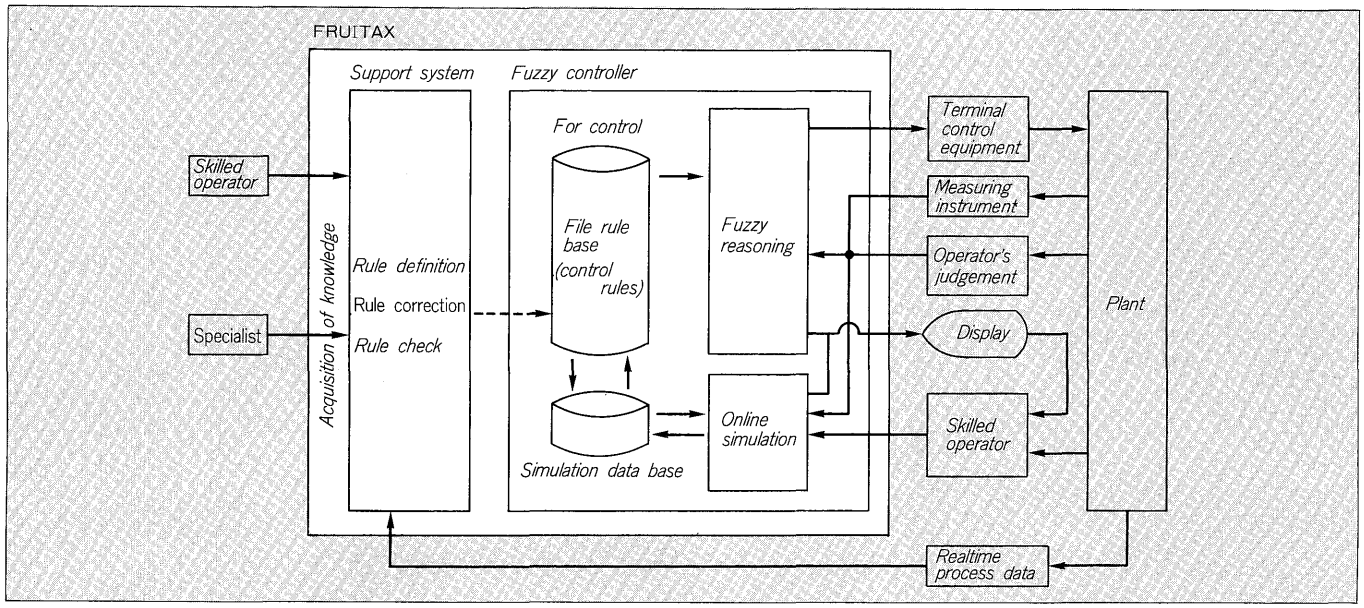
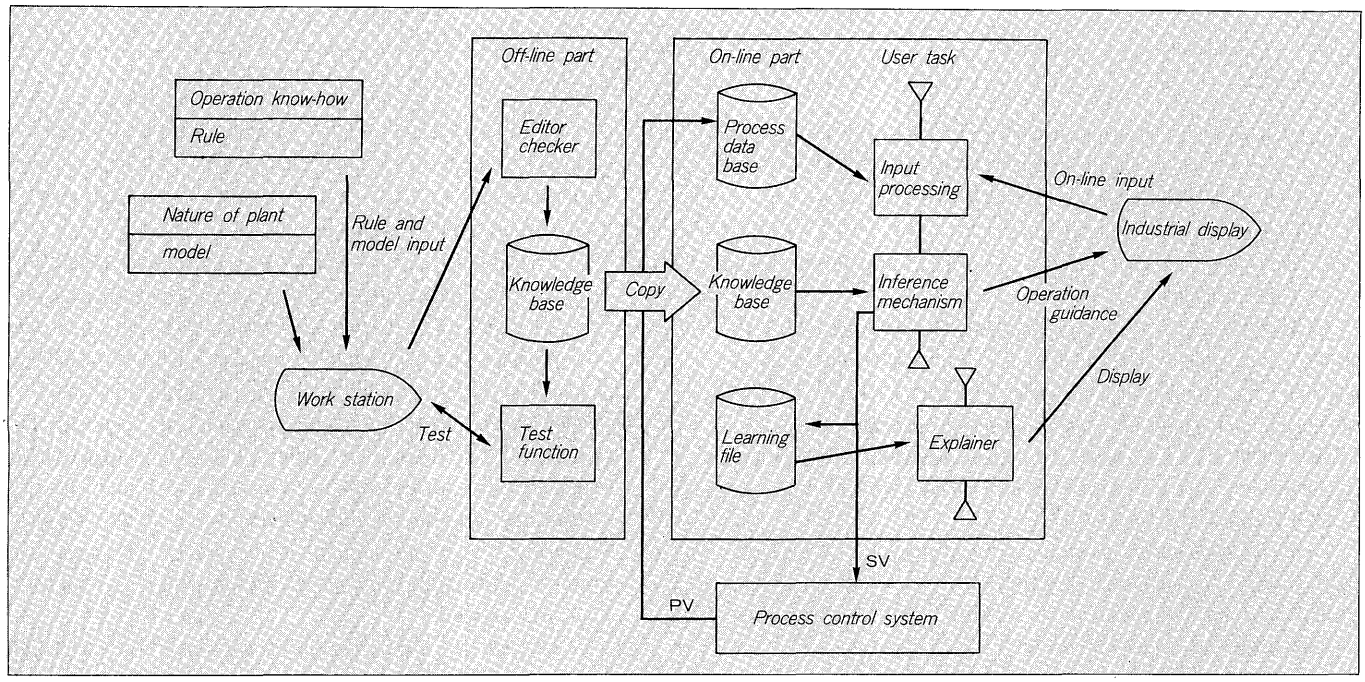


