

Future trends in process automation

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Abstract

The importance of automation in the process industries has increased dramatically in recent years. In the highly industrialized countries, process automation serves to enhance product quality, master the whole range of products, improve process safety and plant availability, efficiently utilize resources and lower emissions. In the rapidly developing countries, mass production is the main motivation for applying process automation. The greatest demand for process automation is in the chemical industry, power generating industry, and petrochemical industry; the fastest growing demand for hardware, standard software and services of process automation is in the pharmaceutical industry.

The importance of automation technology continues to increase in the process industries. The traditional barriers between information, communication and automation technology are, in the operational context, gradually disappearing. The latest technologies, including wireless networks, fieldbus systems and asset management systems, boost the efficiency of process systems. New application fields like biotechnology and microtechnology pose challenges for future theoretical work in the modeling, analysis and design of control systems. In this paper the industry trends that are shaping current automation requirements, as well as the future trends in process automation, are presented and discussed.

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1. Introduction

The starting points in assessing the future needs for automation are, on the one hand, global development and economic trends, and, on the other, the way in which they are reflected in the development of society and the economy. Global risk management will attain ever greater importance in the future. In particular, better control and anticipation is needed in order to contain the risks related to the economy, environment, energy and infrastructure. Faced with climate change and a growing scarcity of raw materials, the world needs to find and develop new environmental and energy solutions. The world's water supply is also in need of development. International competition and global business environments reach everywhere. Business operations and capital markets are dynamic; they seek environments that offer the best opportunities for success in open competition. In addition to business and production, also R&D seeks the best possible operational environments. Economic, organizational and technological trends will cause significant changes in automation technology during the next few years.

By developing technologies, it is possible to find solutions to the basic needs of society and the industry. The development of technology helps to maintain all of the current competitive advantages and to create new ones in many new fields, thus further improving prosperity and well-being. The development of high technology applications further boosts the introduction of new cooperation models: networking among business companies, universities and research institutes, as well as decision-makers in the public sector. A trans-disciplinary approach e.g. in materials development requires expertise in physics, chemistry, biomaterials, electronics, communications, programming and automation.

Globalization along brings with it social challenges and problems in the interaction between different population groups and cultures. The growth of multiculturalism requires new management practices, knowledge of foreign cultures, and the ability to support and take advantage of the existence of minorities and difference. The management and development of skills and competences in a decentralized organization is becoming increasingly important.

The importance of automation in the process industry has increased dramatically in recent years. It has become a force in the entire chemical, oil, gas and biotechnology industries. Innovative instrumentation systems now control complex

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processes, ensuring process reliability and safety, and provide a basis for advanced maintenance strategies. Incessant cost pressures in the chemical and bioindustries leave no alternative to improved productivity. Companies need to take a holistic approach to quality, cost and time issues, and automation engineering will play a central role. Process control ensures that the plant assets continuously operate predictably within the most profitable range, leading to a greater output of consistent products, reliability, yield and quality using less energy (Benson, 1997). This technology will help increase productivity, improve quality and accelerate system modification and retrofitting activity designed to increase flexibility.

In this paper the industry trends that are shaping current automation requirements, as well as the future trends in process automation, are presented and discussed. The paper is structured as follows: In Section 2 development of the automation market for the process industries up until 2010 is presented: market developments by industries, regions and product and services. In Section 3 future automation technology trends, like the integration of production and business operations and industrial communication technologies, are discussed. The paper ends with recent accomplishments and future application trends in process automation.

2. Development of the automation market for the process industries up until 2010 (Schroeder, 2003)

2.1. Market developments by industries

According to the report by Intechno Consulting (Basel, Switzerland), the world market for process automation will grow at an average annual rate of 5.1% between 2005 and 2010 to reach 94.2 billion \$ in 2010. The greatest demand for process automation is in the chemical industry, power generating industry, and petrochemical industry; the fastest growing demand for hardware, standard software and services of process automation is in the pharmaceutical industry. The share of hardware is expected to continue to shrink. Fig. 1 shows the

