Possibilities of intelligent flexible manufacturing systems

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Abstract: The basic requirement of production is to produce as many products as possible, at the lowest cost, with the highest possible quality. These requirements can be met with the new "Intelligent Production" paradigm. In particular, this paradigm involves the use of intelligent manufacturing systems and the introduction of intelligent production management. In this article, we'll look at intelligent manufacturing systems. The intelligent manufacturing system itself is a flexible manufacturing system that can flexibly respond to changes in production requirements as well as changes in its surroundings and interact with its surroundings. As a result of these flexible responses, there is less space, reduced production and investment costs, and increased productivity.

1. Introduction

The time analysis of the entire production process is influenced by the current trend of increasing product requirements. The basic requirement for production is to produce as many products as possible at minimum cost, with the required quality. For these reasons, a new paradigm called "intelligent production" is being put into practice.

Industry automation continues. Today, it's not just about using classic automation tools, but about a flexible manufacturing system. We can now talk about a new generation of intelligent manufacturing systems.

This new manufacturing paradigm involves a high degree of production automation as well as all processes related to production.

This means that on the one hand (the hardware part) is a highly automated production system on which its various parameters relating to the production itself are constantly monitored, as well as those related to the system's own operation (for example oil temperature, bearing vibration and others).

On the other hand, the software section is an intelligent control system that can handle all of these data and make decisions based on both the production and the manufacturing system itself (for example, schedule individual activities for regular maintenance, customize the production process to the current system status, and more).

These two parts together form an intelligent manufacturing system that can flexibly respond to and adapt to the current situation.

Complex component machined with zero defects is a top performance in mass production and it becomes a new challenge required for the new generation of intelligent machine-tools. Increasing the precision and accuracy of machines, products and processes offers substantial benefits to a wide range of applications from ultra-precision to mass production with higher quality and better reliability [1].
The next generation of manufacturing machines will be described as new intelligent reconfigurable manufacturing systems which realise a dynamic fusion of human and machine intelligence, manufacturing knowledge and state-of-the-art design techniques. This may lead to low-cost self-optimising integrated machines. It will encompass fault-tolerant advanced predictive maintenance facilities for producing high-quality error-free workpieces using conventional and advanced manufacturing processes.

Machining process monitoring and control is a core concept on which to build up the new generation of flexible self-optimising intelligent NC machines. In-process measurement and processing of the information provided by dedicated sensors installed in the machine, enables autonomous decision making based on the on-line diagnosis of the correct machine, workpiece, tool and machining process condition, leading to an increased machine reliability towards zero defects, together with higher productivity and efficiency [1].

This new generation of manufacturing systems is characterized by the use of a large number of different sensors that constantly gather information about the system itself and its surroundings. These sensors are located in individual production machines as well as in all production system accessories.

All the data collected by the sensors is sent to an intelligent control system that evaluates it based on various modern decision algorithms to take decisions that can affect not only production but also the production system itself.

1.1. Manufacturing initiatives in the different regions
In 2013, Germany unveiled its Industry 4.0 strategy, which directed a great deal of global attention to the advances in manufacturing systems technology [2]. In the United States, the government launched the Advanced Manufacturing Partnership (AMP) in 2011. Since then, many other initiatives have been rolled out, including the Advanced Manufacturing Partnership Steering Committee “2.0” in 2013; the National Network for Manufacturing Innovation (NNMI) in 2014; and the Revitalize American Manufacturing and Innovation Act, which was signed into law by the President of the United States in December 2014 [3]. Most recently, Manufacturing USA was officially launched by the US government in order to further “leverage existing resources... to nurture manufacturing innovation and accelerate commercialization” by fostering close collaboration between industry, academia, and government partners [4]. In 2015, the Chinese government officially published a 10-year plan and roadmap toward manufacturing: Made in China 2025 [5]. The largest international collaborative program, Intelligent Manufacturing Systems (IMS), which is led by Japan, is also rolling out a roadmap for its next step with its IMS2020 project.