Fig. 2 EIXAX functions and architecture



water treatment plant. It begins to be used in kiln control and other fields where conventional automatic control is difficult. Presently, fuzzy operation boards which to perform fuzzy operations by hardware are also being developed. The field of applications of FRUITAX is intended to be extended to process fields having a short control period.

3.2 EIXAX

EIXAX is an expert system building tool for advanced control for effective application to the industrial world. It is sensor-based realtime expert system building software for plant operation control.

Here, advanced control realizes automatic operation control in fields in which conventional automation was difficult.

In the production process, the operator quickly executes plant operation with his own know-how based on data (sensor base) from the process and operation prediction and other data. When this know-how is analyzed, forward reasoning based on if-then rules and simple models (mathematical models) representing the nature of the plant is performed. EIXAX realizes this "process and procedure" on a computer and has a support function for its building.

As shown in *Fig. 2*, EIXAX is a tool having the following features as a plant operation control expert system building tool:

(1) Expert system building and execution are completely separate

The off-line part is in charge of the support function at building and the on-line part is in charge of execution. These exist as independent programs on the same computer and do not interfere with each other.

(2) Abundant support functions at expert system building

The off-line part has the following support functions:

- Knowledge base editor
- Knowledge base checker
- Knowledge base translator
- test function
- learner
- explainer
- simulator
- simulator function

Static and dynamic operation check and reliability acquisition are possible.

(3) Realtime nature at execution

At the on-line part, the inference mechanism performs inference by using a knowledge base that can be executed at high speed. One criteria is 100 rules/second.

(4) Sensor based system

Adjustability with the on-line part process data base management system is amply considered.

(5) Simultaneous execution of multiple expert systems

With the off-line part, multiple knowledge bases can be created. With the on-line part, time sharing inference of multiple data bases by one inference mechanism is possible. Therefore, multiple expert systems can be developed and executed with one EIXAX.

(6) Adjustability with existing software resources

EIXAX is written in FORTRAN or C, and can be introduced into a conventional process control computer as a simple program. Since subroutines can be called from rules, existing software resources can be amply used.

(7) Ease of building by Japanese language and mathematical model

Building of an expert system at the off-line part can be performed entirely by natural language and mathematical models. A special language is unnecessary.

(8) Many problem solving packages based on Fuji Electric know-how

Since many proven problem solving packages already developed by Fuji Electric are available, a system exceeding expert can be built up by using functions called from rules function.

The following packages are available:

- Linear programming method, nonlinear programming method, integer programming method, etc.
- Kalman filter, autoregression, and other prediction packages
- Problem solving packages by heuristic method
- Fuzzy function package

By using EIXAX,

(1) Practical PA and FA expert systems can be built up.

(2) The automatic operation field can be expanded by computers to fields that cannot be automated by conventional methods.

3.3 ΦNET

ΦNET is an expert system implementation tool at an FA field material flow system.

ΦNET is implemented by making a model of the material flow system by means of a network called "Petri-net" and adding production tools which expresses the operating method of the control operation restrictions, operation conflict resolution, etc. system to this model.

