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MILESTONE REPORT OF THE MANUFACTURING AND INSTRUMENTATION COORDINATING COMMITTEE: FROM MEMS TO ENTERPRISE SYSTEMS

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Abstract: This paper presents problems and issues that are within the broad scope of the IFAC Manufacturing and Instrumentation Coordinating Committee. These issues include from the technologies involved in the components to the methods used in enterprise integration. Information processing and communications are considered as key topics in all the involved technological fields. Also, the paper deals with particular issues of components, mechatronics, robotics, advanced manufacturing technology, manufacturing modelling for management and control, and enterprise integration. Finally, conclusions related to important aspects, promising applications, key control concepts, future challenges and new areas are summarized.

Keywords: components and instruments, mechatronic systems, robotics, low cost automation, manufacturing technology, manufacturing modelling for management and control, enterprise integration.

1. INTRODUCTION

The Manufacturing and Instrumentation IFAC Coordinating Committee has a very broad scope ranging from the technologies involved in the micro electro-mechanical components (MEMS) to enterprise integration and management issues.

The technological base of modern process control and automation systems consists of components and instruments used to sense, measure, communicate, compute and actuate. These components could be part of the hardware and machines. Mechatronics is also part of this technological base.

Robotics uses new components and mechatronics concepts to develop autonomous systems. The technologies involved in components and mechatronics are key elements. Thus, for example, the perception functions should be based on sensors to perceive the robot environment, including optical sensors, tactile sensors, odor sensors, smell and others.

Furthermore, sensor data fusion is a fundamental issue for the reliable perception.

On the other hand, the decreasing cost of smart components, as well as new computer hardware and software technologies, are producing significant changes in automation and particularly in manufacturing automation. In addition, cost is the critical issue in the design and development of new components and mechatronics systems used in the consumer products, automotive and other numerous applications. Moreover, low cost is also critical for the applications of robotics and autonomous systems in many sectors such as service robots, agriculture and others.

In addition to the technologies involved in the above-mentioned paragraphs, manufacturing requires ever more information-intensive technologies to meet the so-called agile automation within the networked manufacturing enterprise. Thus, for example, new manufacturing automation architectures and systems engineering frameworks are important issues in the today's Manufacturing Technology.

The above-mentioned technologies provided the basis of modern manufacturing processes allowing for distributed manufacturing enterprises and operations, as well as e-Work and e-manufacturing.

New modeling techniques to cope with dynamic behaviors and interactions are important manufacturing topics. Furthermore technologies are required to achieve properties such as reconfigurability and quick response.

The upper level of manufacturing is an Enterprise Integration. At this level, enterprise models are a key issue. The manufacturing process provides constraints to this level and, on the other hand, this level provides specifications required in the manufacturing process.

The application of control theory and related concepts across all of the above mentioned areas is a challenging topic. In fact many applications involve processes where no models are available, or where experiments, to obtain the required data for model identification, are very difficult to be carried out. Subsequently, only approximate models can be obtained and the control and decision strategies are valid only for some particular conditions. Education and training of control and automation specialists should balance theoretical approaches and practical issues concerning the analysis and implementation of control and decision systems, as well as the integration in the manufacturing processes and the cost issues.

The current information processing capabilities now offer the possibility to solve complex design problems and to implement complex control laws in real time. Furthermore, communication technologies offer additional possibilities to get measurements and information in general, and lead to distributed intelligence. The next section will consider the impact of information processing and communication technologies in Manufacturing and Instrumentation. These technologies are also important topics in the education and training of control and automation issues. Also particular issues concerning the domains of the different Technical Committees (TCs) of the Manufacturing and Instrumentation Coordinating Committee are presented. These Committees are the following: Components and Instruments (MIC), Mechatronic Systems (MIS), Robotics (MIR), Low Cost Automation (MIL), Advanced Manufacturing Technology (MIT), Manufacturing Modelling for Management and Control (MIM), and Enterprise Integration (MIA). Finally, conclusions and references are presented.

2. INFORMATION PROCESSING AND COMMUNICATIONS IN MANUFACTURING AND INSTRUMENTATION

Two common key issues in all the TCs can be mentioned: information processing and communications. The following subsections will be devoted to discuss these issues.

2.1 Information processing.

Table 1 shows some keywords related to information processing in the domains of the Technical Committees.

Table 1 Information processing in the TCs.