2. Intelligence and intelligent systems
The conventional manufacturing control structure is very efficient under relatively steady operating conditions as it provides a single central control over a range of operations. However a centrally managed, hierarchical control strategy is:

- unresponsive in the face of disturbances such as rush orders, breakdowns, supply stock-outs,
- cumbersome to reconfigure for new products, new manufacturing technologies or different line configurations.

In simple terms, the decoupling of routing, scheduling and planning functions—in both hardware and software—from the changing state of physical shop floor operations means that there is often little or no correspondence between the decisions made and the resulting activities of the resources that execute them. [6]

Automated manufacturing systems are capable of ensuring the long-term required level of quality and production efficiency. This must be achieved without operator intervention. This means that all automated production system subsystems have an impact on the resulting quality and production efficiency. In order to realize the production process in automated production systems, it is necessary to create a proper sequence of individual functions and links between individual subsystems [7]. The exact time coordination of these functions is very important. It is very important to follow the system dynamics in this process.
Indeed, flexible monitoring systems are required under the actual market requirements and thus, reliable process diagnosis is necessary under different cutting conditions. Nowadays, a common problematic shared by conventional process monitoring approaches for part and tool condition monitoring is the lack of reliability under changing cutting conditions hence limiting the flexibility of such automation systems. As a characteristic example of this problematic for process condition based tool condition monitoring (TCM), the process condition is not only influenced by changes in tool condition, but it is also directly affected by cutting conditions. Furthermore, under different cutting conditions, different wear mechanisms can be activated on the tool, each one having its particular impact on process and part condition [1].

Due to the increased complexity of modern manufacturing systems—particularly after all the units/elements been integrated into a common system—process decisions have become much more difficult. There is a strong need to leverage vast amounts of manufacturing data and to utilize the power of computing intelligence to enhance the decision-making process in manufacturing.

Intelligent capability refers to three functions, which operate in an analogy of a human body: sensing, decision-making, and action. With today’s rapid advances in sensing and control technologies, there is no lack of sensors or actuators in manufacturing systems.

The challenge is how to process information and knowledge so that the right decision can automatically be made by a computer at the right time and in the right location, with little or no human intervention. New technologies are emerging in this areas, such as big data analytics, machine learning (ML), and cloud computing, which provide great potential for enhanced intelligent capability in manufacturing [8].

2.1. Intelligence
The notion of intelligence is not unambiguously defined, but in general, the rapid and correct orientation in new situations, which is based on a quick insight, the correct assessment of the necessary information, and the correct conclusions, is considered to be positive manifestations of intelligence. Furthermore, it is mindfulness, understanding, logic, criticality, originality, ability to reveal subtle, hidden, difficult to perceive connections and relationships, similarities and differences, versatility and ability of interests, rich vocabulary and precise concise expression.

Intelligence expresses some general (intellectual) ability, which is the basis for appropriate response in situations where experience is not sufficient.

Intelligence can be called the ability to retrieve information from its surroundings, store it, process it, and respond to the current situation based on the results of the processing.

2.2. Artificial intelligence
Artificial intelligence is the intelligence realized by machines. It is a field of study in computer science that tries to reproduce human brain activity in solving various tasks. This means perceiving your surroundings, learning, planning, deciding and solving problems.

Like any computer program, artificial intelligence is based on the use of algorithms. An algorithm is a set of clear instructions executed on a computer that lead to the desired result.

In recent decades, great progress has been made in AI's artificial intelligence. The methods by which artificial intelligence solves problems and seeks solutions are taken from the established practices of people. The main tools for calculations are mainly searching and mathematical optimization, neural networks, methods based on statistics, probability.

Expert systems are the oldest and most advanced type of intelligent systems that incorporate the "know-how" of a human expert into a computer program. The representation of knowledge in these systems is given symbolically in the form of rules and frameworks.