ΦNET implemented in this way has the following features which incorporate the advantages of both the petri-net and production system:

(1) Model construction with a good perspective
(2) Modeling function with a wide range of applications
(3) Flexible and expandable system construction
(4) Fast processing speed
(5) Efficient data management
(6) Control and simulation are the same model

By introducing ΦNET, FA system software productivity is improved and an ideal facility plan and flexible control system are implemented.

The FC transmitter production line production control simulator shown in *Fig. 3* is described as an example of application of ΦNET in a actual system.

The FC transmitter is a multi-models, small lot production product. The production process and processing method are different for each model. With the ΦNET simulator, a system that represents each production process by network model and the process by model and machining method and facility operating method by rules is created. When the order sheet data from a high level computer system is input to this ΦNET simulator, load forecast by process and process progress of each product are output.

The operator evaluates the results of this computation and when there is a problem, the working time, manpower, and production schedule are changed and simulation is repeated. The optimum production schedule is decided and used in actual operation by repreating this process.

Introduction of this system has the following effects:

(1) Shortening of product lead time
(2) Realization of an efficient facility working plan by load monitoring by process
(3) Reduction of late delivery by monitoring of be progress of each product

Besides this system, ΦNET is expected to the used in yard control system and unmanned carrier control system.

3.4 COMEX

With the advance of technology, use of the computer as a means of freeing man from simple labor is demanded. Artificial intelligence (AI) is one of computer application technologies. "Artificial intelligence" is implemented on a computer and is the science that uses the computer to explain the principle of human intelligence. An expert system is implemented on a computer by combining expertise and inference mechanism as the actual problem solving tool of this AI. COMEX was developed by Professor Haruki Ueno, head of the Physical Sciences Department