MIA	Unified Enterprise Modeling Language, Virtual Enterprises.
MIM	Simulation, Optimization, Knowledge based Systems, Agent Networks and Protocols
MIT	Manufacturing automation, from Flexible and Integrated Manufacturing Systems (FMS / CIMS) to Distributed and Intelligent Manufacturing Systems (DMS / IMS)
MIR	Perception, Autonomous Systems, Sensor Fusion, Virtual Reality.
MIS	Information-driven functions, Software tools, Simulation, Embedded processing.
MIC	Intelligent Components and Instruments.
MIL	Local information processing, Multi-Agents supporting Decision Making at the Shop Floor

The components of an automation/control system, like sensors, actuators and the controller itself, should incorporate the advances of information technology. Thus, local information processing allows for integration at the level of components reducing the total cost and providing new features in the control lines (smart sensors and actuators).

Information-driven functions, simulation programs of integrated mechanical and electronic systems and software tools are key elements in mechatronics designs.

Autonomous robotics is based on the progress in artificial perception, learning, adaptation, and other issues related to artificial intelligence such as intelligent control technologies, and distributed intelligence.

The development of cost effective automation is based on the decreasing cost of computer hardware, software and on life cycle considerations.

Computer Integrated Manufacturing is a mature paradigm in today's manufacturing processes, and flexible manufacturing systems still require significant information processing capabilities. The development of information processing as well as storage capabilities allowed new manufacturing automation architectures based on paradigms coming from the Artificial Intelligence (AI) and the Intelligent Manufacturing Systems (IMS) communities.

Information and decision integration using modern information processing technologies is also a key element in the modern manufacturing processes. Thus, for example, the Knowledge Based Systems and parallel/distributed computing are important technologies in the MIM. Information processing technologies are also very important to implement simulation and optimization of the whole manufacturing process.

Finally, computer models of enterprises, CASE tools and modeling languages are today key concepts in Enterprise Integration.

2.2 Communications.

Table 2 shows the keywords related to the application of new communication technologies across the different areas.

In the Components and Instruments area, field buses for connecting field equipment and control devices play an important role. Moreover, distributed architectures in general are being used to connect intelligent components and instruments. On the other hand, current telecommunications technologies are key elements in many applications such as in the automotive domain where GPS systems are being introduced and where telemetry techniques are being used for vehicle safety. Telemetry and wireless connections are also used in other applications such as environment monitoring.

The development of communication technologies has also an important impact in Robotics, supporting telerobotics and teleoperation for many applications, particularly in field robotics and space applications. Telemetry is also very important for obstacle detection and map building. Similarly, the control of multirobot systems is based on the implementation of suitable connections links, particularly wireless connections.

Wireless connections and the Internet also play an important role in Low Cost Automation. Technologies based on wireless such as Bluetooth are enabling new low cost automation applications in many different areas, including intelligent building and domotics. In addition, the internet enables new low cost solutions to the plant shop floor distributed control, and, in general, to distributed control systems without strict real-time or reliability requirements.

Communication technologies play an ever more prominent role and the manufacturing plant becomes a place where interoperable and autonomous units embedding a digital intelligence transform information flows into products flows (Van Brussels et al, 1999) in order to integrate all the aspects of the manufacturing chain processes over the whole product life cycle and across the entire enterprise (quality, maintenance, technical management, process planning).

As far as the full manufacturing process is concerned (MIM) a fundamental issue is the change from manufacturing to e-Manufacturing. In this change, communication is a key element. The increasing of the e-Work and the integration between manufacturing enterprises and operations are also based on the implementation of communication technologies.

Finally, it should be also mentioned that at the Enterprise level (MIA) the networking of companies and the e-Business greatly depends on the communication technologies.

Table 2 Communications in the TCs areas.

MIA	Network of companies, e-Business.
MIM	Distributed Manufacturing Enterprises and Networked Operations
MIT	Manufacturing chain integration, distributed digital intelligence.
MIR	Telerobotics, teleoperation, teleguidance, telemetry, multirobot systems.
MIS	Wireless and wired connections of mechatronic components.
MIC	Fieldbuses, distributed architectures, GPS, telemetry.
MIL	Teleoperation and diagnostic using Internet at the shop floor; Wireless connections of sensors, actuators and controllers

3. CONTEMPLATIVE STANCE

In the following, summaries of the contemplative stance of the field of each TC are provided.

3.1 Components and Instruments.

3.1.1 Intelligent Components and Instruments in Process Control.

Complex control architectures include many interconnected components. Only distributed systems with intelligent instruments can cope with such a level of complexity. Intelligent instruments should implement communication, control, fault detection and fault tolerance capabilities. They should be able to inter-operate, thus allowing the user to build control architectures with instruments provided by different suppliers.

