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Novel Trends in Manufacturing Systems with View on Implementation Possibilities of Intelligent Automation

Roman Ružarovský, Radovan Holubek, and Peter Košťál

***Abstract*—**The current trend of increasing quality and demands of the final product is affected by time analysis of the entire manufacturing process. The primary requirement of manufacturing is to produce as many products as soon as possible, at the lowest possible cost, but of course with the highest quality. Such requirements may be satisfied only if all the elements entering and affecting the production cycle are in a fully functional condition. These elements consist of sensory equipment and intelligent control elements that are essential for building intelligent manufacturing systems. The intelligent manufacturing paradigm includes a new approach to production system structure design. Intelligent behaviors are based on the monitoring of important parameters of system and its environment. The flexible reaction to changes, the realization and utilization of this design paradigm as an "intelligent manufacturing system" enables the flexible system reaction to production requirement as soon as environmental changes too. Results of these flexible reactions are a smaller layout space, be decreasing of production and investment costs and be increasing of productivity. Intelligent manufacturing system itself should be a system that can flexibly respond to changes in entering and exiting the process in interaction with the surroundings.

***Keywords*—**Sensory equipment, intelligent manufacturing systems, manufacturing process, control system, smart automation.

I. Introduction

THE industrial intelligence is still forwarding. Today we are not talking only about using of IT, classical automated instruments. But when we are talking about flexible intelligent manufacturing systems it is effective to talk also about possible using of new generation intelligent manufacturing systems. This new generation of manufacturing systems is also called intelligent manufacturing systems. All IMS subsystems are including parts of so called machine intelligence (sensor equipment). Using of given systems with combination of machine intelligence will lead to the complete labor remove from the manufacturing system.

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II. Application of CA Systems in the Flexible Manufacturing

CA systems are computer systems that are intended to support of activities at all stages of manufacturing – from development and design of component, production planning to production and assembly, storage and expedition. Application using of CA systems in manufacturing and execution time of the components is shown in Fig. 1.

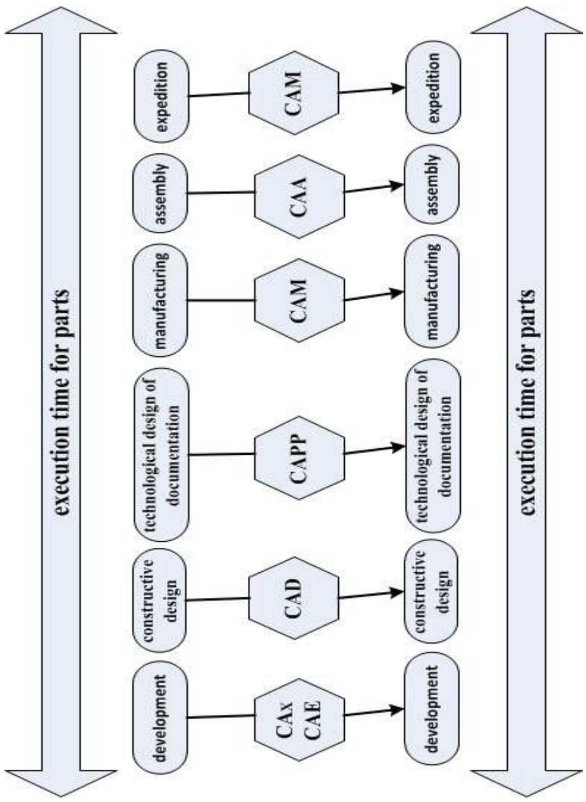

Fig. 1 CA systems and execution time of components

Realization of components consists of:
- stage of development - design and planning,
- stage of technological – implementation.

In the design and planning stage is made after modeling, simulation and analysis activities the complete design and technological documentation, respectively, are generated by CAD and CAPP data - Computer Aided Engineering works CAE. Second stage is characterized by different automated systems with computer support (manufacturing, assembly, storage) - Computer Aided Production Engineering CAPE. Central production planning/manufacturing systems rely on centralized communication, are rigid, lack scalability and robustness, and have a high cost of integration. Mass Production Systems place emphasis on the reduction of products' costs and full utilization of plant capacity.

This manufacturing approach resulted in inflexible plants, associated with work-in-process and finished goods inventories. Computer-Aided Design (CAD)/ Computer Aided Manufacturing (CAM) systems integrate different tools (e.g., e-mail, multimedia, 3-dimensional CAD geometry viewer) in a distributed multimedia-designing environment through the Internet (e.g.). In CAD, the computers are used in the design and analysis of products and processes. In CAM, the computers are used directly to control and monitor the machines/ processes in real-time or offline to support manufacturing operations (e.g., process planning) [1].