Fig. 3 Example of application of ΦNET to FC transmitter production line

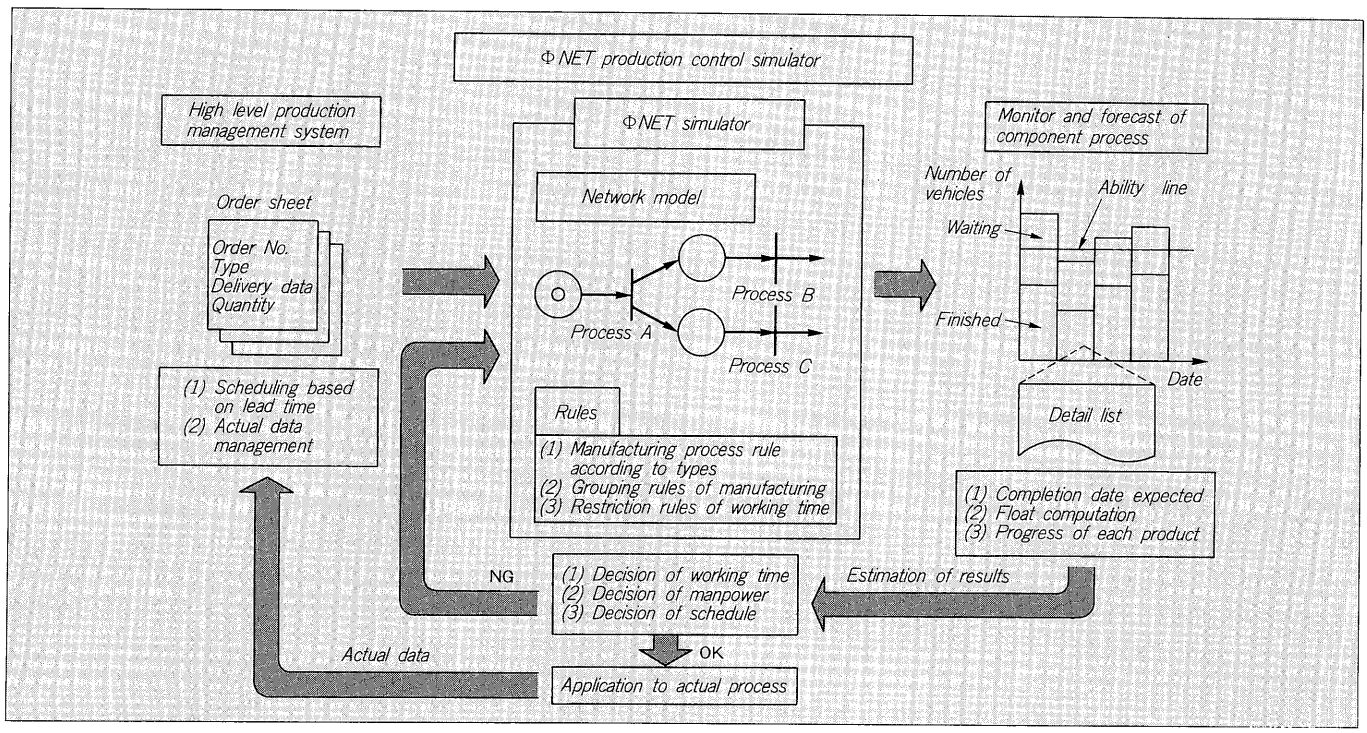
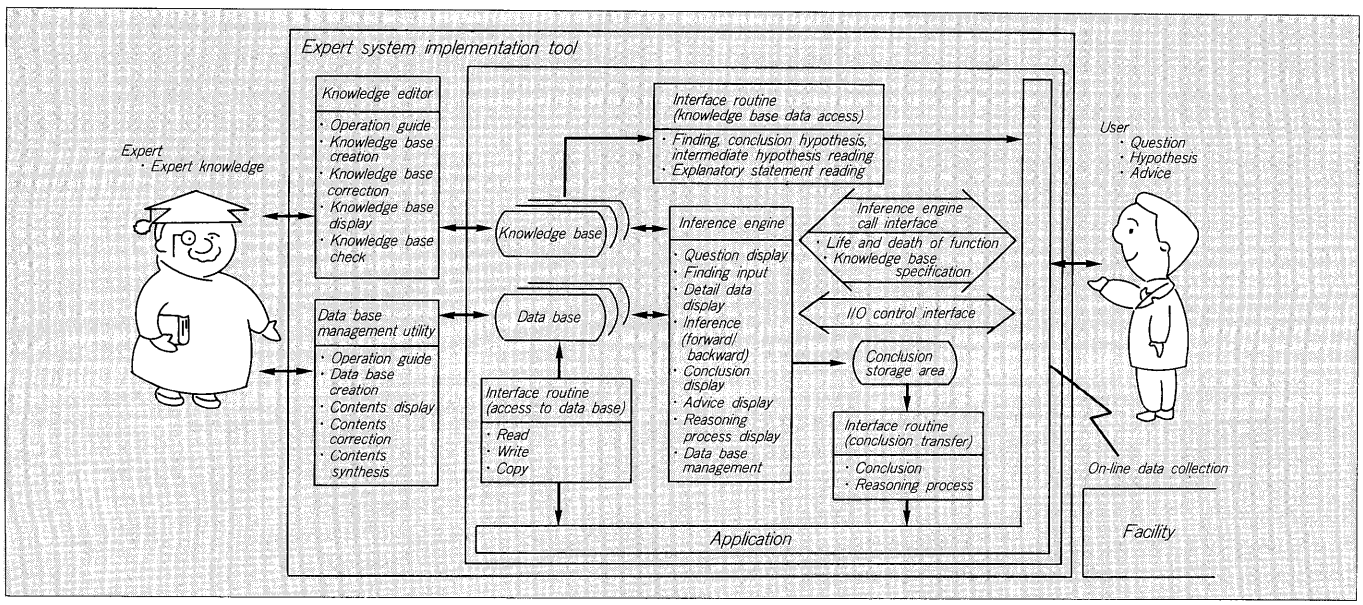


Fig. 4 COMEX functions and architecture



Management Engineering Section of Tokyo Denki University, Fuji Electric Sells this software and develops and sells its application systems. The knowledge expression format of COMEX is applicable to development of a select-type data base. ("Select-type data base" is a data base that defined problem solving way knowledge of a form that selects some conslusions by reasoning.) There are forward reasoning and backward reasoning inference ways. An inference engine can also be used as a subroutine. Its functions and construction are shown in *Fig. 4*. It has various fields of applications. Application examples are given in *Table 2*.

COMEX has the following features and is highly acclaimed:

(1) An expert himself can develop a knowledge base.
- The knowledge expression format is simple and easy to write and read. (Criteria knowledge expression logic used)
- The knowledge gathering and adjusting method is guided.
- A knowledge base can be implemented without a knowledge of AI terminology/programming language.

