

# TECHNICAL DEVELOPMENT OF PROGRAMMABLE CONTROLLER

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## 1 INTRODUCTION

It has been about 15 years since the programmable controller (PC) was born as a product. During these 15 years, micro electronics (ME) has rapidly advanced, the technological revolutions of the PC itself has achieved, and thus, the PC has occupied the significant position as a controller. The market scale of the PC was about 70 billion yens in Japan at fiscal year 1984, and it is said that the worldwide scale is about 5 times as great as that in Japan. Also in the respect of price, the PC has taken place of relay control panels completely, and with the highly functioned models, not only the sequence control but also PID control such as DDC (Direct Digital Control) and data processing can be made.

As for the systems, it is now popular to use the PC in a comprehensive control system by connecting a PC with the other or computer through data way, multiple number of PCs are interconnected within a specific network, and it is actively combined with a personal computer to form a data processing/control complex. The use of the PC in a comprehensive automation system will definitely increase as the factory automation (FA) and process automation (PA) will be further promoted in the future. Now is the time to have another look at the PC, as a system or top down as it had been developed as a unit or bottom up. On the other hand, the remarkable development of the ME, especially the practical development of custom LSI has made it possible to further enhance the performance of PC hardware and to reduce its dimensions.

In this back ground, the PC developing process is reviewed, the future trend is examined, and this paper introduces the significant points of MICREX-F Series developed toward the generation of new automation systems.

## 2 DEVELOPEMENT OF PC TECHNOLOGIES

It is easier to understand the trend of PC development by segregating it by each five years. *Table 1* illustrates summaries of the PC and ME developments and applications

of the PC by systems. The period between 1970 and 1975 can be called a period of cradle for the PC. The PC uses the operating principle of stored program type originated by Von Noyman in 1945 just like a computer. However, the arithmetic processing unit is specialized for sequence control as its main function is bit processing, and in comparison with a computer used at that time, sequence control can be executed more simply and faster. Further, the target of the PC is that the programming can be made at any sites, it should be noted that a portable programming tool (PGT) is developed simultaneously with the PC proper. With this concept, functions of a PC proper is control only. Therefore, the price can be cut down, and as the PGT can be used commonly by multiple number of PCs, the total price could be reduced.

For programmings, the PC features that the objective program can be prepared simply by operating instruction and figure code keys of the associated PGT, the program is automatically converted to machine codes of the PC and stored into the program memory, the machine codes are automatically and reversely converted to the original codes by reading the program memory with the PGT, and the codes can be displayed or printed out. These features allow the PC to be used very conveniently. It seems simple, but at that time, features like this could not be even possible with computers.

Further, for the PC, environmental characteristics and noise resisting performance are strengthened so that the PC can be installed in site and objective machines and equipment to be controlled can be controlled directly.

As described above, it was recognized that the PC was programmable, used simply by anyone and installed in any site, and thus, number of used PCs increased and the position as a controller was established.

From the end of 1965 to about 1980, the PC became to be used more actively, and as the scale merit was recognized, such a large scale PC as 500 points or more output points was produced.

Further, at that time, general purpose ICs were used mainly. However, as the ME was rapidly advanced, high performance 8-bit microprocessors and A/D, D/A converting elements appeared, and this caused PCs capable of numerical calculations and analogure input/output to be de-