Computer integrated manufacturing (CIM) systems have been used to integrate different areas within manufacturing enterprises. They use a graphical user interface within a programming environment and incorporate multimedia packages to facilitate the dissemination of product information (e.g.). Connection of CA systems with the manufacturing is showed on Fig. 2.

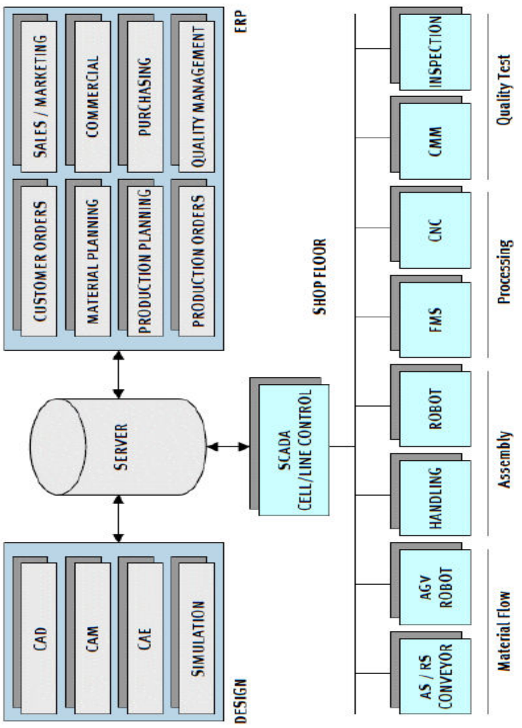

Fig. 2 Connection of CA systems with the manufacturing

Main paradigms of manufacturing engineering and their underlying technologies are presented on Fig. 3.

Nr. Crt.	Manufacturing System/ Paradigm	Focus	Main Strengths	Main Limitations	Technology/ Approach
1.	Mass production	Reduction of product cost; Full utilization of plant capacity.	Full utilization of plant capacity.	Inflexibility; Do not cope with today's requirements.	
2.	CIM	Integration of computers and computer-based tools.	Use of computers to support different activities (e.g., design).	Do not cope with today's requirements.	
3.	Flexible	Manufacturing a variety of products on the same system.	High diversity of manufactured products.	Expensive; (Usually) include unnecessary functions/ software; Subject to obsolescence.	
4.	Reconfigurable	Rapid adjustment of production capacity and functionality.	Modularity; Integrability; Convertibility; Diagnosability; Customization.	Include unnecessary functions/ software; Subject to obsolescence.	
5.	Intelligent	Systems enhanced with human intelligence (e.g., concerning decision making).	Acceptance.	Missing access to a body to interact with, and learn from environment [25], [26].	Agents.
6.	Holonic	Holons [15].	Preserves the benefits of hierarchy and	Centralized control.	Agents, Petri-Nets.
7.	Balanced automation	Optimal mix of machines and humans.	Balance of automated and human-based activities.		Agents.
8.	Bio-inspired	Based on bio-inspired approaches.	High adaptability, Flexibility; Often work well even when a desired task is poorly defined,	Early phase – need further developments.	Agents, bio-inspired computing, evolutionnary computing and related algorithms, bio-robotics, swarm intelligence.
9.	Wise	Wisdom-enhanced manufacturing systems.	Early phase (Expected: considerable increase in performance).	Early phase; this approach needs further research and development.	Wise information and communication technologies (wICT); evolvable hardware; cloud computing.

Fig. 3 Main paradigms of manufacturing engineering systems

III. Analysis of Manufacturing Systems with Respect to Automation Equipment Application

For better understanding of "intelligent manufacturing systems" term, is the most suitable to compare its behavior with behavior of flexible manufacturing system [2]. Automation manufacturing system is today known as manufacturing device with various levels of automation of operating and non-operating activities and with various levels of subsystems integration (technological, supervisory, transportation, manipulating, controlling):

- Technological (set of technological workstations),
- Transportation and manipulating (is realized by industrial robots, manipulators and transporters),
- Supervisory (is included to system if machines in system do not have own supervisory devices),
- Controlling (there are dominating own controlling systems of all devices) [3].

