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Extending Windows/NT for Embedded and Hard Real-Time Systems

Open PC based architectures are presenting unprecedented opportunities for positive change in the nature of dedicated systems in the fields of industrial automation, telecommunications, point-of-sale and others.

The opportunity for Windows/NT to become the dominant operating system for open PC based architectures in these markets will be examined. Extensions to Windows/NT are under development to increase the speed and extent of its market penetration and acceptance.

VenturCom concludes that some hard real-time, scalability, and embedded operation extensions are required to be made to Windows/NT in order to achieve sub-millisecond response times, and to reduce hardware resource requirements while maintaining full compatibility with the enormous range of software written for Windows/NT.

VenturCom, with over 15 years experience in providing real-time and embedded systems technology for builders of dedicated systems, has signed marketing and technical agreements with Microsoft to produce and sell the development tools and extensions required.

EXECUTIVE OVERVIEW

The markets for dedicated, non-desktop, open PC based systems are all around us. They include systems in factories, hospitals, aircraft, telecommunication switching facilities, mobile testing units, cash registers and kiosk's, to name but a few. They share common aspects in their development including dramatic increases in complexity, functionality and intercommunication requirements; a desire for openness and standards; powerful new tools and methodologies to enable project completion in shorter timeframes; extended capabilities in the areas of real-time response and scalability; and a wide range of commercial software components that may be easily integrated

As an example, consider the industrial automation marketplace. It covers a large and diverse group of industries, ranging from the big process industries (the four Ps - paper, petrochemicals, paint, and pharmaceuticals) at one extreme to various types of discrete manufacturing such as automotive, packaging, semiconductor manufacturing, milling and drilling, at the other extreme. Many technical and business pressures are forcing a major change in the control technologies used in these industries — from the older, highly integrated, proprietary architectures to the modular, open PC based architectures.

The opportunity for Windows/NT to become the dominant operating system for these open PC based architectures in the Industrial Automation marketplace is examined in this document. Similar issues abound in the many other dedicated system markets. Several extensions to Windows/NT are proposed to increase the speed and extent of its market penetration and acceptance.

VenturCom concludes that some hard real-time, scalability, and embedded extensions are required to be made to Windows/NT in order to achieve sub-millisecond response times, to meet factory floor and other constraints, and to ensure Windows/NT becomes the O/S of choice in the Industrial Automation and other dedicated system markets.

The Industrial Automation marketplace, for example, is projected as an $8.6 billion market by the year 2000, at least half of which will be spent on the acquisition of open PC software and hardware. VenturCom believes it is a market for which Windows/NT is well suited.

This article is structured into the following sections:

- Background of the industrial automation market; key technologies, major players, overall market size, and growth rates.
- Major technological trends and special requirements of Industrial Automation Applications.
- Extensions to Windows/NT required to support applications in this market.
- Conclusion.

BACKGROUND

Industrial automation includes those applications that are involved with the automation of processes that occur in and around the factory floor. While the vertical segments in which technology is employed are varied and diverse, it is useful to note that industrial automation applications in general can be characterized by the nature of the process that is automated. The spectrum ranges from continuous control applications on one hand, to the sequential (discrete) control applications on the other. Continuous control applications are characterized by petroleum production, for instance, with processes that change very infrequently and that are continuous in nature. Sequential control is characterized by small, discrete operation sets, such as with milling machines.

The two major architectures in industrial automation are DCS (Distributed Control Systems) and PLC (Programmable Logic Controllers (1)) systems. These envolved independently and were optimized to solve the different control problems posed by the two ends of the spectrum described above. PLC's were microprocessor-based replacements for hard-wired relays and mechanical timers and were primarily used in discrete control applications. They were programmed in languages which resembled electrical ladder logic. DCS evolved in industries where continuous control (2) was the norm. DCS systems were based on high speed minicomputers (3) controlling a large number of networked intelligent I/O devices. They typically ran proprietary software, were responsible for sophisticated MMI (man-machine-interfaces), and managed large volumes of data. Between continuous control and discrete manufacturing, there are a whole range of processes — typified by the food and pharmaceutical industries — where there is a sequence of steps to start a production operation, add ingredients, run for a period of time, and then stop when the end product is finished.