Table 1 Development and application of PC

Year	1970	1975	1980	1985
Development of programmable controller (PC)	Practical use of PC			
	Being centered around medium scale PCs having fundamental functions (IO: 256 points), PC manufacturing was proceeded.	Increasing scale and expanding functions IO: 512 points or more, Popularization of PC was accelerated as analogue input/output and four fundamental rule arithmetic calculations were added. At a part, coupling with computers and data way began.	Enhancing functions and reducing price Enhancement of speed and function and reductions of dimensions and price, and communications between PCs and with peripheral machines and equipment were promoted. Enhancement of functions of programming tool and graphical display of program were realized.	Fulfilling series and systemization As a controller of total system, models were systemized to series, and network coupling, improvement of software supporting technologies and reduction of size were promoted.
Development of micro electronics (ME)	General purpose IC			
	<div> <div>8-bit microprocessor</div> <div> <div>8080</div> <div>Z 80 8085</div> </div> <div>16-bit microprocessor</div> <div> <div>8086/8088</div> <div>Z 8000</div> </div> <div>32-bit microprocessor</div> </div> <div> <div>Bit slice processor</div> <div>8048</div> <div>8051/8031</div> </div> <div> <div>8-bit single chip computer</div> </div> <div> <div>68000</div> <div>Custom electronics</div> <div>Gatealley, hybrid IC</div> </div>			
Application of programmable controller (PC)	Selective employment			
	Selectively employed by large plants Gradually became popular and used independently.	Popularization of large scale models Employment of large size PCs by steel mills, chemical plants and other process industries such as water treatment plants increased. Use of PC as a decentralized controller including minicomputer, microcomputer, etc. began.	Popularization of small scale models Use of PCs by assembly and conversion industries increased. Including substitution of relay control panel, small size PCs increased rapidly. Coupling with positioning, NC, personal computer, etc. increased.	Popularization of systemized models Applications as a system product, including network, unified software and man-machine interface were proceeded for automation systems of FA, FMS, PA, equipment management, etc.

veloped, further expanding the applications.

On the other hand, using the microprogram type high speed bit slice type microprocessor (which was developed mainly for CPU of a minicomputer), enhancement of the function and high speed processing of PC could be realized with a simple circuit composition. More practically, the program execution management suited to the PC could be made as well as calculation processings such as step sequence control, comparing calculations, arithmetic calculations, PID control and data operation, and in addition to the normal cyclic control (which is the fundamental program control system of the PC), periodical cyclic control required for DDC, interruption control used conveniently for high speed response and batch control, hierarchy of the program and module structure were realized.

In parallel to the improvements of the functions of the PC proper described above, introducing the 8-bit microprocessor, programming tools responded to the enhanced functions of the PC proper, and the service functions such as program change, deletion, insertion and retrieval and preparation of program parameter collation list were far

improved.

Furthermore, using various general purpose LSIs developed for peripheral circuits of microprocessors, systematic interface functions such as general purpose interfaces (used for connections with printers and computers) developed by using remote IO, current loop and RS-232-C, and interfaces with data way were fulfilled.

In this period of time, employment of medium to large scale PCs was proceeded mainly in the steel mills, chemical plants, water treatment plant and automobile industries, and number of PCs used in decentralized control systems through data way increased.

From about 1975 to 1980, developments of single chip computers, high performance 16-bit microprocessors, highly integrated memories and peripheral LSIs and reductions of their prices gave a large impact to the PCs. Small scale PCs the number of input and output points of which is 64 or less were realized in a low price by using the single chip computers and highly integrated memories. The small scale PCs effectively used functions of the single chip computer, and in addition to the PC proper, functions of pro-

gramming could also be processed. Thus, the programming tools were simplified, and many of them could be made in small dimensions so that they can be attached and detached to the PC proper. At this stage, it became possible to replace relay control panels with PCs completely, and number of used PCs increased rapidly.

For the medium to large scale PCs, it became possible to realize a wide function by combining a processor for PC and 16-bit microprocessor as a multiprocessor. As for the peripheral functions, interface with a remote IO and personal computer became popular, systematic interface functions such as PC-to-PC connection and connection with computers through communication network were strengthened. Further, special functions such as positioning control and temperature control were prepared as a peripheral equipment which could be interfaced with a PC.

Using 16-bit microprocessor, CRT display and LCD (Liquid Crystal Display), readily used PGTs were realized. Although the display capacity of LCD is less than that of a CRT, the LCD greatly contributed in reducing size and weight of the PGT and in improving the portability. On the display, ladder graph, block diagram, title, page number, remarks, control menu, operation guide, etc. were displayed, improving the listing, interpreting and operating performances.

For peripheral equipment of the PGT, low price printers and floppy discs which were popular as a peripheral equipment of personal computers became available, and storage and maintenance of program and documentations were simplified.

Hence, development and demand of PC stimulated mutually, and the PCs were developed mainly in the form of a bottom up. In 1985, the PCs are viewed in bird's-eye in the form of a top down based on the viewpoint of building a new automation system for FA and FMS to be developed in a large scale in the future. Thus, in the future, PC should be used in the form of a system, and consistent model hierarchy, network, man-machine interface, software system, etc. will be required.

