Technologies for Achieving Field Ubiquitous Computing

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Abstract: Although the term “ubiquitous” may sound like jargon used in information appliances, ubiquitous computing is an emerging concept in industrial automation. This paper presents the author’s visions of field ubiquitous computing, which is based on the novel Internet Protocol IPv6. IPv6-based instrumentation will realize the next generation manufacturing excellence. This paper focuses on the following five key issues: 1. IPv6 standardization; 2. IPv6 interfaces embedded in field devices; 3. Compatibility with FOUNDATION fieldbus; 4. Network securities for field applications; and 5. Wireless technologies to complement IP instrumentation. Furthermore, the principles of digital plant operations and ubiquitous production to support the above key technologies to achieve field ubiquitous systems are discussed.

Key Words: field ubiquitous, IPv6, network security, wireless, plant operation, production.

1. Introduction

- Future trends in industry and technology

At the beginning of the 21st century, globalization has become one of the key factors changing every aspect of human society, including world politics, economics, and even our personal lifestyle. Manufacturing is not an exception to this trend. Our industries are enormously affected by globalization, i.e., the “borderless society.” (Fig. 1)

In industrialized countries, economic growth is almost saturated and the rapid shift to aging societies is becoming a major social concern.

In contrast, in developing countries, rapid economic growth is causing several problems, including a lack of a skilled workforce, which threatens to block progress in quality and productivity improvement in the manufacturing industries.

Environmental protection and energy supply are also growing global concerns. The negative legacy of industrialization through the 20th century is beginning to threaten our existence. The entire world is becoming more aware of sustainability issues, as we begin to see that there are limitations in both what we can take from and what we can force upon the natural environment. Resources that were once thought to be limitless are now seen as finite. Global collaboration is essential to address these challenges, and manufacturing industries must play a key role in this process.

The necessity for both safety and security is an age-old but relevant topic. The recent shift to an open environment in manufacturing systems requires maximum consideration of security protection as well as plant safeguarding.

The direct effects of globalization on manufacturing industries can be seen in the recent progress in the global production value chain. Suppliers, manufacturers, and customers collaborate in globally distributed value chains to create common value. Manufacturers today must embrace global networking as an essential part of their manufacturing processes.

In addition, emerging technology trends indicate large-scale changes in the manufacturing domain.

First, high-speed communication network technology currently used in the enterprise domain is finally coming onto the plant floor.

This will not only improve the speed of communications but also trigger a revolution in operating processes.

The ubiquitous computing concept that has been well deployed in the home and office domains provides foresight into the revolutionary changes coming to the manufacturing domain. This will be discussed in more detail later to analyze the implications of the ubiquitous computing concept.

The trend toward globalization is driving us toward worldwide collaboration, uniting local entities to create value that is global in scale. At the same time, it requires the manufacturing system to be agile and flexible, adapting to various changes quickly and meeting individual requirements more closely.

- Challenges for the future of industrial automation

Considering such changes in both industry and technology, four key tasks should be undertaken by customers and suppliers of industrial automation in the near future:

1. More focus on the protection of health, safety, and environment as the first priority.
2. Enable flexible and agile adaptation to various changes in market demands.
3. Meet personalization trends of products and production processes.
4. Keep automation systems up to date for longer periods.

The first tasks should be to protect health, safety, and the environment. Over the years, automation systems have come a long way to help customers reduce energy consumption and increase productivity in their plants.

In the coming years, there will be increasing focus in the design of automation systems on the additional responsibility of protecting health, safety, and the environment, and ensuring sustainability of stable production.

The second task is to enable flexible and agile adaptation to various changes according to market demands. Even in mass
production factories, plant managers are required to produce various types and grades of product with frequent changes in accordance with real-time order intakes from customers. Automation systems are required to have an enhanced capability to handle various types of production information in a more flexible manner.

Another change in manufacturing industries is the emerging demand for tailor-made production, where a very small amount of a product is produced to meet an individual customer’s order. In this case, the production systems and processes as well as automation systems must change constantly. We call this the personalization of production. This trend should also be addressed.