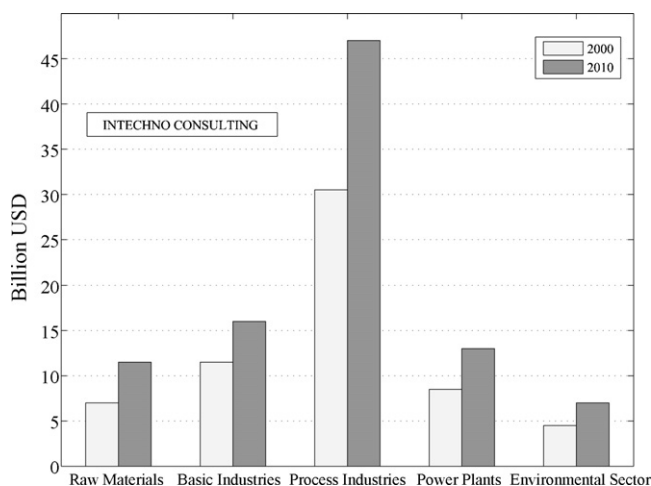


Fig. 1. Development of the world market for process automation up until 2010—segmentation by industries (Schroeder, 2003).

future world market development for process automation in individual application sectors.

2.2. Market development by regions

North America is the leading market for process automation. Asia-Pacific and Eastern Europe are winning market shares from Western Europe and North America. China is a growing engine for automation in Asia, in spite of its lower levels of plant automation. India, too, is gaining market shares worldwide. In the highly industrialized countries process automation serves to enhance product quality, master the whole range of products, improve process safety and plant availability, efficiently utilize resources and lower emissions. In the rapidly developing countries, mastering mass production is the main motivation for applying process automation. Quality and environmental aspects are, however, gaining importance as well. Fig. 2 shows the world market development for process automation by region.

2.2.1. Market development by product and services

About 39.3% of the automation hardware bought in 2000 were for the process control level, and 60.7% for the field level, including all sensors, measurement equipment, and actuators integrated in the various process technological machines. By 2010, the share of control level hardware out of the total hardware will shrink to 35.8% worldwide. Intelligence is moving to field level and the control level products and the systems are becoming cheaper—they are increasingly becoming commodities. Particularly strong growth will be seen in fieldbus communication and Ethernet/TCP-IP components. The former is expected to grow at a rate of 8.2%/year, and that of the latter should be around 17%.

The share of external engineering demand will keep increasing worldwide. It is expected to rise from 13.9% in 2000 to 15.5% in 2010. Engineering expenditures are expected to further increase, especially in those industries with prototype plants. The trend towards rationalization and plant optimization, accompanied by increased integration of automation systems with the information systems of the production site and the enterprise level, will further add to the engineering share out of the total plant project costs. Segmentation by product and external services in the world market development for process automation up until 2010 is presented in Fig. 3

3. Future technology trends in automation

3.1. Current status of the industrial communication technologies (Georges, Remes, & Jämsä-Jounela, 2006)

Evolution of communication technologies has had a strong influence on changes in the structure of industrial automation systems. Up until now, communication support in plant automation systems has been defined according to the computer integrated manufacturing (CIM) concept. In this hierarchical structure, different levels of functionality are identified in such a way that each device is designed for a specific task, and

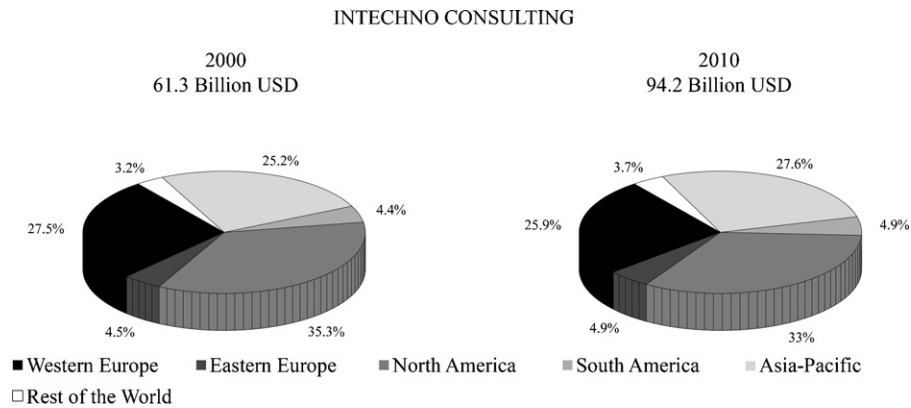


Fig. 2. Development of the world market for process automation up until 2010 segmentation by regions (Schroeder, 2003).

specific networks are used to interconnect devices at the same level, i.e. those running the same task.

However, the devices have recently started to include more than one function, or module, which increases the intelligence level of the equipment automation. Devices like sensors that have traditionally been used for measurement now have to support e.g. maintenance or monitoring tasks. This means that the traditional hierarchical structure has to be replaced by a distributed communication architecture. Nevertheless, the hierarchical structure still exists – and this is also advisable – in most of the process control strategies.