### **[3] PRODUCT SERIES AND TECHNICAL DEVELOPMENT**

*Table 2* shows main points of product series and technical development of PC at Fuji Electric.

F-MATIC series covers fundamental PCs which use mainly general purpose ICs. Number of IO points is 128 to 768, and memory capacity is 1 to 4k words. The main points of the technical development are shown in (1) and (2) of the *Table 2*. At (1), basic technical development of PC such as program language, duplex, self-diagnostics, and processing systems for the program language, duplex and self-diagnostics were made. At (2), it was made possible to insert peripheral modules on the bus for expansion of functions by using common bus system. Numerical calculation and single loop control of simple PID, etc. can be made by adding calculation module using an 8-bit microprocessor, and coupling with a data way and PC-to-PC

mutual coupling can be made by adding a transmission module.

MICREX-E Series is a high function PC which uses bit slice type high speed microprocessor in the main processing unit (MPU) and multimaster type common bus as the standard bus.

Since printed circuit boards of various functions can be applied to the common bus, desired functions can be composed by properly combining the various functions, and thus, decentralized control systems coupled with remote IO and data way, multicontroller system which couples PC with another with parallel bus, positioning control using high speed counter, programmable monitoring system (PMS), etc. were realized.

Program language (EPOL) was made by greatly expanding ranges of F-MATIC series, and this language covers a wide range including logical sequence, setp sequence, PID control, data processing, formation of hierarchical program and program module, designation of program control mode, etc.

The programming tool uses a 16-bit microprocessor and CRT display. Programming can be made based on ladder diagram and block diagram, and thus, the programming tool can be used easily.

FUJILOG series covers small to medium scale PCs developed by limiting functions and aiming at reduction of the price. A number of different models are available so that the PCs can be applied to various purposes. For the medium scale PCs, the programming tools are independent and separated from the PC proper, while for the small scale PCs, the programming tools can be attached to and detached from the PCs. The main points of technical development for these series are indicated in (3) of the *Table 2*.

MICREX-F series was developed by fully utilizing the most advanced ME technologies based on the above described technical developments so that the PCs can be applied to the new automation systems of future FA and FMS. The main points of the technology are indicated in (4) of the *Table 2*.