Using of intelligent production systems is conditioned by efficiency of all subsystems, which are contain in given system. Subsystems are developed with automatic manufacturing systems, in order to save the system parameters. Automatic manufacturing systems in repetitive production, where is demanded big rate of flexibility, are called flexible manufacturing systems. To category of automated manufacturing systems (flexible manufacturing systems) are included one or more technological workstations, at which are all inputs, material and immaterial, automated. Basic classification of automated manufacturing systems takes into the account also the number of the machines in the system as well as flexibility of the production. According to this classification we distinguish three basic types of automated manufacturing systems:

- Flexible manufacturing cell – up to maximum three of the machine tools; it's characterized by highest level of flexibility,
- Flexible manufacturing line – is characterized by the lowest level of flexibility; range of goods is narrow and being produced in large batches,
- Flexible manufacturing system – minimum three machines and more; is characterized by lower level of flexibility.

IV. Implementation of Intelligence in the Manufacturing Systems

Intelligent manufacturing system presents system with self-contained capability of adaptation to unexpected changes, i.e. assortment changes, market requirements, technology changes, social needs etc. However, intelligence of these systems is frequently understood as control of the software product, and not as implementation of modern technologies of machine artificial intelligence [4]. Intelligent production systems consist of subsystems like automatic production systems (technological, supervisory, transportation, manipulating). Subsystems have to be equipped with aids, which give to subsystems specific level of intelligence. It is possible to consider it as higher phase of flexible production systems. Components of an intelligent manufacturing system consist of (Fig. 4):

- Intelligent design,
- Intelligent operation,
- Intelligent control,
- Intelligent planning,
- Intelligent maintenance.

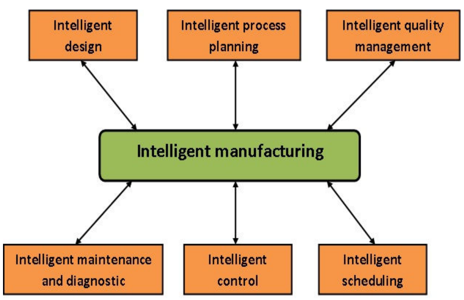

Fig. 4 Components of an intelligent manufacturing system

Manufacturing engineering systems evolved in order to meet several objectives, such as:

- Reduction of cost,
- Reduction of lead times,
- Easy integration of new processes, sub-systems, technology and/ or upgrades; interoperability,
- Reduction of production waste, production process and product environmental impact to 'near zero',
- Fast reconfiguration; fast adaptation to expected and unexpected events.

V. Mechanical Periphery Intelligence Enhancement Potential and Limitations in Production

Monitoring of all actions inside the production process but also in its environment is aimed at increase of this system reliability and failure prevention of the system itself or avoidance of defective products. There are several possibilities how to enhance production system intelligence. In term of automation production is the most complicated operation. Sequences like correct grip, orientation and positioning of the component entering the production system in disordered condition (e.g. loose in a container) are very easy to realize by a human. In term of automation however these seemingly simple acts represent one of the most complicated problems. Usually we try to keep aloof from such acts in the automated production process so that individual components enter the production system already oriented and in a defined place by means of various feeders, tanks or pallets. In case the automated production system is entered by individual components which are un-positioned and non-oriented an intense cooperation between the sensor subsystem and various intelligent mechanical peripheries is necessary. Various types of sensors (contact, contactless, pressure, sensors of strength and moments, CCD cameras and others) are used dependent on specific demands of the specific application. Simultaneous combined use of various sensor types affords solution opportunities also of very complicated monitoring tasks. Individual sensor types can differ also in their output signals. Some sensors have only simple binary output signals, others can have a more complicated output signal consisting of several simple binary signals (e.g. sensor differentiating colors) and others can provide an analogue signal (e.g. rheostat thermometer). All these signals must be processed and correctly evaluated by the control system because only on the basis of this information it can correctly respond to the actual state of the production system en bloc, of its individual subsystems as well as the actual state of the technological process.

One of the application areas of monitoring systems is the area of robotized assembly. Equipping of assembly systems by sensors is one of the basic levels of increasing of automation and machine intelligence. Sensorial systems provide scanning and monitoring of various functions of assembly process, assembly technology, properties of assembly objects, mounted parts and properties of environment. Realization of monitoring functions provides suitable sensor sorts, whereupon the supervisory systems provide the control interventions. Sensors are the basic devices for capturing of information and their transformation. The present monitoring systems have reserved structures which are realized according to application or purpose.

Selected sensor or sensorial systems (monitoring systems) must meet technical, economic and operative indices. Factors, which affect their selection are multiple and multilevel. Center of the sensors application is mostly in robotized assembly, where the sensorial systems enable to assembly (so-called intelligent robots) and others technical elements to identify and monitor workspace and system environment with building elements. In robotized assembly the ideal event occurs when PR can recognize, place and grab random oriented object.