Nowadays, the most advanced subset of machine learning is learning through neural networks. The artificial neural network is divided into multiple layers, the inlet passing through the inlet layer and then through the hidden inner layers, with each layer extracting more abstract information. Finally, the output is transmitted through the output layer. In the case of the presence of multiple inner layers, we call the network a deep neural network and the approach is called deep learning.
In recent years, considerable effort has been devoted to the development and use of distributed artificial intelligence systems.

The problems that today's artificial intelligence research has to cope with are, in addition to the limited computing power, the system itself. Although partial tasks (like speech recognition, answering, image recognition, and so on), are already solved at a certain level, the complex solution is still far away.

3. Intelligent production

Intelligent manufacturing is a progressive building of integrated production management that connects all technological aspects (sensor use, process control, IT systems, production planning, ...) with the addition of intelligence through modelling, advanced management including cognitive automation concepts, diagnostic tools. Optimization, simulation, and expert knowledge are in harmony and interaction with human intelligence [9].

The concept of intelligent manufacturing remodels the ability of decision support systems to form generative systems that can acquire knowledge, learn, and adapt to changing environments and the actual composition of system components. A characteristic of smart production is the ability of the system to learn as well as the ability to obtain the information needed to manage an integrated production system.

The main components of intelligent manufacturing are shown in Fig. 1

Products and production are mainly related to the following parts:

- intelligent design - information is produced at the time of product design that can affect production both positively and negatively. (technology design, tolerance,…). This information carries the 3D model of the product and all its components as part of the input to all subsequent pre-production and production phases;
- the intelligent design of production process - a selection of suitable production technology based on product design, finding suitable technological parameters that are close to optimal, selection of suitable production process, design of material flow during production,…
- intelligent planning - scheduling production so that it can be completely realized at minimum time, including purchasing all the necessary material, availability of free capacity of all necessary equipment and their operation,…
Intelligent Quality management - correct recognition of important (required) and unimportant parameter controls correctly determine the methodology and scope of quality control ...

The production system itself relates mainly to the following two parts:

- intelligent management - the intelligent manufacturing system can react to some unexpected situations that may occur and be monitored by the control system (blunted or broken tool, the control system is able to detect and respond to this problem, for example, temporarily replaces it with another if possible if not, report a fault, fixture detect improperly inserted workpiece,…). Of course, this manufacturing system can only work if its peripherals (eg fixture) have a certain level of intelligence, so they can monitor their functions while communicating with the master system's control system, which in turn communicates with its superior system.

- Intelligent maintenance - the control system monitors the status and performance of the individual components of the production system. Based on the evaluation of these data, it suggests smaller maintenance interventions flexibly and possibly plans. (for example, by monitoring the cutting forces it can assume the need for a tool change, or postpone the tool change term, the machine work time is measured and, based on the actual measured values, it can make a proposal for scheduled maintenance).

All of the above intelligent manufacturing components must work closely together. In order to implement intelligent manufacturing technology, industries are preparing to develop cloud computing platforms based on IoT. It has been estimated that investment in IoT is expected to reach $60 trillion in the next 15 years. By 2020, it is predicted that more than 50 billion devices will be connected to the Internet. In order to unleash the benefits of IoT for industrial applications, many software platforms are being developed and deployed, such as the aforementioned Predix platform by GE.

GE’s Predix is a comprehensive, purpose-build industrial platform for the implementation of intelligent systems to monitor and control physical devices or systems through the Industrial Internet. A significant feature of all such platforms is the capability to build “digital twins.” A digital twin is a computerized model of a physical device or system that represents all functional features and links with the working elements. A digital twin is more than a virtual computer system for simulation study. It provides the operation status, insights, outcomes, and knowledge that are associated with the proper functions of the physical system. A digital twin is capable of communicating with the physical system it represents via real-time sensing devices, so as to keep it almost synchronized with the real-time status, working condition, position, and environment situation. Digital twins allow for the prediction of future conditions [8].