### **[4] NEW PC MICREX-F SERIES**

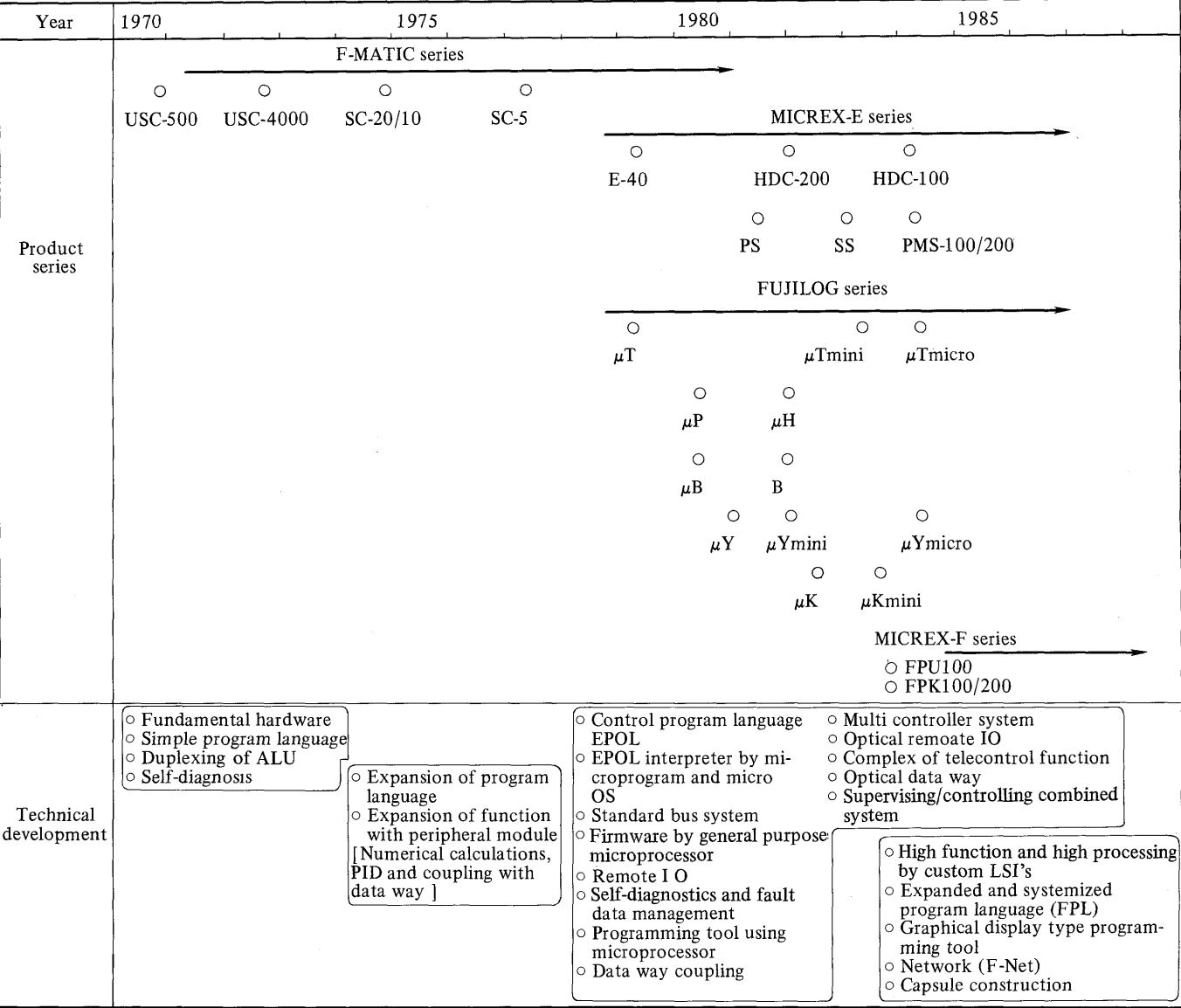
MICREX-F series features the variegated components, the network which connects one component to another, allowing flexible composition of a control system, and programming tools and powerful program languages suited to wide range application fields.

The component is accommodated in a compact and rigid molded case, serial interface with a network and its own control power supply are built in, and it is so constructed that it can be installed independently.

Because of the independency of the function and image of the shape, this component is called a capsule. The capsules are briefly classified into a processor capsule (P capsule), terminal capsule (T capsule) and function capsule (F capsule).

As a PC, the processor capsule performs calculation processing, and capsules are available in series in response to

Table 2 Product series and technical development



each functional level. As it is introduced in other paper of this special issue, there are MICREX-F100 series and MICREX-F200 series, and in the future, the series will be further increased.

For the terminal capsules, there are digital input/output (DI, DO), analogue input/output (AI, AO), counter input, pulse output, etc., and number of DI or DO is 16 per capsule.

The function capsule performs special processings such as positioning control and interface with a personal computer.

For all of these capsules, the connections are made entirely with a serial interface, and therefore, the wiring can be made simply and changes and additional installations can be made easily. Further, for the structure, independent installation can be made. It is not necessary to accommodate capsules into the control panel, and installation space can be reduced.

Decentralized installation of capsule is the fundamental idea in the MICREX-F series, however, by combining a

processor and terminal or two or more terminals into a single unit, smaller size system is also available so that the capsules can be logically applied to the system to be controlled in which input/output interfaces are centralized.

The network connects one capsule to another with a serial transmission system, and the transmission control uses a custom LSI and hybrid IC to increase speed, enhance the functions and to reduce the dimensions. As long as the control hierarchy is concerned, this network belongs to the level below the LAN (Local Area Network) and Fuji electric's micro data way (DPCS-F), and this should be called a field network. Taking the initial F of field and F of the MICREX-F series, this is called F-Net.

The F-Net is constructed in two levels, T link which transfers data between P capsule and T capsule, and P link which transfers data between P capsule to another so that a network can be logically constructed.