Finally, keeping automation systems up to date for longer periods is an ongoing challenge. Even if customer demands change frequently, plant and production systems continue to work for very long periods, such as 20 to 30 years. Automation systems should help to protect user-created assets, such as control and production strategies, over many years while system components are adequately updated using the latest technologies. Continuous efforts to develop new technologies and proactive adaptation to revolutionary changes in business practices are essential to take on these challenges.

The concept of ubiquitous computing is particularly relevant and promising in addressing the 2nd and 3rd challenges listed above. The implications of the ubiquitous computing concept deployed on the plant floor are discussed below.

- Ubiquitous computing on the plant floor
  Ubiquitous computing promises to provide many benefits to society: in our homes, in our communities, and even in manufacturing plants.
  The key benefits of ubiquitous computing can be summarized as enabling us to utilize information in the following ways:

1. From anywhere:
   Ubiquitous computing removes location dependency.

2. At any time autonomously:
   Ubiquitous computing performs a variety of tasks autonomously at any time without any conscious effort on the user’s part.

3. Clearly as if on-site:
   Ubiquitous computing does not block access to any information, and helps us work remotely as if performing the task on-site.

4. From the user’s viewpoint:
   Ubiquitous computing implements functions from the user’s point of view, rather than from that of the system builders.

5. Adapting quickly to changes:
   Change is naturally absorbed in ubiquitous computing environments. Ubiquitous computing is capable of adapting to frequent changes in a flexible manner.

Ubiquitous computing is eagerly awaited both on the plant floor and in the production field. For example, let us envision a plant where sensors and control devices carry out continuous self-diagnosis and autonomously execute predictive maintenance to prevent malfunctions. A network enables operation of the plant from any location around the globe and eliminates the necessity of stationing experts at each facility. Equipment and devices on the production lines engage in an autonomous dialog with human operators and are capable of adapting to unexpected changes by upgrading their functionalities online.

We named this concept Field Ubiquitous Innovation, ubiquitous computing applied to the plant floor.

In the following sections, some of our efforts to make Field Ubiquitous Innovation a reality are introduced.

- Beyond the traditional view of IT
  Traditionally, we have believed the plant floor cannot allow a “reset culture” or “best practice-based responsibility.” Absolute
responsibility, deterministic response time, and deep real time are what we call the 3Rs that symbolize the essential characteristics of plant floor systems.

Recent BPR (Business Process Re-Engineering) experience in office and enterprise domains has provided insight into the revolutionary changes that will come to plant floor operations and management. It is essential to re-engineer the total operation flow to make full use of the latest developments in IT.

The remodeled 3Rs on widely used IT infrastructure will be established.

2. Technologies for Achieving Field Ubiquitous Innovation

A number of technologies are required to make the Field Ubiquitous concept a reality. In this paper, three important technologies are discussed [1]. (Fig. 2)

The first is IP instrumentation. Internet technologies, especially IP network technology that has become a de facto standard and has been widely used in the office and enterprise environment, will inevitably be implemented on the plant floor. We have named this IP instrumentation.

The base technologies supporting IP instrumentation include:
No. 1: IPv6, a new version of the Internet Protocol, which will be applied to field networks.
No. 2: Security technology that accommodates the requirements peculiar to plant floor applications.
No. 3: Wireless communications in the field environment that liberate customers from the restrictions of field wiring.

The second technology is Digital Plant Operation.

Taking full advantage of the rich information that can now be gathered on the plant floor due to distributed intelligence, the methodology of plant operation will be fundamentally changed to a higher level, which we call Digital Plant Operation.

A few features of Digital Plant Operation are shown using the following two examples:
No. 1: A plant tracking simulator running on-line in real-time to uncover the hidden behaviors of a plant.
No. 2: Abstracted plant operation that enables more intuitive operation of the plant to achieve the final objective.