A brief survey of the most important industrial, low-layer protocols (referring to the ISO model) is given in the following. In addition, some currently essential or emerging high (ISO model) layer data specifications are also described.

3.1.1. Low-layer communication protocols

The most widely available industrial networks at the present time can be classified into three main categories: *traditional fieldbusses*, *Ethernet-based networks* and *wireless networks*, as shown in Fig. 4.

The worldwide leaders within the automation domain with respect to the number of installed Fieldbus nodes are held by PROFIBUS (about 14 million nodes) and Interbus (about 7 million nodes). A good commercial position is also held by Foundation Fieldbus. Fieldbus technology has reached a stable

phase within industrial automation, and fulfills the current technical requirements of local industrial communications at the field level of an enterprise (Neumann, in press).

HART and Foundation Fieldbus have opened the door to field intelligence. Instruments are not only smarter about the process variables they monitor and manage, but they are also more effective at diagnosing their own health. The next stage is to widen this diagnostic capability to the process surrounding the instrument. As this trend continues, we will benefit from predictive intelligence. We will know more about the health of the process, which will enable earlier detection of potential problems and profit-draining inefficiencies. We will move from abnormal situation management to abnormal situation prevention.

The increased data transfer needs have gradually favoured the adoption of the currently popular office network technology – *Ethernet-based networks* – into industrial environments. Several organizations (e.g. IAONA (Industrial Automation Networking Alliance)) are promoting the use of Ethernet in industrial automation. In these applications, the fieldbus standards also include Ethernet-based networks, which implement the Ethernet protocol in low layers. The main development area is the real-time requirements of these networks. Currently, the working group IEC (International Electrotechnical Commission) WG11 is refining the RTE requirements. The Ethernet-based industrial networks included in the IEC 61784 standard are: Ethernet/IP,

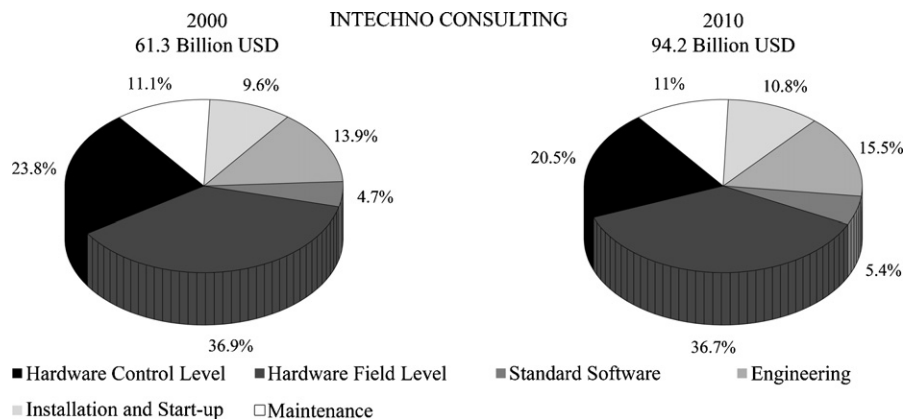


Fig. 3. Development of the world market for process automation up until 2010—segmentation by products and external services (Schroeder, 2003).

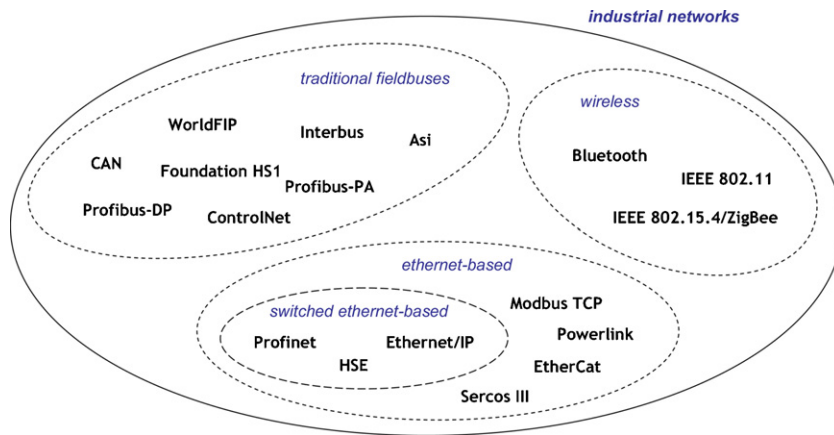


Fig. 4. Classification of the most widely available industrial networks (Georges et al., 2006).

