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INTEGRATION OF ADVANCED MONITORING IN MANUFACTURING SYSTEMS

Novel concept of monitoring systems integration, reference models and test application for manufacturing are presented in the paper. Research results are an answer for industry needs for development of IT solutions that will allow to integrate information flow in production systems. The idea of standalone advanced monitoring devices connection with Shop Floor Control, MRP/ERP and machine operators is discussed. The concept of monitoring systems integration has been formally described by reference models. They corresponds with original multilayer data structure proposed on the base of data tree. Data model allows to describe orders, products, processes and to save monitoring results. Both kind of models has been the base for implementation of the integrated monitoring system demonstrator. The demonstrator developed in the frame of research was built on the base of multiagent technology. It allows to keep high flexibility and openness of the system, as well as easy implementation of various intelligent algorithms for data processing. Currently, an application of integrated monitoring system for real production system is developed. The main problems and future development of monitoring integration in discrete production are presented and discussed in the article.

1. INTRODUCTION

Development of manufacturing systems is based more and more on taking an advantage of applying intelligent solutions into machine and production process control and monitoring [21]. In the future production systems monitoring should play significant role as a feedback from machining process to client who order particular product and expect certain quality [15]. It will be an important element of local and global control of the machining and manufacturing processes as well. Significant problem in this area is effective integration of technical and social systems [18] and man machine cooperation [19].Connection of technical systems, manufacturing processes and advanced information management in which an important role plays monitoring is will force new revolution in whole production sector [8]. It is also named as a smart manufacturing [4],[6]. Quick development of IT systems, computing technology and development in data processing creates a critical mass for the change in information management also directly in machining processes [5]. In the future a rapid change in the area of process and machine condition monitoring is expected

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on the base of Cyber-Physical-Systems (CPS) [29]. Comparing to embedded systems that are currently in use, advanced CPS should enable much higher capability, adaptability, scalability, resiliency, safety, security and usability. The future applications of CPS can be more transformative than the IT revolution in the past, as researchers points [24]. Probably next generation CPS will be able to execute extraordinary tasks that are currently difficult to imagine [29]. Cyber-Physical-Systems technology impact on manufacturing very often is comparable to the way that smartphones changed communication between people and interaction with Internet. It should transform the way people and IT applications interact with technical systems. Solutions operating similarly to smartphones should allow performing number of parallel processes containing: data collection, advanced processing and problems solving. Novell control, monitoring and communication devices basing on new smart Cyber-Physical-Systems should drive innovation into number of areas of manufacturing systems.

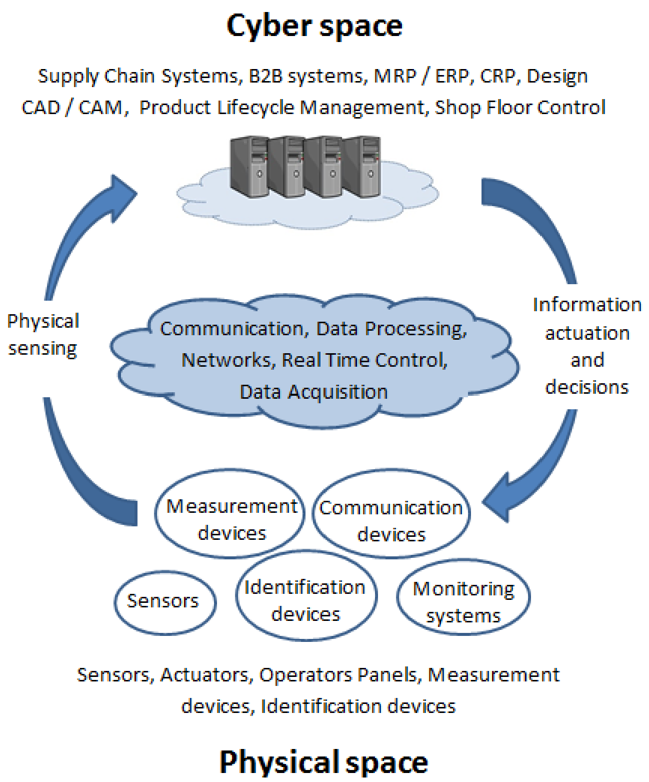

Fig. 1. The concept of the Cyber-Physical-Systems implementation in integrated monitoring of discrete production process and machine operators integration into data flow

Wide applying of integrated monitoring systems strongly depends on development of advanced devices that will be inexpensive, flexible and easy to use by machine operator or middle technical stuff [3]. They have to be based on some kind of miniaturised cyber-technical solutions that can be easily implemented in machines, tools or even products. Such solutions have to connect advanced computing systems, monitoring equipment like sensors, intelligent software applications and communication devices. They have to be easy to configure and implement closely to machining process. Future advanced embedded technology called Cyber-Physical-Systems (CPS) probably would be the base for development of such solutions. According to NSF definition Cyber-Physical-Systems are engineered systems that are built from, and depend upon, the seamless integration of computational algorithms and physical components [17].