Typical applications are in the field of large scale and distributed control systems: power plants, discrete event or continuous production processes (manufacturing, chemical/petrochemical, biotechnology, etc.). Thus, for example, solutions have to be developed:

- For the design of validated distributed architectures, including the modeling of intelligent instruments and their interconnections and co-operation, and the proof of correctness of the overall architecture especially to prove that the system does not enter dangerous states when faults occur, etc.

- For the individual optimal operation of sensors and actuators, including reliable estimations, data validation, cross-checking, fault detection and isolation, fault accommodation, reconfiguration in the case of faults, etc.

- At least for the simple and reliable connection of intelligent instruments: field bus protocols (see next section), real time operation, error handling, time constraints handling, etc.

Also there are specific needs in Microsystems Technology (MST) and their applications in several fields including medicine and surgery.

3.1.2 Field buses.

Different companies or consortia have developed Field buses for more than 15 years. Field buses are special purpose networks that are basically used in real time application for connecting field equipment and control devices. They take more and more a major place in automation systems, embedded systems and building automation (Green 1998; Neumann, 1999). The concept of field buses itself is very complex because of the number of different applications, devices, characteristics and tuning properties. It has been impossible to find a consensus at the international standardization level because of the very important economical impact of the distributed automation systems architectures (Fantoni, 1999; Piggin et al., 1999). At the end of the year 2000, a so-called «standard» has been voted in (IEC 61158) by the IEC TC65, which is not a standard. It is composed of eight field bus specifications. Some of them propose more than 4 profiles without taking the physical layer variants into account.

One of the current problems is related to the evaluation of such profiles, taking the traffic characteristics into account in order to be able to characterize the quality of service of these field buses and to help the end users, when a choice has to be done. Another problem is related to the definition of software in order to help the end users and the engineering companies at all the stages of the development. It includes design, configuration, programming, test and commissioning stages. With the development of Internet technologies, several companies are trying to provide products and systems at the field level that could be compatible with Internet. It is then important to prove that the timeliness is always met with such solutions, or to be able to distinguish, formally, the real time functions from the others (Thomesse 1997).

The main challenges for researchers in the Field Buses area within the next years will be: to prove the application-required quality of service and the interoperability of devices in a system. More generally, to achieve these goals, there is an important need for new models and for new modeling techniques for qualitative and quantitative properties. Due to the combinatorial explosion, the techniques based on transition-state machines models (with all variants) are now much too limited to deal with these problems. Thus new techniques must be explored and developed.

3.1.3 Components and Instruments in the transportation/automotive application field.

A significant domain in which Components and Instruments will play an important role is the Transportation/Automotive field. This subsection summarizes some significant issues related to this field that will illustrate the general concerns mentioned above.

Improvement of a car occupant safety, comfort and mobility are the main research domains for the automotive industry by the end of this century (Little, 1997). New, very sophisticated functions called ADAS (Advanced Driver Assistance Systems) will be installed in our vehicles within the next 10 years. These functions could for example improve the environmental perception of the driver, sometimes, in critical situations they could take decisions instead of him (collision avoidance, . . .) but also perform totally new automatic operations directly related with safety for example (airbag firing, . . .). The development of these new functions is concerned with the introduction in the automobile application field of new sensor and actuator concepts. These “intelligent” sensors will be able to provide synthetic information to the decision algorithms or directly to the driver. It implies the adjunction to the “basic sensing device” of upper signal processing levels, which allow extracting the pertinent information from a set of measurements, to fuse the information provided by several sensors, to classify them, etc.

Two main research directions can be identified: The first one is related to the perception of the vehicle environment. Many developments have already been performed in that direction: the most important and moreorless close to mass production are concerned with navigation devices, vehicle longitudinal control (ACC, stop and go), vehicle lateral control (lane keeping, . . .), vision enhancement. They are mainly based on the development of GPS, RADAR, LIDAR, video and IR sensing devices (Matthies, 1994). (see Figure 2 and 3).

The other research direction is more recent and concerns the perception inside the vehicle. Two important topics are emerging: The driver monitoring to detect and predict driver's vigilance degradation and next to warn him about critical situations, but also new trends in the direction of driver's health status monitoring (Grace, 1999; Wierville, 1994); and the passenger occupant detection.