The third technology is ubiquitous production, which is a distinct element. This is not built on IT-based technologies, but leverages chemical-based technologies. Microreactor technology facilitates a new mechanism of chemical synthesis by bringing chemical reactions inside micro-fluid channels.

3. IP Instrumentation

3.1 Architecture

The term IP instrumentation, i.e., Internet Protocol-based Instrumentation, represents a revolutionary innovation where Internet technologies penetrate the plant floor. The differences in architecture between the conventional system and IP instrumentation can be summarized as follows. (Fig. 3)

In the conventional system, different network technologies are applied to different layers. The enterprise, information, control, and field wiring levels each have their own network. To utilize data, applications must be developed for each layer with exhaustive consideration of network characteristics.

In contrast, in the expected system architecture of IP instrumentation, all layers will share a unifying network technology with IP. By unifying the system network, we can design more flexible systems that can overcome traditional limitations, such as geographical barriers in remote applications. IP also improves connectivity between different systems, providing a common network infrastructure for vertical integration and horizontal integration.

3.2 Road to IP Instrumentation

The standardization of the FOUNDATION fieldbus [2],[3] represents the first stage in the revolutionary innovation coming to the area of field wiring. It is a digital communication standard by fieldbus foundation, replacing the conventional point-to-point 4–20 mA analog communications with multiple-point
digital bus communications. The data transmitted go beyond traditional process variables and incorporate maintenance data, configuration parameters, etc. This change will enable both wiring cost reduction and innovative utilization of extended field data. Further new benefits, such as control in the production field, predictive maintenance, and asset optimization, will also be realized.

IP instrumentation is the second stage of innovation on the plant floor. We view Internet technology as one of the potential answers to emerging requirements for more effective usage of extended field data, more flexible field wiring, and more adaptive production systems. This innovation promises further optimization of work processes going beyond control and monitoring, bringing increased capabilities and efficiency to maintenance and asset management, etc. (Fig. 4)

Two factors are key to the success of full-scale IP usage in the production field. The first is the retention of user benefits that have been achieved by the existing field wiring to date. Concrete examples of existing user benefits include fast and deterministic real-time response and robust intrinsic safety capability. IP instrumentation must ensure the same level of reliability or dependability of field wiring that are provided by current systems.

The second key success factor is overcoming the potential shortcomings associated with IP instrumentation. The following two issues are particularly important. First, the network must be secure and protected against cyber attacks. Second, the engineering environment must be well prepared for easy and cost-effective integration.

3.3 IPv6: Next-generation Internet Protocol

Internet Protocol is a network layer protocol widely used for packet-switched inter-networks. The current version, IPv4, carrying a 32-bit length address field, supports about 4.3 billion Internet addresses. This may sound like a huge number, but as Internet communications have become more common, a much larger address space is required to meet increasing demands. Everything from personal items to huge government systems will require IP addresses for communications in the age of ubiquitous communications. The new version, IPv6, which has a 128-bit length address field, supports an address space with $10^{38}$ addresses.

However, IPv6 is not merely an address expander. Internet Protocol security (IPsec), which is part of IPv6, has the potential to offer more advanced encryption capability, much tighter security against network intrusion, and support of easy-to-configure connectivity to a wider variety of devices. We developed and standardized an IPsec key exchange protocol named KINK [4]. KINK is suited to these devices because it is cryptographically low cost and scalable. (Fig. 5)

To dispel a common misunderstanding about the applicability of IPv6 in a very harsh production field environment, we have developed an IPv6 chip specifically designed for field devices. This innovative IPv6 chip has a TCP/UDP protocol stack and built-in security functions in the hardware layer, thereby enabling field devices with limited CPU resources to utilize IPv6. In the link layer, it allows two-way modem connections in addition to Ethernet connections, thereby enabling 1 km long-distance transmission, power supply, and intrinsic safety.

We believe the FOUNDATION fieldbus will continue to play a key role in IA(Industrial Automation) systems. We are now developing a software architecture to enable FOUNDATION Fieldbus applications running on IPv6.