Expected strong influence of Cyber-Physical-Systems on future manufacturing signalised by researchers, as well as industry needs for integration of monitoring and control devices in one systems was the reason to propose by author a concept of Cyber-Physical-Systems implementation in monitoring. The general scheme of the CPS implementation into future monitoring systems is presented on the Fig. 1. According to it the Cyber-Technical-Systems will connect miniaturised physical devices, like sensors, identification stuff, measurement devices, etc., with data processing based on highly advanced, easy to program and reconfigure software. Application of such solutions should allow to real breakthrough in manufacturing systems control and monitoring.

The aim of the research presented in the paper was to develop the concept of advanced standing alone monitoring devices integration into one system. Such a system will be integrated with Shop Floor Control and farther with IT management systems like MRP/ERP and systems operating on supply chain level. Currently, integrated systems should to be built on the base of available technology. In the future Cyber-Physical-Systems should be applied. In the area of discrete processes monitoring a deep literature and on-going projects survey has been done. The results were published in original review paper [23]. The next step in the research was focused on development of integrated monitoring system reference models and demonstrator. Currently an industrial application is under research.

2. INTEGRATION OF MONITORING SYSTEMS IN MANUFACTURING

Development of highly effective agile manufacturing systems is connected with growing requirements on process robustness, responsiveness to client demands, and achievement of a sustainable production environment [30]. It requires integration of whole information flow from the production process till management level. Currently most of companies use a fully integrated management IT systems. Usually they have a modular structure that covers all areas of company management, financial aspects, cooperation in supply chain, etc. This kinds of systems have also a production module, however in most cases it is limited to production orders preparing. Advanced Shop Floor Control systems that integrate management level and production processes usually are limited to fully automated systems [22]. In most cases in discrete production processes there are now solutions that can offer automatic information flow from machine and process level, machine operators and performed by them tasks, like parts measurement, to management IT system [28]. As a result usually a feed-back information from manufacturing process is limited to paper based reporting about production progress without possibility of process and machine condition monitoring and advanced on-line data processing [26].

Quick development of advanced monitoring systems can be seen as an answer on growing requirements on manufacturing process quality and stability, what is shown by latest literature reviews do by Byrne et al. [2], Teti et al. [27] and Oborski [23]. However, advanced monitoring applications are built as a standalone devices dedicated for supervision of a particular process or machine tool. Research on integration of monitoring devices with IT company backbone are slowly begin [23]. Because of the specifics of the discrete production process like milling, turning, EDM, etc, it is difficult to use IT tools like SCADA systems dedicated mostly for process industry. Integrated monitoring systems for discrete production and especially for machining process have to allow performing large amount of highly changeable data. They have to take into account a structure of a particular products and manufacturing process. A data acquisitioned by sensors and specialized systems have to be processed by dedicated advanced and very often intelligent algorithms. It is not rare that measurement frequency have to be extremely high like in the case of Acoustic Emission [10].