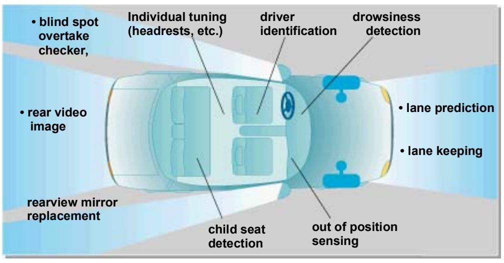

Fig. 1. Radar applications.

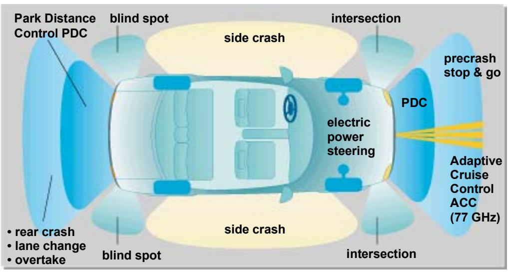

Fig. 2. Video applications.

3.1.4 MEMS and MST in the Transportation/Automotive application field.

Since the 70s MAP (Manifold Absolute Pressure Sensor) have played an increasing role in automotive applications (Grace 2001;Schmidt 2001). In the future, automotive applications are expected to become a significant part of the MEMS/MST market. Supported by their low cost, reliability and size, an important migration from electromechanical technologies to MEMS/MST has begun some years ago.

MEMS/MST application opportunities in automotive are influenced by safety considerations (for example airbag actuation: accelerometer, pressure sensor; seat occupancy: presence and force sensors, displacement sensors); by comfort and convenience applications (for example climate control: mass air flow, temperature, humidity, air quality sensors; Navigation: yaw rate gyro, wheel rotation, etc) as well as drive train applications (for example fuel injection with pressure and nozzle sensors) and diagnostic/monitoring applications (for example tire pressure sensors).

3.2 Mechatronics.

For many years control engineers have been using sensors and electronic processing to enhance and/or alter the performance of mechanical systems, and in some cases to provide functionality, which is not possible without the electronics. However the sophistication which has become possible through increasingly powerful processing devices and heightened software skills has created the opportunity for a new range of products and processes, and the discipline of Mechatronics was identified around 15-20 years ago to give emphasis to the opportunities provided and the skills required. It provides a core idea with which like-minded engineers and researchers can associate themselves.

A synergetic combination of mechanics, electronics, software and computing requires that its exponents must individually have a multi-disciplinary understanding of the relevant scientific and engineering principles. (This can be contrasted with the more general area of systems engineering for big systems, in which the necessary skills are brought together by a highly-organized team approach.) This individual knowledge must be sufficiently comprehensive to be able to create the innovative combination, which makes up a mechatronic solution.

Mechatronics has started to make important contributions across a range of products and processes, examples being in the area of automotive and aircraft engine control where the traditional mechanical controls have almost entirely been replaced by electronics, also in chassis control for cars where electronic controls are starting to play an important role in stability and handling. Other more general applications are robotics, micro-machined electro-mechanical systems (MEMS), smart structures, etc

To support this there must be appropriate design methods and tools supported by computer design facilities. The individual software tools for mechanical, electronic and software are all available, and there has been considerable progress in bringing these together to provide a coherent simulation environment by which the performance of a given mechatronic system can be assessed. The actual creation of the system structure has been largely a human-dominated process that relies upon the insight and ingenuity of the engineer, and a key development is to consolidate the accuracy and ease of use of simulation tools for mechatronic systems. However this needs to go further, because currently the availability of design methods that enable optimized combinations of mechanics, electronics and software to be formulated for a particular is much more limited. A general theory and/or methodology for handling this synthesis problem for complex multi-disciplinary systems to meet multiple objectives and constraints are needed to maximize the impact of mechatronics.

Another essential area, especially for safety-related applications, is in the area of fault diagnosis and tolerance. Generally the integrity of mechanically based products and processes can be assured by careful design of critical components, supported by targeted maintenance regimes, which as far as possible avoid dangerous failures. However failure modes for sensors, electronics and software are much more diverse and integrity now has to be provided through functional and analytical redundancy. A good theoretical basis for fault detection, isolation and reconfiguration (FDIR) is now available, but the FDIR sub-system becomes part of the mechatronic system design process, not only in terms of performance and first cost, but also related to reliability and whole-life cost. Therefore, important developments are expected to bring established FDIR techniques into application-specific frameworks.