Fig. 5 Example of application to diagnosis system (L25 used)

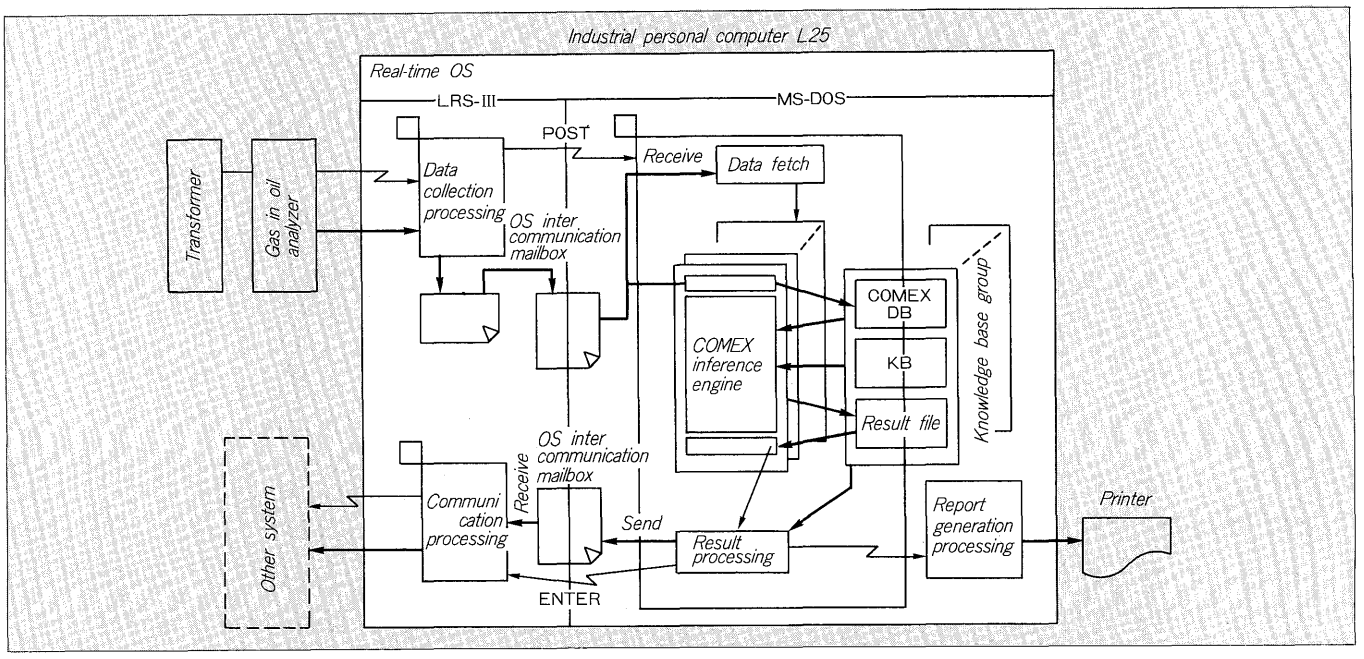


Table 2 Examples of COMEX application systems in company

No.	System name	Functions	Remarks
1	Oil transformer diagnosis	Deduces the trouble cause by decoding the gas-ratio in the oil transformer oil and specified the maintenance work.	L25 automatic input
2	Abnormal vibration diagnosis system	Deduces the trouble cause and trouble point from the vibration characteristic when a hi-pressure turbine rotates.	PC9801-VM2 off-line input
3	Controller selection inquiry system	Selects the best controller from the controller installation environment and application. When judgement is impossible, specifies the investigation items.	L25 manual input
4	PC module selection system	Decides the combination of function modules needed from the functions demanded by the PC programmable controller.	FM16β manual input
5	S series design know-how retrieval system	Retrieves the items which require attention when designing a processing system on the S series.	FM16β
6	File sorting retrieval system	Judges where the data distributed to the section and the data sent to the outside from the section should be registered and retrieves the location of the desired data.	FM16β

(2) Usable and effective expert system on the scene can be implemented.
- On-line/sensor base system can be implemented.
- Called from already used software written by FORTRAN.
- Can also handle large scale problems.

(3) Used anywhere
- Widely installed and operated from personal computer to general-purpose computer.
- Developed knowledge base can be used with computers having another architecture.

When recent examples of introduction of COMEX are considered, the number of examples of use in implementation of equipment diagnosis and work order guidance systems is increasing rapidly. An example of typical system architecture commercialized by Fuji Electric is shown in *Fig. 5*.

4 CONCLUSION

In the advance of distribution and automation in the measurement and control field, the current state, in which process control is being made more sophisticated by advanced control incorporating an AI system, was introduced for the AI system developed by Fuji Electric and examples of its application.

The growth of AI technology is expected to be accompanied by expansion of the field of applications and promotion of AI system level improvements in the future.