4. Intelligent manufacturing system

As industrial production is evolving, new generation generations of manufacturing systems are also being developed—intelligent manufacturing systems. These systems are equipped with "intelligent" control systems. Nowadays, the use of real artificial intelligence in these systems is a far future. First steps are being taken to increase the intelligence of these systems by implementing various modern decision algorithms. A basic part of such systems is also a subsystem that allows extended monitoring of the operating status of the system and its surroundings. The information obtained in this way constitutes the basic input for the said decision algorithms.

For a better understanding of the term "intelligent manufacturing system", it is best to compare its behaviour with the classic ("non-intelligent") production system.

Today, the automated manufacturing system is known as a production facility with various possible levels of automation of both operational and off-site operations and with different levels of subsystem integration (technological, transport, handling, control) [10]:

- technological (production equipment)
- Control (own control systems of all devices)
- transport and handling (using industrial robots, manipulators and conveyors)
- monitoring and monitoring (monitoring observes the status of the production system and its individual subsystems, can be connected to maintenance, inspection checks production quality)
• Energy (supplies the production system with the necessary energy and also monitors and evaluates its consumption)
• warehouse (used to store semi-finished products and finished products)

An intelligent manufacturing system is a system that has the ability to adapt to unexpected changes, such as product changes, market demands, technological change, social needs, etc.

He is able to collect and process information from his surroundings. Based on the results of the evaluation of the information obtained, it is able to make a separate decision affecting the production facility, the production process or its surroundings.

Intelligent manufacturing systems also consist of subsystems, as well as automated manufacturing systems (technological, surveillance, transport, handling). However, these subsystems are highly integrated and equipped with technical means that allow the subsystems concerned to have a certain level of intelligent response to external stimuli. These intelligent manufacturing systems can be seen as a higher level of flexible manufacturing systems [9].

The control system of manufacturing and assembly systems is possible to understand as the integration of combined elements of control system. The control system is realized as a mechanical, pneumatic, hydraulic, electro-pneumatic or electro-hydraulic control structure. That means the control system could be to accept as an individual system that is represented by a hierarchically ordered control system of manufacturing and assembly process [11].

In terms of automation, assembly is one of the most complex operations. Sequences, such as proper gripping, orientation, and placement of a component entering the assembly system in an unordered state (e.g., freely in a container) are very manageable. However, in terms of automation, these seemingly simple tasks are one of the most difficult issues. Usually, we try to solve this task in an automated assembly process so that individual components enter the assembly system already oriented and in a location specified by various feeders, containers or pallets [12].

In case individual components that are unpositioned and unoriented enter into the automated system, intensive cooperation between the subsystems is needed to determine the current position and orientation of the component and other various intelligent mechanical peripherals. Different types of sensors (contact, contactless, pressure sensors, force and torque sensors, cameras, etc.) are used depending on the specific application requirements. See e.g. [13], [14], [15] and others.

The simultaneous combined use of different types of sensors provides a solution to the possibility of a very complex observation task. The different types of sensors can also vary in their output signals. Some sensors have only simple binary output signals, others may have more complex output signals, which consist of several simple binary signals (e.g. a colour sensing sensor), and others may provide an analogue signal (e.g. a resistance thermometer). All these signals must be processed and evaluated correctly in the control system because it is only on the basis of this information that it is possible to correctly respond to the current state of the production system of its individual subsystems as well as to the current state of the technological process.

Equipping manufacturing systems with sensors and a control system that can send the data for evaluation and processing to its superior system is one of the fundamental steps towards increasing the intelligence of these systems. Sensory systems provide the ability to monitor the various functions of the manufacturing process, manufacturing technology, properties of the objects being processed, as well as environmental properties. These monitoring systems are always implemented depending on the specific purpose of use.