It is almost inevitable that there will be a progressive development of products and processes, which have for many years been principally mechanical in nature towards mechatronic solutions. The potential is enormous, because developments in sensing, computing and electronics technologies, which result in increasing cost-effectiveness inherently, favor such solutions in the long term.

3.3 Robotics.

Robotics was developing rapidly in late sixties, seventies and eighties. In nineties it reached a certain maturity level that allowed this field to develop fast but in more organized manner.

At the beginning of its rapid ascent (1968-1990) development in the field of robotics was driven mostly by the demand created in manufacturing industry. Manufacturing industry at that time was undergoing major changes from NC machine based production to the so-called "intelligent manufacturing". In later stage of development robotics was driven by service industry and special applications as space or medical robotics.

Robotics is a field dealing with the extension of human capabilities and abilities to perform certain tasks. Robotics is an interdisciplinary field and is addressing problems related to automation of industrial processes, service industry, special applications, transportation and human like robots. The typical robot used in automation of assembly or more general production is a manipulator, in service industry-mobile robots or humanoids. Special applications involves on one hand use of robots in hostile environment like space, handling radioactive materials and, on the other hand teleoperation, microrobotics and use of medical robots for surgery. In transportation robots are used in form of autonomous, unmanned vehicles. A good example is an Unmanned Aerial Vehicle (UAV) or cars without drivers.

The broadly accepted definition is that robotics is an intelligent connection of perception to action. Robots have to sense their own surroundings and react according to the changing environment. The methodology used in robotics is focused on intelligent methods, autonomous systems and real-time algorithms. The development of robotics goes hand in hand with the development of computer systems, especially microprocessors. The recent major accomplishments in the area of robotics are related to the exploration of space Sasiadek, 1994) in particular in designing, preparing and executing the unmanned robotic exploration missions in form of autonomous vehicle/spacecraft, as well as, design and implementation of the Space Station Remote Manipulator System (SSRMS) on the Alpha Space Station. Other major accomplishments are UAVs, telerobotics, humanoids and microrobots.

The future trends in robotics will be certainly focused on development of more intelligent, more autonomous and versatile robots that will extent human capabilities. In particular the following fields are attracting much attention, efforts and funding:

- development of UAV and autonomous driverless car/vehicle;
- telerobotics and teleoperation including haptic and virtual devices;
- development of micro and nano-robots;
- humanoids;
- sensor fusion and environment perception;

The expected future applications are the following:

- non-invasive surgery, often teleoperated where robots are introduced through the vein or blood system;
- an artificial, intelligent, humanoid servant/soldier;
- pilotless civil transportation aircraft;
- autonomous robotic car/vehicle;
- unmanned, teleoperated mining;
- artificial "perceptor" with integration (fusion) of vision, smell, tactile, etc. receptors;

In order to realize these trends the major progress in fuzzy logic, neural networks and genetic algorithms is expected. The major constraint in future robots' development is the computing power for real-time control.

3.4 Low Cost Automation.

Beginning with the 1st IFAC Symposium on Low Cost Automation in Valencia, 1986, it was the intention to bridge the gap between control theory and control engineering practice by the development of applications using low cost techniques. This did not mean basic or poor performance control but intelligent solutions considering the complete life cycle of an automation/control system with respect to cost: cost oriented automation.

As was pointed out by Ortega (1992) at the 3th IFAC Symposium on Low Cost Automation in Vienna, the transfer of knowledge between the academic community and the industrial user is far from satisfactory, and this is particular the case regarding the small and medium sized industry. On the other hand, developments in control theory are based on principles, which can appeal to concepts the practical engineer is familiar with. Albertos (1998) at the 5th IFAC Symposium LCA in Shenyang stated that LCA deals with control solutions for simple processes, a wide application spectrum and a reduced risk operation (from a process viewpoint), basic control techniques, reduced number of tunable parameters, interpretability of requirements (from a control design viewpoint) and easy operation and maintenance, modular solutions, portable controller, multipurpose, flexible and easy to upgrade (from an implementation viewpoint). The components of an automation/control system, like sensors, actuators and the controller itself, should incorporate the advances of information technology. Local information processing allows for integration at the level of components reducing the total cost and providing new features in the control lines (smart sensors and actuators).

The cost of wireless links will fall while the cost of wire-line connections will remain about constant, making wireless a logical choice for communication links. However, wireless links won't be applicable in all situations, notably those cases where high reliability and low latencies are required.