Windows/NT, with the addition of certain key extensions and features, is well positioned to be the dominant operating system on the factory floor by the year 2000.

Clearly, therefore, the boundaries between PLC-based systems and DCS systems are permeable. Microprocessor-based analog I/O modules can be integrated into PLC's, so they can control continuous systems. DCS systems can control PLC's at a lower level for specific discrete control functions. The most important difference between continuous and discrete control is the response time required by the controller device. Continuous control applications (PID loops in the pharmaceutical industry, for example) rarely require a response time of under 100 milliseconds. Discrete control applications, particularly multi-axis motion control applications, typically require a sub-millisecond response time.

This article focuses on real-time and scalability enhancements to support PLC-based and other discrete control applications so that Windows/NT can dominate the entire spectrum of requirements on the shop floor and eclipse its competition.

The table below presents information on the market size and growth rates for PLC based control systems worldwide.

Year	Units (millions)	Revenue (billions)	Growth rate
1994	8.62	$4.65	10.5%
1995	9.85	$5.20	11.8%
1996	11.32	$5.84	12.4%
1997	12.92	$6.54	12.0%
1998	14.56	$7.25	10.8%
1999	16.20	$7.94	9.6%
2000	17.78	$8.60	8.3%

Table 1. World market analysis for PLC systems (4)

Among the manufacturers in the PLC market are Allen-Bradley, Bailey Controls, GE Fanuc, Honeywell, Modicon, Omron, Opto 22, Siemens Industrial Automation, and Westinghouse. Information from these manufacturers and industry analysts indicates that a major shift is occurring in the market toward the PC platform — in conjunction with intelligent I/O interface cards — as an alternative to the traditional PLC. (The reasons for this trend are described in detail in the next section.) While today, PC based hardware commands only a small portion of the total revenues from the industrial automation market, it is expected to grow to about 50% of the total revenues before the year 2000, making this a $4,300,000,000 market opportunity (5).

System software for the PC is critical for the easy development, integration, networking, and maintenance of the next generation of PC-based automation systems. Windows/NT, with the addition of certain key extensions and features, is well positioned to be the dominant operating system on the factory floor by the year 2000.

MAJOR TECHNOLOGICAL TRENDS

The following major technological trends have contributed to driving the industrial automation industry towards PC based control systems:

Rapidly decreasing cost of industrial PC hardware . . .

Industrial PCs with functionality equivalent to a medium-size PLC now cost less than half that of the PLC. ($2000 versus $5000). This trend is driven by the explosive growth and intense competition in the PC industry.

Standardized networking protocols on the factory floor . . .

This is the most sweeping and powerful of trends in the industrial automation world — the opening up of the factory network(s). In the past, much of the I/O could only be connected to the controllers by the same vendor. Open I/O buses are changing and allowing one controller to connect to another vendor's I/O. There are two networks that are prevalent today: control-oriented “field” networks that must be inexpensive enough to connect to small discrete components, and high speed data networks that must have the capability to communicate large data files with the enterprise-wide network. In data networks, ethernet is rapidly winning the standards war over MAP (Manufacturing Automation Protocol), Scramnet (from Systran) and token-ring protocols. At the field-bus level, a definite standard has yet to emerge, but industry analysts expect Control Area Network (CAN) (6) to become the dominant standard in the near future. Such standardisation, along with the cheap network interface cards for the PC, make the PC architecture a very effective platform from which to control plant I/O.

Increasingly sophisticated Operator Interface (O/I) requirements . . .