Profinet, Interbus, Vnet/IP, TCnet, EtherCAT, Powerlink, Modbus TCP and Sercos III.

In the same way as for Ethernet, the *wireless* architectures have also started to be adopted for industrial use. At the present time there are no established and widely accepted wireless fieldbusses. However, support for the Wireless Local Area Network (WLAN) using office standardized IEEE 802.11 (IEEE, 1999) is becoming more and more established. Another interesting development area deals with the Wireless Personal Area Network (WPAN) technologies, including Bluetooth network IEEE 802.15.1/BT (Haarsten, 2000) and the network currently under development IEEE 802.15.4/ZigBee (IEEE, 2003).

Wireless communication has a lot to offer in the process industry. The technology has attractive features as it reduces the need for complicated, expensive cabling at large chemical plants. Maintenance personnel on the production floor can remain in contact with the control centre. Isolated instrumentation, for example pump stations located at remote sites in the mountains, can be integrated into the automation strategy. Wireless technology also offers the advantage of flexibility. Ease of use, visualization, parametrization, and diagnostics through remote links are important considerations.

A comparison of the key properties of the currently most widely available networks in each of the three main categories is given in Table 1.

3.1.2. High-layer data specifications

The communication part of an automation device might have to exchange different kinds of data like process measurements, controls, diagnosis, monitoring, historical data, etc. In order to manage these different types of data, the communication stack defines high layers which contribute to the integration of the information sources and to the specification of the product data and safety and security data.

The information standards for process operation and maintenance are driven by OpenO&M Initiative joint working groups, mainly representing three industrial organizations: MIMOSA (for the asset management related information standards), the OPC Foundation (for data transport standards) and ISA's SP95 (for Enterprise-Control System Integration Standards Committee). One of the most strongly established

standards, the OPC, also enables the use of state of the art technologies such as web services, the ability to provide secure data exchange, and the use of encapsulated data with eXtensible Markup Language (XML). On the other hand, the traditional fieldbusses (like Profibus or Foundation Fieldbus) have defined the FDT/DTM concept for manufacturer-independent integration of field devices.

3.2. Integration of production and business operations

Plants in the different process industry fields must be seen as production systems: their elements are the process (material transformation), inbound logistics (material transport), the plant (physical shell), automation (automatic operation) and organization (manual operation, supervision, management). Operation is a collaborative process of this production system. Optimization means the best allocation of functions to these components of the production system. This integrated approach is increasingly being expanded to production networks representing complete value-creating production chains. Suppliers and customers are often included in this approach.

Virtually seamless horizontal and vertical integration of information, communications and automation technology throughout the whole organization is thus needed in order to address the complexity of today's processes. The buzzword in the industry is seamless communications. Manufacturing Execution Systems (MES), which are normally positioned between the Enterprise Resource Planning (ERP) and control system levels, can be used to optimize a business process on the shop floor, improve product quality, increase process reliability and reduce compliance and validation efforts. The well-known production control (MES) systems in the process industries include ABB industrial IT production Planning, Honeywell Experion PKS-Optivision, Metso DNA MES, Tietoenator TIPS and Siemens Simatic IT-Systems. The main modules of the ERP systems are Master Production Schedule, Material Requirements Planning, Logistics and Customer Service Management. The market leader of the ERP systems is the German SAP AG. i2 Technologies, and ASP AG APO systems are correspondingly the most common APS systems on the market for supply chain management. The draft system

Table 1

Comparison of the currently most widely available industrial networks, classified into traditional fieldbusses, real-time Ethernet and wireless network categories