3.4 Field-oriented Network Security

The embedded security function provided by IPv6 is a base for achieving a secure field network. However, further enhancements are necessary to ensure secure communications on the plant floor. The conventional firewall model of network security is becoming out of date as mobile terminals and wireless connections come into play and collaborative manufacturing among geographically remote facilities becomes a reality.

In the emerging new environment, it is critical to establish a secure communication channel between both ends, not assuming any specific network topology. To address this challenge, we are developing what we call a secure plug & play mechanism [5]. This is a security framework applicable to low-end as well as high-end field devices, enabling easy plug & play engineering and network security simultaneously.

Furthermore, protecting individual field devices is not sufficient as a comprehensive network security measure. The network itself must be safeguarded against communication errors and network malfunctions that would could arise from cyber attacks.

3.5 Field Wireless Communications

The third key technology that enables IP Instrumentation is wireless technology. People in the industry community used to be rather skeptical about introducing wireless communications in the manufacturing field because of its physical limitations and security vulnerabilities. Now, however, there is a more positive attitude about its potential benefits.

Expected benefits of wireless solutions include freedom from the restrictions of wired connections of field devices. This change in attitude is remarkable especially in the oil & gas upstream and in other industries that operate widely distributed facilities in areas where communications infrastructure is minimal. For maintenance purposes, people often wish to install additional sensors, without having to give careful consideration
to the network configuration beforehand. This is one of the potential applications of wireless solutions.

However, several obstacles must still be overcome to allow the implementation of wireless solutions in the field.

Wireless solutions always suffer from limited power supply. Devices are sometimes installed without any power supply, and are expected to have their own power source. Power management is a mandatory feature for field wireless devices. Typical plant floors and production fields are full of metal tanks, pipes, and noise-generating machinery that interfere with wireless communications by reflecting, absorbing, and interfering with radio waves. (Fig. 6)

Addressing such issues requires a quite different technology from the wireless communications used in the office domain. In addition, security is another important task in wireless solutions. We are accelerating our R&D activities in three key areas [1].

The first area is the development of key elemental technologies for field wireless networks. Our research is focused on the mesh network system as well as the gateway system that bridges IP and wireless networks.

The second area is prototyping of wireless units and evaluation of their applications.

The third area is activities for international standardization. Interoperability of field devices is essential and international standardization of the field wireless protocol is an issue that must addressed. We are actively participating in both the ZigBee Alliance based on IEEE802.15.4 and the ISA SP100 standardization activities.

In addition to these key activities, we are beginning to work on the vision of dependable wireless communications. Wireless means no physical wire that can be cut off, and it has the potential to evolve into an extremely reliable network. Dependable wireless communications will grow into an essential complementary component of IP instrumentation in the near future.

4. Digital Plant Operation

The next topic concerns digital plant operation, which is the second research theme involved in realizing Field Ubiquitous Innovation. Our research has two targets in digital plant operation [1],[6],[7].

The first target is to realize transparent operation. Transparency means that the inner behavior of the plant can be seen according to a given purpose. In addition, the fundamental behavior of the plant can be seen before the distortion caused by individual implementation constraints, such as the different configurations for plant equipment at each plant.

The second feature is realizing an abstracted plant operation. First, operators can understand the plant more intuitively using the Key Performance Indicators (KPIs) that essentially describe the plant. Then, the operators manipulate the plant with a primary intention, such as “produce a certain volume of product with a certain quality level,” instead of conventional physical actions such as “manipulate valve opening 3%.”

Figure 7 shows a typical scheme of a digital plant operation. The plant simulator is placed in the center of the scheme producing the predicted plant inner behavior and calculating KPIs. The advanced HMI is another key element that complements the lack of on-site vividness that may be caused by such extensive use of IT. The advanced HMI is beyond the scope of this paper.