Most process controllers traditionally include a basic display — a bar graph of process variables and set-point values. Push buttons allow adjustment of these values. Networked versions of these controllers can be managed from a central point, where more sophisticated displays are implemented. Requirements for OI are rapidly increasing to include many non-traditional functions. For example, some OI panels now include operator "help" information. Some sophisticated systems can walk an operator through an entire sequence of operations — functioning as a training station. For such advanced OI functions, the PC is the most suitable platform because of the broad availability of PC-based video adapters and CD-ROM controllers.

Increasing end-user pressure . . .

Perhaps the most significant influence on vendors to move towards open PC-based systems is pressure from their large end-users. The results are already occurring in the market through new specifications like OMAC (Open Modular Architecture Controllers). OMAC was developed by the automotive industry as a description of the preferred architecture of future controllers (standard systems using ISA, PCI or VME for bus architectures and employing standard interfaces between them). The automotive industry believe that it is imperative that PLCs are replaced by the OMAC architecture in order to contain costs and improve maintainability of the control systems. According to Jerry Yen, Supervisor of CNC/Motion Controls at General Motors' North American Manufacturing Center (Warren, MI), the last two major projects undertaken by GM's Powertrain group both used PCs (7) rather than PLCs. A similar standards effort is proposed by the group called OSACA (Open System Architecture for Controls within Automation Systems) developing standards for machine tools (NC), robot controls (RC), programmable logic controls (PLC), and cell controls (CC).

The above trends have caused the PC to emerge as the "next generation" control hardware of choice. Windows/NT is already beginning to appear as the O/S platform for the implementation of control systems. At ISA/95 in New Orleans, leading industrial automation vendors — including Allen-Bradley, Fisher-Rosemount, Foxboro, GE Fanuc, Honeywell, Intellution, Opto 22, Siemens, Setpoint, Square D, and Wonderware (8) — announced NT-based control applications.

Becoming more modular, control system implementations are increasingly being built using off-the-shelf components. This is in contrast to the monolithic control software (particularly in DCS) of the past. The use of a component software approach allows a developer to rapidly build multiple independent parts and then to quickly integrate these with other software components. Control software lends itself to component-based approach because it is usually made up of easily identifiable independent functions such as graphic displays, trending, data logging, alarm monitoring, I/O scanning and database processing, for example. The OLE specification from Microsoft is the preferred architecture for the implementation of component-based software. The OLE component Object Module (COM) is based on the concept of component software and allows applications to "connect" to each other as software objects. An object is a collection of data and accompanying functions that can manipulate the data. The control-system developer's job becomes easier with a more focused design effort, smaller development teams that can better react to customer needs, and the ability to reuse software modules. For users, component software means a much greater range of software choices, along with greater productivity.

The importance of component software is underscored by two recent developments:

- The forming of the OPC (OLE for process control) task force, a five company team (Fisher-Rosemount, Intellution, Intuitive Technology, Opto 22 and Rockwell Software) whose goal is to ensure interoperability between all Microsoft OLE-based process control applications.
- The announcement of Component Integrator for Windows/NT from VenturCom, a tool which allows the rapid integration and deployment of component based software.

Windows/NT is already beginning to appear as the O/S platform for the implementation of control systems.

While the above are positive signs of the acceptance of Windows/NT (and OLE as an enabling technology for the implementation of component-based applications) in the automation marketplace, it has yet to be seen as the most suitable operating system for control applications, particularly those applications that are at the discrete end of the spectrum. This is primarily because of perceived weaknesses in the areas of real-time performance and scalability. (See the next section.)

Note that in addition to the above, there are several other critical pieces of enabling technology which are required to build industrial automation control applications, including:

- Asynchronous exception management capability
- Remote monitor and control
- Support for special embedded target hardware
- Tools to build, deploy, and test target systems

VenturCom has already begun work on these extensions and is expected to release these as part of its Component Integrator for Windows/NT product later this year (1996).