Network type	Main manufacturer	Throughput	Range (length)	Device number	Energy efficiency	Applications
Traditional fieldbus						
CAN	Bosch	10 kb/s–1 Mb/s, 31.25 kb/s, 1 Mb/s, 2.5 Mb/s (5 Mb/s optical fiber)	40 m @ 1 Mb/s, 5 km @ 10 kb/s	Max. 32	–	Automotive and industrial control, embedded systems
WorldFIP (1158-2)	Schneider		(1 km/seg. @ 1 Mb/s, max. 4 km seg.) 100 m @ 12 Mb/s, 1.2 km @ 9.6 kb/s	Max. 256 (64/seg.)	Power over network solution	Factory, distributed real-time
Profibus-DP	Siemens	9.6 kb/s–12 Mb/s		Max. 126	–	Factory automation, general purpose environment
Profibus-PA	Siemens	31.25 kb/s	1900 m (per seg.) 5 km @ 5 Mb/s, 30+ km (fiber) up to 13 km	Max. 32/seg.	Power over network solution	Process control, hazardous environment
Control Net Interbus	Rock well automation Phoenix contact	5 Mb/s 500 kb/s		Max. 99 Max. 512	– –	Factory applications Factory, remote io, manufacturing technology
Asi	Siemens	167 kb/s	100 m/seg, 300 m	Max. 62	Power over network solution power over standard twisted-pair wiring	Sensor bus
Foundation fieldbus H1	Fieldbus foundation	31.25 kb/s	Max. 1900 m	Max. 32		Process
Real-time Ethernet						
Ethernet/IP	Rock well automation	10, 100 Mb/s, 1Gb/s	IEEE 802.3	–	–	Factory applications, manufacturing technology systems
foundations fieldbus						
HSE	Fieldbus foundation	100 Mb/s	100 m/seg.	–	–	Factory
Ether CAT	Beckhoof	100 Mb/s	100 m/seg.	Up to 65,535 devices	–	Decentralized io and motion control
Powerlink	B&R	100 Mb/s	100 m/seg.	–	–	Motion control
ProfiNet	Siemens	100 Mb/s	100 m/seg.	–	–	Factory, distributed automation objects, communication between systems, manufacturing technology
Sercos III	Bosch Rexroth	100 Mb/s	100 m/seg.	Max. 254	–	Fast motion control
Modbus TCP	Schneider	10, 100 Mb/s, 1 Gb/s	IEEE 802.3	–	–	Communication between systems
Wireless						
IEEE 802.11 (a/b/g)	–	11 Mb/s, 54 Mb/s	30–100 m		Power consumption medium	SOHO
Bluetooth, IEEE 802.15.1	–	1 Mb/s	10 m	Up to 7 slaves per piconet	Low	WPAN, cable replacement technology
IEEE 802.15.4/ZigBee	–	20, 40, 250 kb/s	10 m	(Support large network)	Very low	WPAN, for sensors and control devices, wireless sensor network
Ethernet (IEEE 802.3)		10, 100 Mb/s, 1 Gb/s	10/100 base T–100 m/seg. (twisted-pair)	–(Almost unlimited)		