The implication for factory automation systems is that processing and storage will become cheap: every sensor, actuator, and network node can be economically provided with unlimited processing power. If processing and storage systems become inexpensive relative to wiring costs, then the trend will be to locate processing power near where it's needed in order to reduce wiring costs. The trend will be to apply more processing and storage systems when and where they will reduce the cost of interconnections. The cost of radio and networking technology has fallen to the point where a wireless connection is already less expensive than many wired connections. New technology promises to further reduce the cost of wireless connections, in particular Bluetooth.

Recent accomplishments in the above-mentioned sense are:

- Low cost numerical controls for machine tools and manufacturing systems (so called job-shop controls).
- Programmable Logic Controller (PLC) shifting from PLCs to general purpose Personal Computers. PCs can easily perform many of the functions originally built into a PLC.
- Life Cycle Assessment of Automation/Control Systems: design, production, implementation, maintenance, qualifying operators (human skill), refitting, recycling/disassembling with respect to costs.

Low Cost Automation is also related to:

- Organizational change and implemented information technology in Small and Medium Sized Enterprises for cost effective use of automation/control systems;
- Total Productive Maintenance with Tele-diagnostic via Internet to reduce costs for specialists;
- The internet protocol can be used for networking of controls, sensors and actuators;
- Shop floor control and maintenance with decision support based on automatic generated proposals by multi agents.

3.5 Advanced manufacturing technologies

Up to now, Integration in Manufacturing has been the main paradigm for companies to meet their objectives such as productivity and flexibility by means of highly automated and computerized manufacturing systems. CIME (Computer Integrated Manufacturing and Engineering) illustrates this technically oriented production development strategy, integrating around common information system (data communication, storage and processing) CAD/CAM technologies (Computer Aided Design / Computer Aided Manufacturing), production planning and control, and process automation. This strategy has led companies to integrate their business processes and their manufacturing processes across the entire Enterprise. Information technologies, such as ERP (Enterprise Resource Planning) and MES (Manufacturing Execution System), are now available to meet more or less this fully computerized and automated integration.

Beyond this integration, communication technologies now allow to digitally integrate the entire manufacturing chain, from design through manufacturing, through supply management, to maintenance and service. This applies over the whole product life cycle, from the idea of a product to its final end use and disposal. The next generation of manufacturing systems will have to support all facets of this globally distributed "extended/virtual enterprise" as addressed by various paradigms such as Agile Manufacturing Systems (USA) and the Fractal Production System (EU). The key challenge is to distribute the digital intelligence down to the field factory level in order to enable flexible and autonomous operation of distributed units to transform information flows into product flows (see Fig. 4).

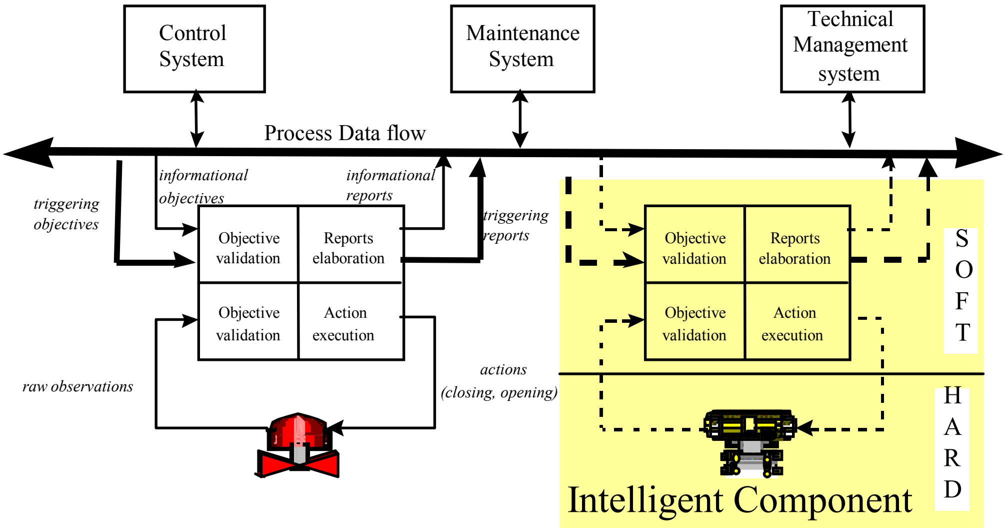

Fig. 3. Integrated-Distributed shop-floor CMMS/IAMS architecture based on interoperable field components (Iung et al., 2001).