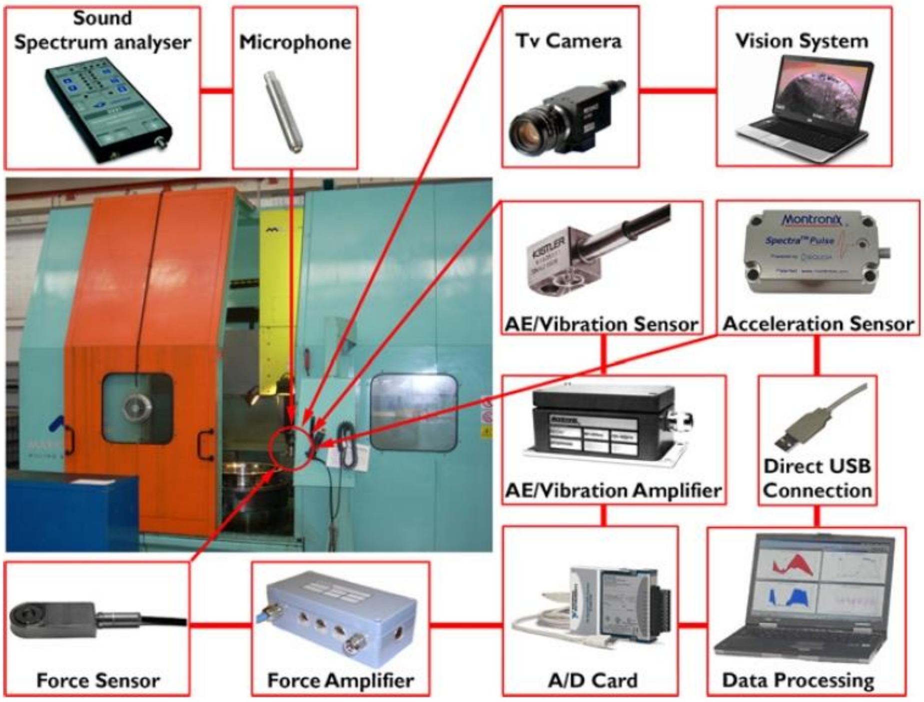

Fig. 2. Example of modular multisensory monitoring system for machining process monitoring [27]

Usually advanced monitoring system for discrete manufacturing process consist of number of different highly sophisticated sensors, data processing devices and decision taking software based on intelligent algorithms (see Fig. 2). A large number of highly variable parameters is a significant problem in process, workpiece, and machine tool condition monitoring. A high sampling frequency is dictated by high-speed tool or workpiece rotation, movement of machine elements, as well as by characteristic of measured physical variable. For example often used in milling and cutting process condition monitoring Acoustic Emission (AE) has a useful frequency between 50 kHz to 2 MHz [9]. To manage this problem, data has to be collected locally, processed to eliminate various kinds on noise and analysed by dedicated algorithms implemented in Real Time systems [25]. Raw data processing result is selection of an important information, that can be used for further action. On the base of it artificial intelligence algorithms can take decisions about process status and appropriate actions [1]. Those decisions and information about monitored process, machine, workpieces condition should be available for control systems, machine operators and IT systems operating on shop floor and management level. Currently there is no such solutions dedicated for manufacturing systems [23].

3. DIFFERENT APPROACHES FOR MONITORING SYSTEMS INTEGRATION

Researchers working on monitoring systems usually focus on identification process or machine status. On the base of this information a decision about tool change or machine stop can be done [27]. However, information from integrated monitoring could be used also on different levels of manufacturing system. Three general approaches has been proposed to order this area:

1. Integration of monitoring systems and functions with direct machine functions control.
2. Integration of monitoring systems with tool path generation systems – CNC control and CAM systems
3. Integration of monitoring system with company management IT systems