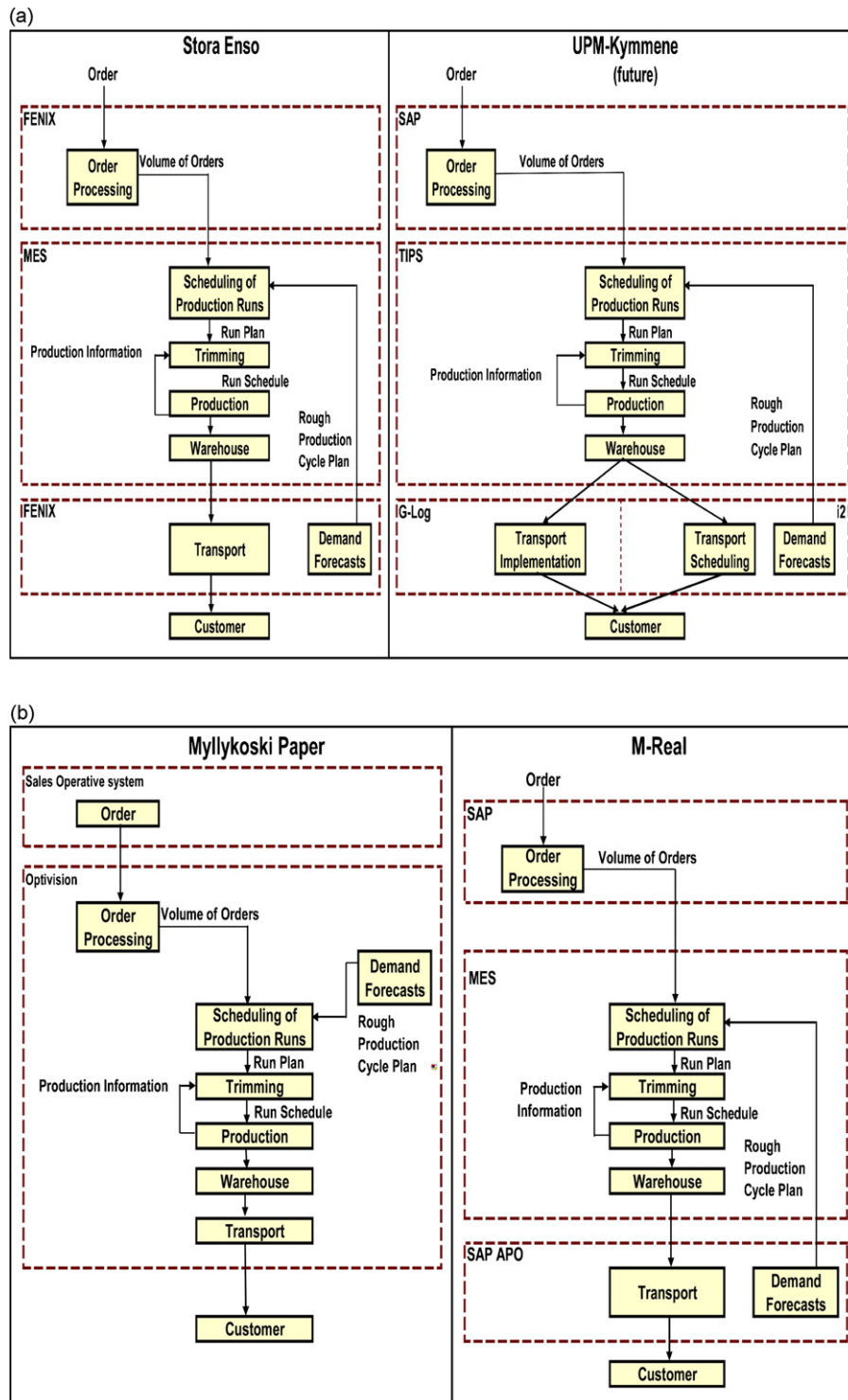


Fig. 5. (a and b) Integrated Production Management Systems in the Finnish Pulp and Paper Industries (Kuukka, 2004).

descriptions used in the different Finnish pulp and paper companies are presented in Fig. 5a and b as an example of the development trends in one process industry sector. Plant optimization, accompanied by increased integration of automation systems with the information systems of the production site and the enterprise level, is justifiable also expected to be the main objective of the process automation in these enterprises in the near future (Kuukka, 2004).

4. Recent accomplishments and future application trends in process automation

4.1. Process control and MPC

Model predictive control has become a standard multi-variable control solution in the continuous process industry, and now covers over 90% of industrial implementations of

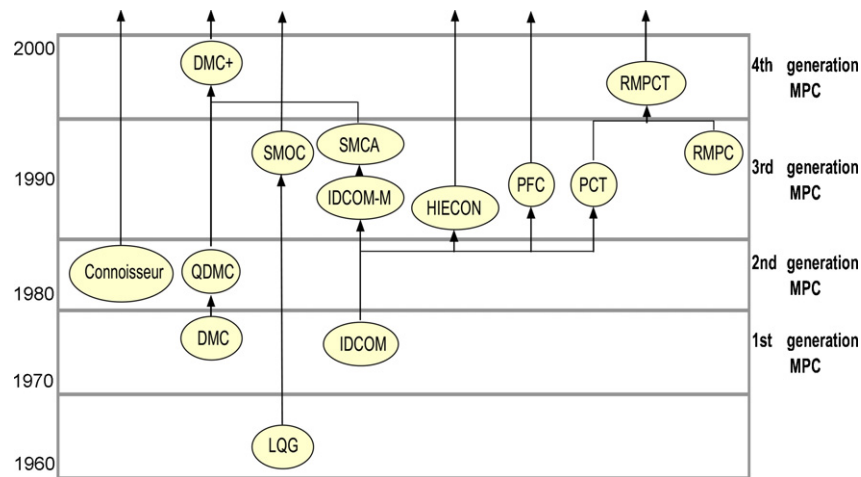


Fig. 6. Approximate genealogy of linear MPC algorithms (Qin and Badgwell, 2006).

multivariable control (Richalet, Rault, Testud, & Papon, 1976, 1978). One reason for its success is its ability to handle multivariable systems subject to input and output constraints (Dochain, Marquardt, Won, Malik, & Kinnaert, 2006).

A brief history of the MPC technology development is presented in Fig. 6 as an evolutionary tree for the most significant industrial MPC algorithms (Qin & Badgwell, 2006). The first description of MPC control application was presented by Richalet et al. (1976, 1978), and the developed software was called IDCOM. The dynamic matrix control (DMC) algorithm also represented the first generation of MPC technology and was developed by Shell Oil engineers.