An extensive survey of manufacturing systems has made it possible to identify the main current trends for manufacturing systems, which can be summarized as follows:
• specialization that is characterized by a broad focus on key competencies;
• the transition from vertical to horizontal management systems, the change from highly centralized to decentralized (each individual element, adapted to decision-making ability / intelligence);

[...]
Developing the system's own capabilities and capabilities (eg adaptation), which usually occur at lower levels of the system. Production systems with these characteristics have a high level of integration, are easily expandable and adaptable;

- development of technologies and applications to support all requirements of current distributed production systems;
- competitiveness, businesses must remain competitive in terms of costs and benefits; (corresponding equipment and machines enabling new production processes);
- sustainability [eg taking environmental protection into consideration];
- production technologies and equipment (eg to evaluate different system configurations with regard to quality, system reliability);
- integration of people, software and machines, functional features such as fault tolerance;
- openness, adaptation; each unit of the production system should take appropriate and justifiable decisions (eg in terms of resource utilization, including planning algorithms, planning and execution control) that have a common goal and work together to achieve it;
- performance analysis [12]

5. CONCLUSION
At present, we are often witnessing a disproportionate reduction in the product life cycle, market liberalization, and ever-changing customer demands. As a result of these phenomena, manufacturers are forced to gradually rebuild their production from mass production to small series with a wide variety of similar product variants.

The concept of all production facilities is subordinate to the nature of production. New generation production systems differ from a flexible production system not only in construction but especially in their properties and capabilities. For these reasons, the implementation of new generation production systems in the manufacturing process brings wide possibilities for increasing productivity and reducing production costs.

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References
[1] Mekid S, Pruschek P and Hernandez J 2009 Beyond intelligent manufacturing: A new generation of flexible intelligent NC machines, Mechanism and Machine Theory 44(2) 466–476
[2] Kagermann H, Wahlster W and Johannes H 2013 Recommendations for implementing the strategic initiative INDUSTRIE 4.0. National academy of science and engineering
[3] Reed T 2014 H.R.2996 - 113th Congress (2013-2014): Revitalize American Manufacturing and Innovation Act of 2014, 16-Sep-2014, https://www.congress.gov/bill/113th-congress/house-bill/2996, [Accessed: 09-Aug-2019]
[4] Obama B 2011 Strategy for American innovation: Driving towards sustainable growth and quality jobs. DIANE Publishing
[5] Lee X E 2015 Made in China 2025: A new era for Chinese manufacturing, CKGSB Knowledge
[6] McFarlane D, Sarma S, Chirn J L, Wong C Y and Ashton K 2003 Auto ID systems and intelligent manufacturing control, Engineering Applications of Artificial Intelligence 16(4) 365–376
[7] Velíšek K and Košťál P 2007 Self Organizing Manufacturing Cell Philosophy, Scientific Bulletin. XXI(May)
[8] Chen Y 2017 Integrated and Intelligent Manufacturing: Perspectives and Enablers, Engineering 3(5) 588–595
[9] Meziane F, Vadera S, Kobbacy K and Proudlove N 2000 Intelligent systems in manufacturing: current developments and future prospects, *Integrated Mfg Systems* **11**(4) 218–238

[10] Danišová N and Velíšek K 2007 Intelligent manufacturing and assembly system, *MD* 413–416

[11] Ruzarovsky R, Horvath S and Velisek K 2008 Designing of automated manufacturing and assembly systems, In book: *Annals of daaam for 2008 & proceedings of the 19th international daaam symposium*, Vienna Univ Technology, Karlsplatz 13, Wien, a-1040, Austria 1201–1202

[12] Holubek R and Kostal P 2013 The Intelligent Manufacturing Systems, *Advanced Science Letters* **19**(3) 972–975

[13] Danisova N, Ruzarovsky R and Velisek K 2011 Design alternatives of intelligent camera system for check parts at the intelligent manufacturing-assembly cell, *Information Technology for Manufacturing Systems II, PTS I-3* **58**(60) 2262–2266

[14] Danišová N, Ružarovsky R and Velíšek K 2013 Designing of Intelligent Manufacturing Assembly Cell by Moduls of System Catia and E-Learning Module Creation, *Advanced Materials Research* **628** 283–286

[15] Danišová K and Velíšek N 2010 Shelf storage system running at the intelligent manufacturing cell, *Proceedings of World Academy of Science, Engineering and Technology* **70** 529–533