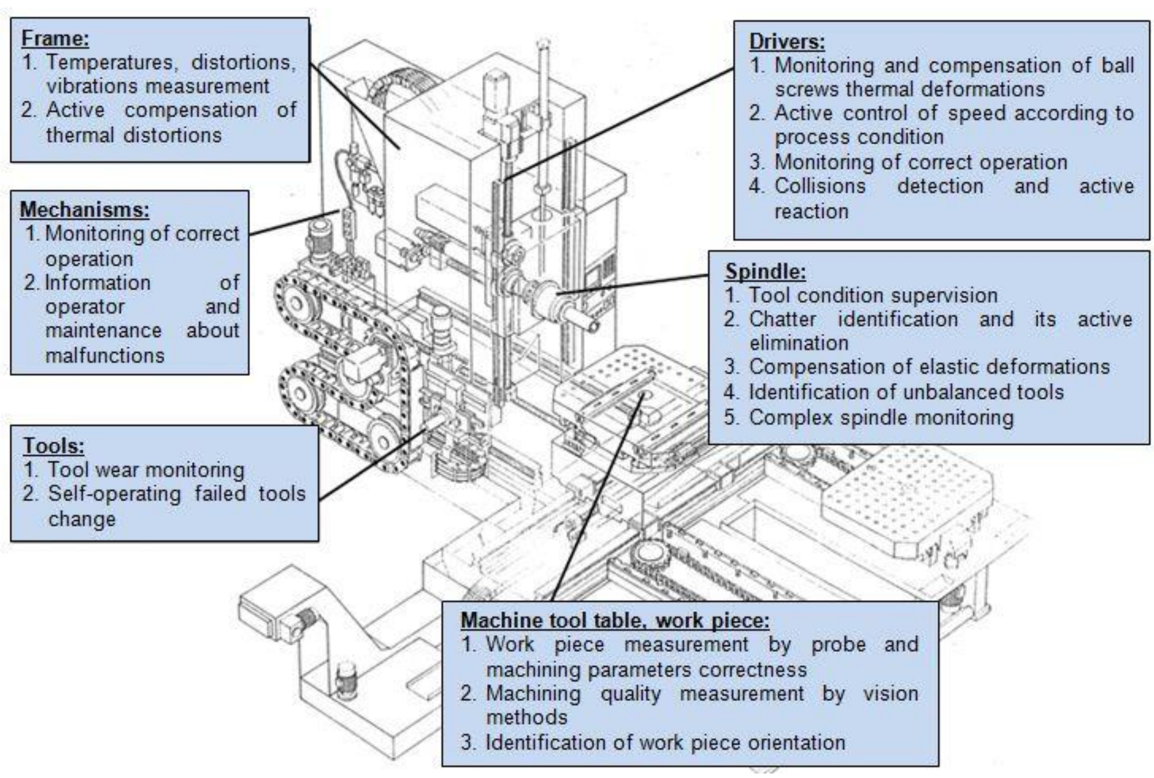

Fig. 3. Integration of monitoring and control functions in future smart machine tool

The first approach is focused on integration of monitoring systems on the level of machine control. Connection of monitoring and control could be used for active reaction on identified incorrect conditions, like tool brake of particular devices operation. Examples of monitoring functions application and its integration into control of various machine mechanisms and process are presented on the Fig. 3.

Wide use of monitoring data to control and optimise operation of machine mechanisms will move traditionally controlled machine tool in to smart machine, flexibly reacting on negative trends and appearing problems. Quick development of such approach will be strongly supported by development and wide application of smart miniaturised control and monitoring devices based on Cyber-Physical-Systems.

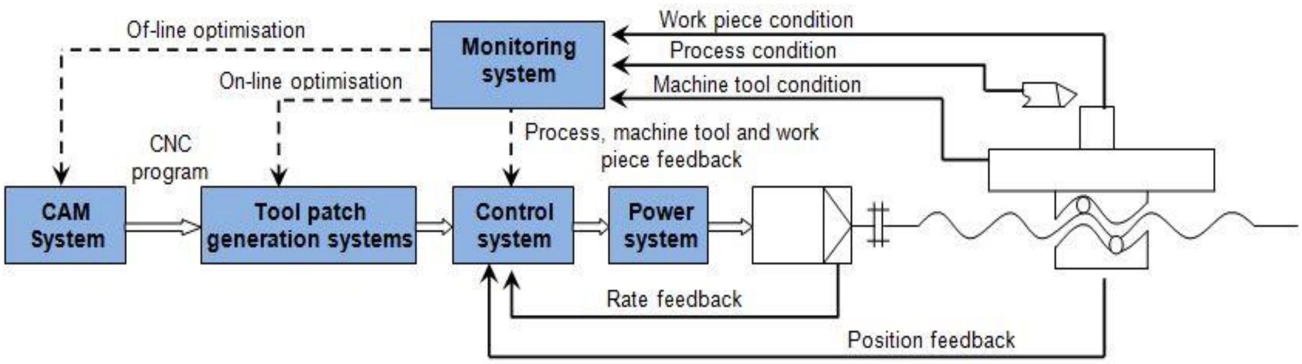

Fig. 4. The concept of monitoring data based optimisation of the machining process

The second approach is focused on integration of a monitoring system with tool path generation. Information about process, machine or part status could be used in on-line and of-line machining process optimisation. Information about incorrect process condition or machine dimensions change can be used for on-line corrections of settings done by CNC control system. For example cutting speed reduction in the case of growing cutting force, or rotation speed change in the case of chatter appearing. An of-line optimisation could be done as well. In this case a data about process and machine condition in performing particular machining process should be transferred into CAM systems. In CAM an off-line optimisation of ISO code could be done to improve process performance. Different production strategies or parameters optimal for identified process conditions could be set (see Fig. 4).

The third approach of monitoring integration is focused on closing gap in information flow between manufacturing system and management level. Information from monitoring would allow for effective management of parts production process. Currently in most companies with discrete production information about order performing is collected on the base of paper reports. A fluent, automatic on-line information flow is impossible [16]. Integration of process, machine and part condition monitoring with company IT systems could be used in different area of order management. The general concept of integration with IT company and supply chain management systems is presented on Fig. 5.