Information plays an ever more prominent role, not only in the process of controlling (discrete-time, discrete-event control) manufacturing systems, with a different degree of intelligence, but also in the process of integrating all the aspects of the manufacturing chain processes over the whole product life cycle and across the entire enterprise (quality, maintenance, technical management, process planning, ...).

The main consequence of the above mentioned paradigm shift is to put into question the traditional hierarchical control approach in favor of more appropriate hierarchical (partial behavioral hierarchy) control architectures.

In this way, two promising technologies have generated a considerable amount of attention in the IMS community: Multi-Agents Systems coming from the Distributed Artificial Intelligence community as a software technology and Holonic Manufacturing Systems coming directly from the IMS community as a manufacturing technology. Rather than fixed control architectures, new control architectures emerge that are able metamorphically to meet the dynamic requirements of agile manufacturing.

Many unresolved issues remain: how to choose the appropriate control structure (alternative solutions), when to relax hierarchy for cooperation and vice versa (according to operation modes, or environmental constraints), how to guarantee the basic control behavior properties (determinism, synchronous versus asynchronous, ...), what kind of software and hardware technologies to select for industrial implementations (to replace PLC, field technologies, ...), etc.

The key challenge for research and developments in manufacturing automation engineering is then to move from isolated problem solving approach to cooperative reasoning approach able to cope with the global complexity of agile manufacturing systems. As opposed to the area of intelligent control where there exists a large amount of theoretical research, the field of advanced automation requires a substantial effort to develop formal techniques to deal with the complexity of the problem.

To cope with this role of anticipation in intelligent manufacturing systems, new innovative mathematical tools, such as those used in anticipatory systems computing, could be necessary for designing, modeling, simulating, optimizing and controlling systems, taking into account their anticipatory states rather than only their present and past states.

A major role in applying more technical intelligence in manufacturing will be played by mechatronics technology, including micro-technologies.

The technological aspects being well addressed by the IMS program, intelligent automation becomes the main scientific challenge. IFAC, through TC MIT, should play a major role in developing theoretical foundations in this field. Since the challenge concerns both information and control technologies, a joint IFAC-IFIP task force should be set up.

3.6 Manufacturing modeling, management and control.

One of the most important aspects of MIM technology/techniques is to enable the collaboration in distributed manufacturing enterprises and operations, including reconfigurability, quick response, connectivity, effective interface integration, and e-Work (Groumpos et al, 2000). Furthermore, modeling with process view of behavior and interactions is needed for all levels of manufacturing, from the highest to the lowest level (Villa and Bradimarte, 1999; Banaszak et al, 2000).
Promising applications are: Production networks, collaborative manufacturing, information and

decision integration; Applications in small and medium companies, supply chains, and in e-Business; Improving the choice, implementation, and performance of enterprise software and decision support systems.

The key control concepts in production, supply chain, service and manufacturing business remain the theory of constraints and optimization of time to market, value added, cost, customer satisfaction, and competitive advantage.

The key challenges for MIM technologies/techniques are: Change in objectives, scope, tools, and operational scenarios; Ability to demonstrate applicability; Ability to develop/revise/adapt solutions that are readily and reliably useable in operational environments, with appropriate response time; Implementation throughout the manufacturing cycle; Implementation in legacy automated systems; Fundamental change in manufacturing to e-Manufacturing.

New areas are: Multidisciplinary integration of management and manufacturing contradictions; Developing new enabling technologies for robust collaboration, such as e-Work (Nof, 2000) based enterprises; Network-based enterprise modeling, coordination, and management for supply chains (Li et al, 2000); Modeling autonomous behaviors of manufacturing systems (Huang and Nof, 2000); Introducing parallel/distributed computing to every aspect of MIM; Models for micro- and nano-manufacturing systems.

Modeling (Raczynskyi 2000) will become more important given the increasing complexity of collaboration needed to cope with global markets, global competition, and ecological constraints in the ever-evolving and turbulent manufacturing arena. The increase in system complexity demands corresponding decrease in operational complexity for humans. It may be less important for non-automated, exclusively local operations in the future. Because horizontal and vertical disintegration over manufacturing value chains is becoming more common, we need new theories, models, and tools for the distributed (fragmented) yet inter-dependent systems and enterprises.

3.7 Enterprise integration.

Enterprise integration (Kosanke et al, 2000) is approaching the construction methods and the vocabulary of large-scale systems, especially enterprises, its scope extending from management to control. Thus the technology is at the cross roads of Engineering and Management. The most important part of this technology is the development of the GERAM framework (Vesterager, 2000) which by now has found its way to several international standards as well as has applications in manufacturing engineering, software engineering and defense logistics.