The transmission path uses a bus system so that the coupling with a capsule can be made electrically in a high density, trouble of a capsule does not adversely affect the

transmission system and capsule attachment and detachment can be made on-line. The purposes are not only to transmit data toward a long distance but to simplify the connection between capsules, and therefore, the working ease and reduction of expenses are taken into considerations and electrical transmissions are used mainly. The transmission rate of P link is 5M bit/sec., and P link uses coaxial cable. The transmission rate of T link is 500k bit/sec., and T link uses paired stranded cables. Optical transmission can also be made easily by attaching an adapter as required, and a network can be composed by using both light and electricity logically.

Optical data transmission is essentially for transmission in a ring state, and is not familiar with bus composition. However, the bus system is realized by using bidirectional optical transmission, and it is so designed that transmission path can also be composed in a loop state so that the transmission will not fall down with a trouble in one place.

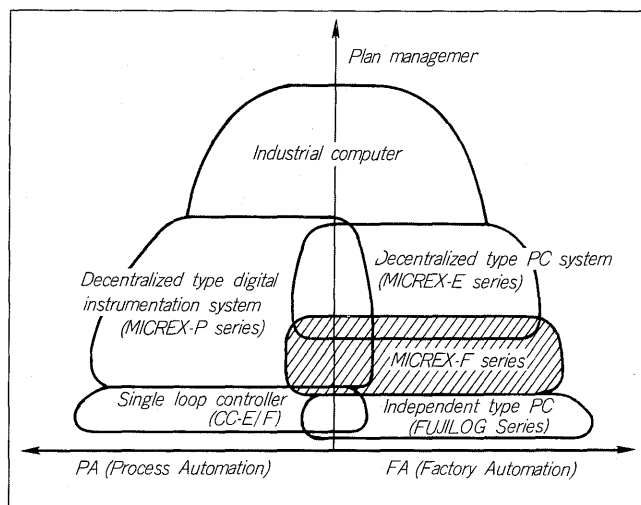
Since the purpose of the F-Net is to transmit control data in the real time, control data must be transmitted correctly under a high speed and within a predetermined time. However, providing a series of transmission sequence with open slots, unperiodically occurred data such as data for programming and messages required in an FA and FMS can also be transmitted.

Developing EPOL, the program languages are made in a powerful language system with which logical sequence, step sequence, PID control, comparing calculation, arithmetic calculation, functional calculation, data control, etc. can be described. Further, it is so designed that each capsule can use the subsets of the program language in response to the functional level, providing a consistency as the MICREX-F Series. Because this program language is a language of MICROEX-F series, it is called FPL.

The FPL is basically to express a program in a graph or diagram. Setting up the command codes suited to the graphical expression and using a custom LSI, a system which capable of executing the codes under a high speed was developed. Further, to reduce load of programmers, the program execution management, linkage between programs, data transmission procedure, synchronization of transmitted data and program processing, self-diagnostics and fault data management, etc. are automatically performed with micro-programs and built-in software (firmware).

As a custom, the programming tool is called a program loader, and aiming at easiness of graphical program display and operation, two models of portable program loader which use LCD are available. The usage feature of the program loaders is that connecting to the T link of an F-Net, programming can be made from anywhere on the T-link. Also in a wide range system having a network, the fundamental spirit of PC, namely, the programming at the

Fig. 1 Positions of total control system and MICREX-F series



site, is efficiently displayed.

Fig. 1 indicates position of the MICREX-F series in the total control system provided by Fuji Electric. This strengthened the intermediate layer between the MICREX-E series and FUJILOG series. However, for the future, efficiently using the MICREX-F series developing idea and keeping the harmony with the already existing equipment, the MICREX-F series will be expanded.

## 5 POSTSCRIPT

Now is the time of full scale FA and FMS developments, and it is assumed that increase of PC's significance in the future will be the essential stream. At the same time, existence of PC is in a turning point.

In the period of time like this, PC developing process was reviewed and main point of the MICREX series PCs provided by Fuji Electric toward the new generation were introduced. For the details, it is requested that separate papers in this special issue be referred.

For the PC developing process, all the PCs placed in the market were not surveyed. However, Fuji Electric has participated in the development and manufacturing of the PCs since its birth, and as necessary survey at each process was conducted, the PC developing process introduced in this paper is believed to be true.

The PC developing history counts about 15 years by now, and during these years, we received important and valuable opinion and advice and powerful supports from a number of people both inside and outside Fuji Electric. Taking this opportunity, we should like express our deep appreciations to these people.