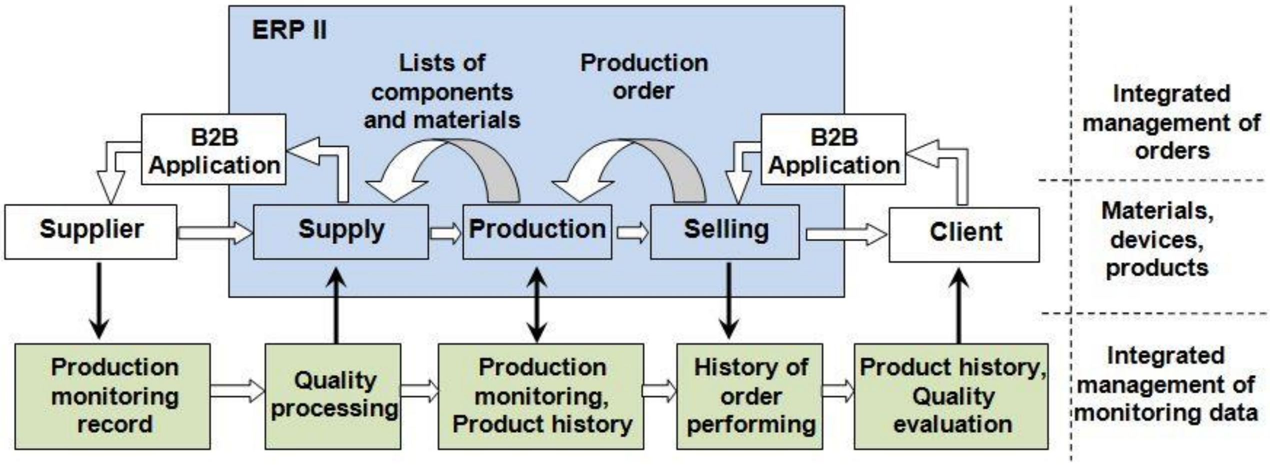

Fig. 5. The concept of monitoring data integration with orders management

Integrated applications should connect into one system various devices responsible for monitoring of different process, machines or workpieces. It have to arrange information according to order, production process and product structures.

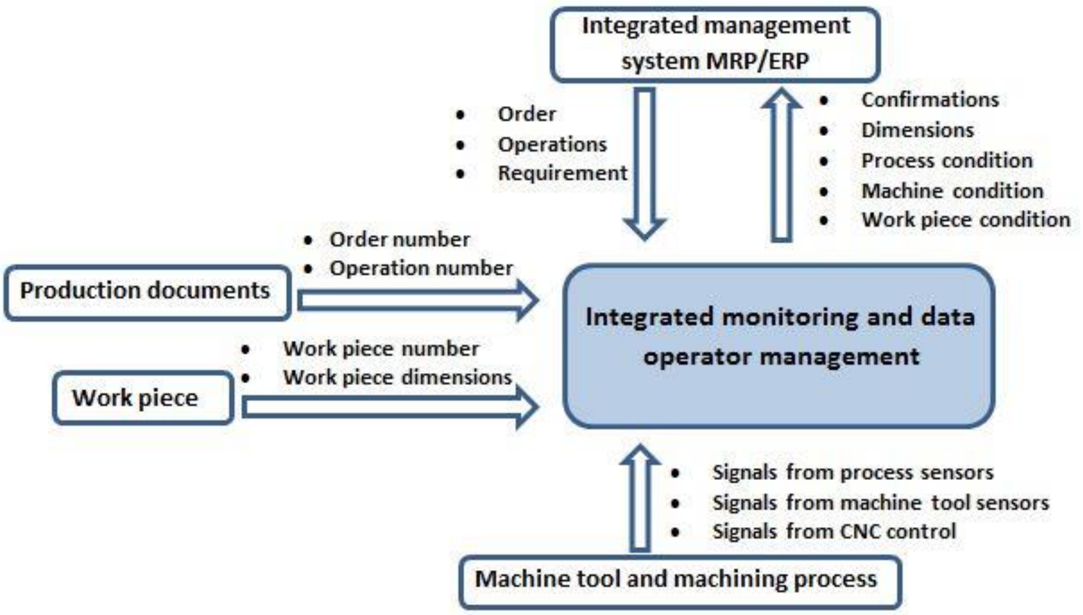

Fig. 6. General scheme of the information flow around single machine tool and its operator

Moreover, integrated monitoring system can manage not only data from monitoring. In production systems equipped in CNC machines, where usually work operators, it can support also integration of all information flow necessary to perform production and to have real, useful feedback from production process. Such widely defined integration of information flow (Fig. 6) is currently implemented in integrated monitoring system presented in further section of the article.