Sensorial equipment applied in assembly systems use three basic groups:

- tactile sensors,
- proximity sensors,
- visual sensors.

Development of the new kinds of sensors takes place in all three groups. Classification of the most frequently used kinds of sensors is on Fig. 5. Tactile sensors are used in case, that technical, realization instruments, mostly assembly robots, are in direct contact with object of assembly. Important are especially sensors which enable control of the object presence, identification of grasp force, monitoring of the starting position of assembly tools, let us say other functions. With tactile sensors are equipped tentacles, position table, transporting units, other units and devices. For recognizing of the orientation, kind of objects, detection of edges are used visual sensors of various kinds [5].

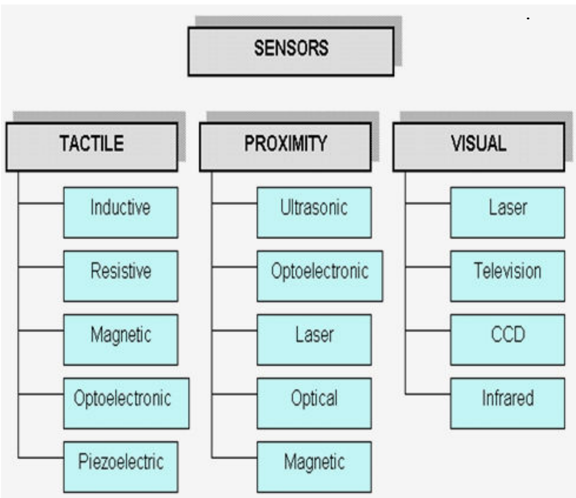

Fig. 5 Classification of the most frequently used kinds of sensors

These sensors are generally in cylindrical or angular cases with digital, analog inputs, with connectors, or fixed with cable, e.g. for machining, packing and transporting devices. Present tactile sensors are conceived primarily on the basis of pressure and force measuring. Output signals are treated to signals suitable for proper level of control. Among main advantages of ultrasound sensors belong:

- Contactless detection of object presence and position measuring,
- High precision of measuring,
- High measuring distances,
- Measuring is not affected by particles in the air etc.

Other tactile and proximity sensors are also the magnetic sensor. These types of sensors proved thanks to their high switching distance.

VI. Challenges and Trends

An extensive survey on manufacturing systems allowed the identification of the main current trends for manufacturing systems, which can be summarized as follows:

- Specialization, characterized by an extensive focus on core competences,
- Outsourcing,
- Transition from vertical to horizontal structures (e.g., concerning management systems), from highly centralized to decentralized structures (e.g., where an individual element, unit or sub-unit is enhanced with decision making/ intelligence capabilities),
- Evolution towards self-properties or self-sufficiency (e.g., self-adaptation) which generally occur at low levels. Manufacturing systems with these characteristics have a high level of integration, are easy upgradable, evolvable and adaptable (e.g., to new market conditions,
- The development of technologies and applications to support all the requirements of current distributed manufacturing systems,
- Competitiveness: the enterprises should remain competitive, e.g., in terms of costs (e.g., lifecycle costs, investments) vs. payoffs; adequate equipments and machines (e.g., sensors) adequate to new manufacturing paradigms; sustainability (e.g., to consider environmental concerns into design),
- Technology, equipment and manufacturing systems' selection (e.g., to evaluate various systems configurations based on life-cycle economics, quality, system reliability);
- integration of humans with software and machines; non-functional properties, e.g., fault tolerance,
- Openness, self-adaptability; each unit/sub-unit/ element of the manufacturing system should independently take optimal wise decisions (e.g., concerning resource utilization, incorporating scheduling algorithms, planning and control execution techniques), having a goal-driven and cooperative behave,
- Performance assessment.

Concerning future trends; it is rather difficult to forecast long term trends for manufacturing engineering systems.

VII. Conclusion

Despite the developments in the area of engineering systems and advancements of information and communication technologies, current (manufacturing) engineering systems fail to address all the needs of today's manufacturing enterprises.

Current trends of manufacturing engineering system are towards enhancing machines with bio inspired and human abilities (e.g., intelligence, wisdom, cognitive functions), and in hiring (fewer) highly skilled employees. However, this trend has to be closely accompanied with (positive and negative) human, social and environmental consequences. Currently, due to shortened product life cycle, market liberalization, a great competitive pressures and constantly dynamically changing demands of customers, enterprises are forced to gradually rebuilding the nature of its production to mass production and small series with a wide range of products. This phenomenon relates with many problems.

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