A successful industrial controller for the process industries must maintain the system as close as possible to the constraints. The second generation MPC algorithm, like QDMC, provided a systematic way to implement these input and output constraints, but there was no clear way to handle infeasible solutions. The third generation MPC algorithms distinguished between several levels of constraints (hard, soft, ranked), provided a mechanism to recover from an infeasible solution, addressed the issues resulting from a control structure that changes in real-time, provided a richer set of feedback options, and allowed for a wider range of process dynamics (stable, integrating and unstable) and controller specifications. The increased competition and mergers of several MPC vendors have led to the two main fourth generation MPC products: RMPCT offered by Honeywell, and DMC-plus offered by Aspen Technology with features such as multiple optimization levels to address prioritized control objectives, additional flexibility in the steady-state target optimization including QP and economic objectives, direct consideration of model uncertainty (robust control design), and improved identification technology based on prediction error methods and sub-space methods.

Thousands of MPC applications have been reported in a wide variety of application areas. Most of them have been in refining, but a significant number of applications can also be found in the petrochemical and chemical sectors. Significant growth areas include the pulp and paper (Marcangöz and Doyle, 2006) and food processing industries. The first multivariable MPC technology to cover the entire papermaking

line has recently been published (Anon, 2007). The largest number of nonlinear MPC applications encompass chemicals, polymers and air and gas processing. The size and scope of NMPC applications are typically much smaller than those of linear MPC applications.

Major developments in the process control community in general aiming at contributions to systems and control theory are expected, e.g. in nonlinear optimal control, combined state and parameter estimation for nonlinear systems, robustness analysis and robust synthesis methods for nonlinear systems, spatial decomposition, decentralization and horizontal coordination of large-scale nonlinear network-like processes and hybrid discrete-continuous control theory emphasizing systems with equally complex discrete as well as continuous parts. For the latest review on future trends in process control see Dochain et al. (2006).

4.2. Applications of AI methods

Most of the applications of the AI methods in the process industries have been designed for unit processes in the beginning of the production chain, especially in pulping, mineral and metal processing. A typical feature of these processes is the difficulties involved in constructing detailed mechanistic models. Increasing international competition is forcing the process industry to be more efficient and to emphasize the importance of the high quality of the end product. The most successful AI applications can be found in the area of quality control of the end products, where a small improvement in control can give a considerable competitive edge to the enterprise compared to its competitors.

The importance of artificial intelligence techniques in real-time process control is emphasized in many of the published articles, and the MM processes especially are reported to benefit from the application of AI techniques (Jämsä-Jounela, 2001).

4.3. Process monitoring and fault diagnosis

Monitoring the quality of the product online and predicting/preventing process disturbances are the key issues in producing

higher quality products, optimizing the production chain, and thereby improving the efficiency. Operational safety of processes is of importance and therefore should be the first objective of process control. Problems caused by operational faults range from increased operational costs to forced shutdown of processes. The increased complexity and the degree of integration of modern chemical plants means that the potential economic loss is greater and the diagnosis of fault locations more difficult. It is estimated that inadequate management of abnormal process situations causes annual losses of US\$ 20 billion in the petrochemical industry in the USA. Consequently, managing disturbances is seen as the next challenge in developing and implementing new control systems.

Venkatasubramanian, Rengaswamy, Yin, and Kavuri (2003) and Venkatasubramanian, Rengaswamy, Kavuri, and Yin (2003) published a review of monitoring methods, especially those applied in the field of chemical processes. They classified the methods according to the form of process knowledge used. One category is based on process models, and includes both qualitative causal models and quantitative methods. The other category is based on process history, and includes both qualitative (e.g. rule-based) and quantitative methods (neural networks and multivariate statistical methods). A large number of successful applications have been reviewed, e.g. by Komulainen, Sourander, and Jämsä-Jounela (2004).

4.4. The new extended role of operators and operator-support systems

In recent years the process industry has explicitly developed and implemented new automation and information technologies in order to remain competitive. This has led to a situation where massive amounts of measurement data are now available. At the same time, the technology has advanced and the number of operators at plants has decreased, thus making their work more demanding with more responsibilities. New challenges in the operator's work are the management of critical situations and decision making in a range of problem situations. In critical situations, the decisions must be made quickly and therefore all the relevant information must be readily and easily accessible.