VenturCom Ad

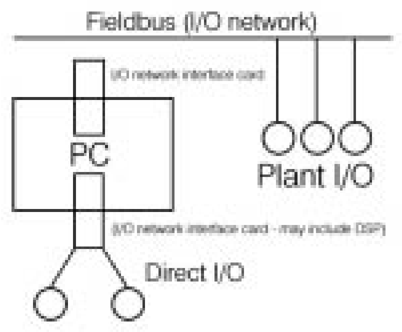

Figure 1. The typical PC-based control architecture

PROPOSED EXTENSIONS TO WINDOWS/NT

Real-time performance requirements

Fundamentally, control applications are responsible for monitoring input data, performing application-specific transformations on the input data, and setting control outputs based on the result. The typical PC-based control architecture is shown in figure 1.

A PC interface card is connected to a fieldbus (9) (or is directly connected), which then is connected to I/O in the plant. The interface card is mapped into shared memory space on the PC. The control software running on the PC is responsible for monitoring the input data in memory and managing the output data in shared memory. The maximum frequency at which this occurs is no more than 5 Khz. The ability of the software on the PC to maintain the desired throughput is essential in ensuring correct operation of the control system.

Within discrete manufacturing, motion control applications are at the extreme end of performance requirements. Even in this case, direct servo control is performed using a specialized DSP processor (companies like Motion Engineering and Delta Tau produce popular DSP based PC cards for motion control), and the PC is generally responsible for a higher level of control that has less stringent performance requirements. Device drivers are available from these manufacturers that download control code onto the DSP processor, which then performs microsecond-level control of the motor.

It is important to note that it is critical that the PC software be able to perform at anticipated rates. On the plant floor, the control system is responsible for controlling large pieces of machinery. Fail safe equipment typically is going to cause a shutdown that can cause large economic loss, such as the discarding of the entire part which was being worked on by the control system when the failure occurred (10).

The real-time requirements for the majority of control applications are as follows (11) :

- A real-time timer with the ability to generate precisely timed control functions of up to 5 Khz with jitter of less than 50 microseconds.
- Once operational, zero time base drift for this timer.
- The timer overhead should not be more than 10 microseconds. At a 5 Khz frequency, this implies that no more than 5% of the processor bandwidth is used in generating this timer function.

Note that the above implicitly requires that the maximum execution time of all sections of non-interruptible (by the timer) code running on the PC must be tightly bounded and measured to be less than 50 microseconds. This includes interrupt service routines, critical kernel code that runs with interrupts masked, etc. Also, note that in practice, given the fact that asynchronous interrupts can occur (by definition) at random, the timer function should have the ability to mask hardware interrupts for the duration of its execution.

In addition to the above requirement, it is also critical that the control software not be prevented from having direct access to all the features of the I/O devices. For example, some I/O devices provide diagnostics (12). If these functions are not available to control software, the value of the I/O device is substantially reduced. Performance requirements also dictate that the accessibility of the I/O ports be available directly to the application software (without a need to go through the NT kernel.) The other significant performance-related extension to NT is, therefore, the ability for application software to directly access memory and I/O spaces (with no performance penalty whatsoever.)

Finally, in conjunction with the above real-time extensions to NT, an accurate performance analysis tool with the ability to measure key performance metrics should be available. The vast variety of available hardware/software combinations requires that system performance be measured in situ and evaluated for correctness of operation.

Scalability

PC-based controllers employed on the factory floor will be tasked with managing a number of different configurations of I/O. These may range from managing over 1000 I/O points on a supervisory computer in a central control room down to managing perhaps 10 points at a specific cell on the floor located right next to factory equipment that generates high temperatures. Clearly, the type of PC employed for each scenario will be very different. A 90 MHz Pentium with 32 megabytes of RAM, a gigabyte drive, and enterprise network access is perhaps suitable for the supervisory computer. For the 10 I/O point application on the factory floor, a 33 MHz 486 with 4 megabytes of RAM, a flash disk and an A/D interface card in a PC-104 form factor is a more appropriate platform. For each of the above platforms, the software configurations (including the base Windows/NT system) must have the ability to be scaled to fit within the hardware constraints.