4.1 Plant Tracking Simulator

The plant simulator used in such a scheme is a dynamic simulator running on-line in the real plant operation. It collects actual data of the real plant through the DCS and runs simulation iteratively to adjust parameters of the plant model to make the model correspond with the real plant. This is what we call the tracking simulator. (Fig. 8)

The tracking simulator visualizes the inner status of the plant by interpolating and estimating unmeasured process variables. It also supports plant monitoring and maintenance with calculated KPIs. More importantly, it enables prediction of the future dynamic behavior of the plant by accelerating calculation in the simulator. Using case simulations with varying parameters, it can help determine the optimal conditions of plant operation in advance.
4.2 Real-time Utilization of Plant Models

Figure 8 shows how the tracking simulator uses the plant model on-line and in real-time. The tracking simulator runs simultaneously with the real plant, and continuously adjusts the model parameters by comparing the responses of the real plant to the model using a tracking algorithm. Over time, the simulator comes to behave in almost the same way as the real plant.

The adjusted parameters are transferred to the prediction simulator or to the static simulator by the user’s commands. The prediction simulator runs the accelerated simulation to predict the future behavior of the plant, while the static simulator is used to predict the future steady-state.

5. Ubiquitous Production with Micro-plants

Micro-reactor technology enables new chemical synthesis by bringing chemical reactions inside micro-fluid channels, enabling a safe and environmentally friendly small-quantity production method. Micro-reactor technology is expected to lead to significant innovation in the chemical industry’s manufacturing process. Micro-reactors reduce reaction time and enable highly selective production of intermediate compounds [8].

In addition, when moving to mass production, micro-reactors can simply be multiplied in number, avoiding all the problems generally associated with the scale-up process. (Fig. 9)

The leading technologies utilized for micro-reactors are MEMS technology and the micro-flow technology.

One concrete example of a micro-plant prototype is an on-site gas generator using an electrochemical micro-reactor. Currently, fluorine gas is made in large chemical plants and packed in high-pressure gas cylinders, which are then transported to semiconductor factories and connected to the gas supply piping of semiconductor production equipment. Using an on-site fluorine gas generator, customers can both reduce cost and improve safety.

In such a production system, exactly the necessary amount of products can be produced at any time at the site where it will be used; this is “ubiquitous production.”

6. Conclusions

In summary, a few key points regarding field ubiquitous innovation are presented:

1. We have introduced various new technologies into automation systems but are still bounded by the traditional IA culture. Now, at the start of the 21st century, it is inevitable that we will begin to see the real benefits of information technologies, such as the Internet, the world wide web, etc. This will require loosening of the rigidity of traditional plant instrumentation, breaking it up into many appropriate pieces and rearranging them on the Internet. (Fig. 10)

2. IP instrumentation is a key platform for this revolution, but is still a prerequisite for a much broader series of necessary changes. It is very important to adapt the business models and operational philosophy to the new platform to realize the effectiveness of IP instrumentation. The digital plant operation concept is the key vision that will usher in this broader change.

3. The physical plants themselves are not exempt from the emergent change, and will begin adapting to the new age opened by IP instrumentation. Ubiquitous production by micro-plant technology is one illustration of the new forms of physical plants to come in the digital plant operation era.

IP instrumentation will realize collaborative production over the Internet and bring operational efficiency to the next level. In this way, such new styles of operation as centralized plant operation from skyscrapers and outsourcing of asset management services will be realized.

References

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Received his BS and MS degrees in Control Engineering from the Tokyo Institute of Technology in 1969 and 1971, respectively and the doctorate in Management Science & Technology from Tohoku University in 2008. On 1971, he joined Hokushin Electric Corporation (which merged with Yokogawa in 1983), and he is currently an Executive Fellow at Yokogawa. In 1999, he was appointed head of the Industrial Automation System Business Division. From 2003, he was a Director, Chief Technology Officer and Executive Vice President of Corporate R&D Headquarters. His research interests include control systems architecture for manufacturing, development systems for embedded software and Management of Technology. He is a past president of the Society of Instrument and Control Engineers Japan (SICE). He is a member of the Policy and Strategy Board of the Japan Electronics and Information Technology Industries Association (JEITA) and is a board member of the IPv6 Promotion Council of Japan.