It has been shown through many applications that this unifying framework allows better communication between various disciplines that approach the enterprise integration problem from their own perspective. Also some new areas, as the construction of networks of companies and virtual project enterprise s and consortia can be modeled much easier then before, due to the uniform treatment by GERAM of enterprise entities, such as companies, networks of companies, projects and products.

The most promising applications are the improved designs for agile networks of companies which through better reference models can react to market demands quicker and with easier to predict results.

The key control concepts are related to decisional models and their interactions that allow considerations to be made regarding the tightness of control between enterprise entities as well as explicitly treat such important system properties as agenthood and autonomy.

Key challenges are: The lack of mature extendible CASE tools that would allow their users to extend the set of modeling languages necessary for any one project; the relatively low number of openly published enterprise reference models (due to the competitive advantage that companies can derive from the possession of such models); and the slow progress of the definition of a Unified Enterprise Modeling Language.

A significant new area is the application of GERAM to project management, where not only the project's service but also its management and control are simultaneously designed so as to achieve lean and dynamic projects while improving the project outcome and other performance indicators.

Enterprise Integration will significantly increase in importance, witness the numerous companies as well as Defense that by now either follow the principles of Enterprise Integration (Enterprise Architecture) or are actively engaged in the assessment of its potential to business design and improvement. The technology allows the higher-level management issues to be combined with aspects of control, thus mutually improving the chances of successful applications.

4. CONCLUSIONS

The Manufacturing and Instrumentation Coordinating Committee covers a vast scientific and technological area. All Technical Committees included in this Coordinating Committee are strongly related to the applications in several domains. Furthermore, theoretical aspects related to modeling and control are also considered. Information processing and communications play an important role as shown in section 2 of this paper.

The most important issues related to the contemplative stance of the fields of the Technical Committees are summarized in Table 3.

Table 3 Summary

	MIC	MIR	MIM
Important aspects	Hardware and software components and instruments for process control.	Augmenting human abilities and capabilities, replacing humans in many everyday activities.	Distributed manufacturing, modeling behaviors and interactions.
Promising applications	Large scale and distributed control systems, transportation systems (automotive).	Unmanned Aerial Vehicles, humanoids, teleoperation/ telerobotics, manufacturing, services, and intelligent vehicle.	Production networks, collaborative manufacturing, applications in SME, supply chains, e-Business, enterprise software and decision support.
Key control concepts	Artificial intelligence, neural networks, fuzzy techniques, genetic algorithms for high-level supervision, classical control theory.	Intelligent control, sensor fusion, autonomous systems.	Theory of constraints and optimization.
Key challenges	Proving architectures, self-checking of components, new perception sensors, and connection of field equipment and control devices.	Real-time intelligent perception and control, humanoids.	Changes scenarios, demonstrate applicability, operational environments, implementations, e-Manufacturing.
New areas	Microsystems in medical fields.	Humanoids, creation of "Friend of Humans" in work and entertainment.	Management and manufacturing contradictions, robust collaboration, parallel/distributed computing, and modeling in: network-based enterprise, autonomous behaviors, and micro- and nano-manufacturing,.

	MIT	MIS	MIA	MIL
Important aspects	Integration in manufacturing. CIME, Intelligent Control of unstructured shop-floor processes	Synergetic combinations of mechanics, electronics and computer control	GERAM framework.	Life cycle assessment of automation systems with respect to total costs.
Promising applications	Manufacturing Execution Systems MES, Flexible Manufacturing Automation	Automobiles, consumer products, manufacturing, railways, ...	Designs for agile networks of companies.	Manufacturing automation, Building automation.
Key control concepts	'Flat' hierarchical automation architectures, Safe Manufacturing for IT based embedded automation	Robust control, adaptive control, algorithms and architectures for embedded control, FDIR	Decisional models.	All but robust.
Key challenges	Intelligence in Manufacturing. IMS, E_Automation, Unified Manufacturing Automation Modeling Language	Software tools, optimization of control configuration, safety and reliability	Case tools, enterprise reference models, Unified Enterprise Modeling Language.	Integrated information processing in sensors, actuators and controllers, wireless networking.
New areas	Holonic Manufacturing Systems, Agile Manufacturing, Formal Systems Automation Engineering.	Any product or process that is currently provided by a principally mechanical solution	Application of GERAM to project management.	Multi agent supported shop floor control and maintenance.

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