Under the category of scalability, we identify the following two requirements:

- Ability to scale an NT system down to function inside 4 megabytes of RAM
- The ability to run entirely off EPROM based (read-only systems

CONCLUSION

Windows/NT is a mature, full-featured operating system with a large base of commercial off-the-shelf application support. It is already the standard operating environment for most applications at the enterprise and desktop level. In this document, we have identified two key areas: real-time performance and scalability where NT should be extended to improve its applicability to include factory floor automation controllers. These extensions are key ingredients that are necessary to implement a seamless enterprise network, which includes the entire range of corporate computing equipment: back-end office servers, desktop computers, and factory floor automation controllers. The benefits of such information-sharing capability are enormous and have the potential to generate a quantum leap in the productivity of manufacturing industries. This will cast the Windows/NT environment as the de facto standard for corporate computing and the operating environment of choice for the next generation of factory automation controllers.

VenturCom concludes that some hard real-time, scalability, and embedded extensions are required to be made to Windows/NT in order to achieve sub-millisecond response times, to meet factory floor constraints, and to ensure Windows/NT becomes the O/S of choice in the Industrial Automation Marketplace. As an $8.6 billion marketplace by the year 2000, at least half of which will be spent on the acquisition of open PC software and hardware, VenturCom believes it is a market for which Windows/NT is well suited. VenturCom has the design and the knowledge to complete the development of the necessary extensions to Windows/NT. Development of the extensions has already begun with the support of partners including Microsoft, Rockwell (parent of Allen-Bradley), Rockwell Software, Unisys, ABB, Orsi Automazione, Wizdom Controls, Wonderware, Ziatech, and Meiden. ■

REFERENCES

1. Though not strictly correct, we choose to include CNC applications in this category given their discrete nature.
2. Process control is an example of continuous control; an entire industry segment comprising manufacturers of process control equipment can be identified. Some of the leaders in this segment are Fisher-Rosemount, ABB, Honeywell, Yokogowa, Siemens, Siebe, Elsag Bailey, and Allen-Bradley.
3. Foxboro's I/A series is an example of a DCS.
4. Data from Frost & Sullivan, as reported in The programmable logic controller: Adapting in an environment of change, InTech, March 1995, pp. 52-56.
5. Tom Bullock, Senior Analyst, Industrial Controls Consulting Inc. as quoted in EE Times, 7/24/95.
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9. An IEC and ISA approved physical standard for control networking of I/O devices.
10. This is not the worst case.
11. For all timing information in this document, we assume a 90Mhz Pentium processor.
12. "PC or PLC: What's in a name?", David Gee, InTech, September 1995.

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Prior to holding this position, he held several positions at Lynx Real-Time Sytems, a developer of a Unix-like Real-time operating system, including Vice President of Sales. He was Vice President of Sales at Myrias Computer Corporation, a producer of massively parallel supercomputers. He was OEM Group Sales Manager at Concurrent Computer Corporation a producer of real-time computer systems.

Earlier in his career, Mr. Rogosin spent 12 years at Digital Equipment Corporation in Sales and Sales Management with focus on technical and real-time markets. He also sold instruments, measurement and test equipment, and control systems for Leeds and Northrup Company.

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For eleven years prior to reorganizing the company and redefining his role in 1995, Zimmerman served as VenturCom's president. During this period, he led the company from being a consulting-based business that managed major UNIX software development contracts to a growing product-oriented company.

Immediately after co-founding VenturCom in 1980 with colleagues from the Massachusetts Institute of Technology (MIT), Zimmerman served as the company's director of engineering.

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Prior to holding this position, he was a consultant with Network Equipment Technologies of Redwood City, California, where he developed key components of the company's embedded real-time software for its T1 multiplexor product. Prior to that, he was Vice President of Engineering at VenturCom's Cambridge headquarters, where he was the architect of the first generation of VenturCom's embedded UNIX product.

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