A study to analyse the features and use of the operator's support systems at two Finnish paper mills has recently been carried out (Pikkusaari-Saikkonen, 2004). Automation systems at the plant include a variety of solutions provided by different vendors and which had been in use for very different periods of time. The production lines have the following process control and information management systems: process control, machine control, quality control, web inspection, process analysis, production planning, and condition and runnability monitoring systems. One hundred operators were interviewed. The most critical and most widely used systems were process control, quality control and monitoring, as well as production planning systems. According to the study, only 30–40% of the existing operator-support systems currently installed at production sites were actually used due to the usability problems and operators' poor knowledge of the systems. The

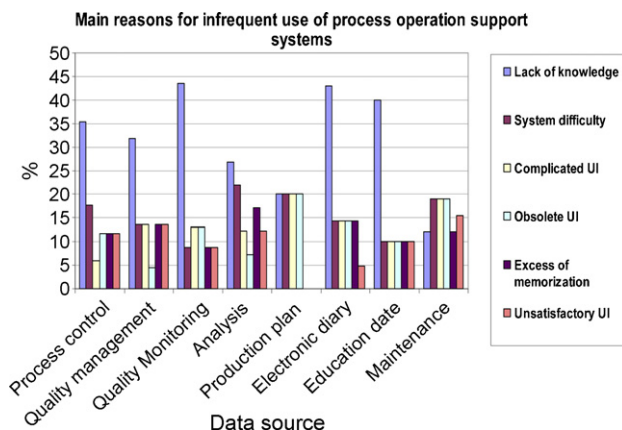


Fig. 7. Use of operation support systems (Pikkusaari-Saikkonen, 2004).

main reasons for infrequent use of process operation support systems are presented in Fig. 7.

Most of the information affecting the decision-making process during the critical situations is so called tacit knowledge. Ensuring that this tacit knowledge is retained as large groups of older operators retire, especially in Europe, will be an additional challenge for the process industry. In the future, the efficient management of knowledge supporting the decision making will thus become more and more important. One clear trend in the development of process control systems is to include features for knowledge and information management. The knowledge and performance support systems will be integrated as a part of process control systems, making it an optimal solution to support operations in the whole production line, as reported by Laukkanen (2005).

The study of interactions between human and machines is an important aspect in the adoption of control technologies, and involves both technical issues and social implications. Human machine studies consider all the conditions where humans use, control or supervise tools, machines or technological systems. It fosters analysis, design, modeling and evaluation of human machine systems (HMS), which include decision-making and cognitive processes, modeling of human performance, real and virtual environments, design methodology, task allocation-sharing and job design, intelligent interfaces, human operator support, work organization, and selection and training criteria. Over the last few decades there has been a shift from the more hardware oriented HMS topics to the more software and system oriented topics (Ollero et al., 2006).

Information is a very powerful asset that can provide significant benefits and a competitive advantage to any organization, including complex production technologies. In the case of complex processes the design of an integrated information system is extremely important. There is also a clear trend to use the so-called data warehousing methods by which the data can be used for query, reporting and data analysis to extract relevant information about the current state of the production, and to support the decision-making processes related to the control and optimization of the operating technology. The focus is on the material and information flow through the whole enterprise, where the OSS follows the

process through the organization instead of focusing on separate tasks of the isolated process units. The main function of the information integration methods cannot only be data analysis and mining but also the support of the human–system interaction (Pach, Feil, Nemeth, Arva, & Abonyi, 2006).

5. Conclusions

The importance of automation technology continues to increase in the process industry. The barriers between information, communication and automation technology are, in the operational context, gradually disappearing. The latest technologies, which include wireless networks, fieldbus systems and asset management systems, are boosting the efficiency of process systems.

In large plants in the bulk industries, the main emphasis in the future will be on the optimization of the assets. This optimization includes the initial capital, the operation of the plant and the distribution of the products. Process control will clearly have a key role to play in this. In order to seek agility, the industry is moving towards various types of intermediate manufacture. The plants are smaller and tend to be closer to the customer. The key drivers to this are customization of size, quality, service and effect. The aim is agile plants which have the economics of a large single stream plant and the flexibility of a batch plant which, within limits, is able to make almost any product required. The dependence on process control will increase.

Design of very large distributed systems has presented a new challenge to control theory. A key issue in control engineering is the application to highly complex systems: the coupling of complicated and large heterogeneous systems in which different disciplines are involved and different types of information are available or have to be uncovered. New modeling methods are reported to be required which should provide a framework in which a priori knowledge of the process can be combined with existing modeling techniques. Controller design methods should be prepared to use such models as well. Control over the networks systems involving an extremely large number of interacting control loops, coordinating large number of autonomous agents, and handling very large model uncertainties, will be in the center of future research (Bars et al., 2006).

Challenges for future theoretical work are modeling, analysis and design of control systems in new application fields like biotechnology and microtechnology.

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