4. REFERENCE MODEL OF INTEGRATED MONITORING SYSTEM

Research presented in the paper was focused on integration of monitoring applications with company IT system. General description of integrated monitoring systems was proposed in the form of multilayer reference model. The aim of the model is supporting development of such a systems by performed tasks and applied equipment hierarchical ordering. Tasks performed by technical systems like: sensors, monitoring devices, and software modules responsible for signal acquisition, data processing, decision making, product history archiving and cooperation with management IT systems, were ordered in separated layers. Every layer is responsible for performing specific tasks and processing different kind of data. Particular layers implementation is based on different hardware systems and use different software solutions. Characteristics of every layer and performed data are described in Table 1. The multilayer reference model of integrated monitoring system general view is presented on the Fig. 7. The aim of the concept of the integrated monitoring system developed in research is collecting all necessary information from various monitoring devices.

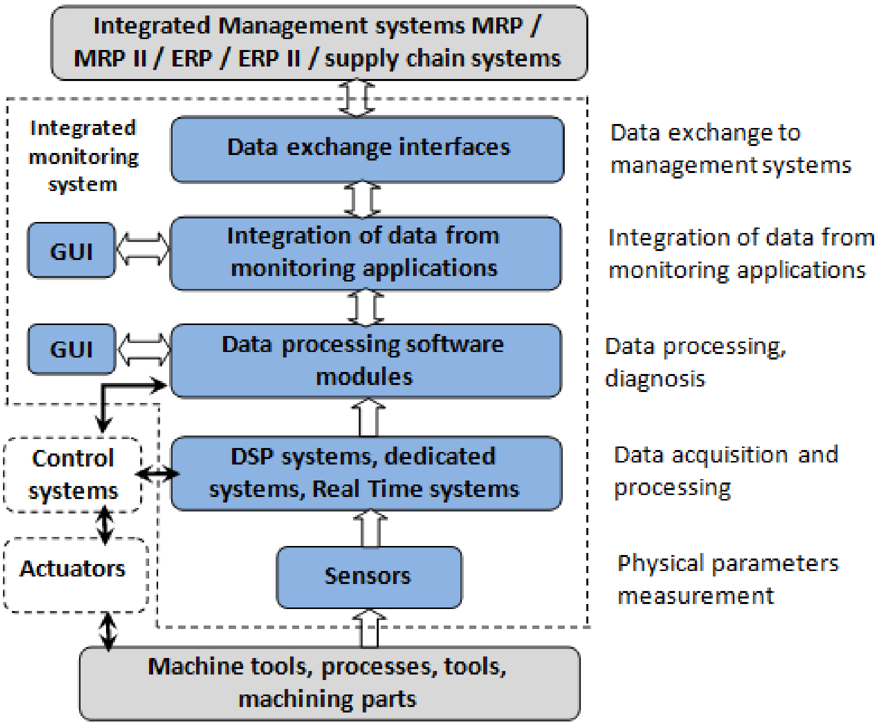

Fig. 7. Multilayer reference model of integrated monitoring system

Data and information about status of particular orders, process conditions, identified problems, diagnosis and taken decisions processed and collected by monitoring system have to be available for all interested players. It should be available for people and systems working on the management level, designee, process planning and supply chain.

Table 1. Characteristic of particular layers of the reference model

No.	Layer	Characteristic	Data
I	Measurement of physical quantities	Physical quantities are changed by various sensors on the electric signals. They transfer information about status of the physical process in probing moment.	Large quantity of short data, often measured with very high probing frequency
II	Acquisition and signals processing	Acquisition of signals from sensors and their processing usually by filtering to eliminate noise, conversion to digital form, elimination of signals that don't contain information. Usually it has to be done in Real-Time.	Very big quantity of highly changeable data has to be processed in Real-Time. Special measures / aggregated data are at the out.
III	Data processing, diagnosis	Data processing aiming at identification of monitored object condition and problems type. Very often are used an intelligent algorithms. Diagnose can be delivered to machine control systems, machine operator or Shop Floor Control systems	Quantity of data much lower than in II layer. They are in the form of measures or aggregated data. At the output are signals informing about identified problems and object parameters.
IV	Integration of monitoring systems	Integration of data from local monitoring systems into coherent data structures. Integration on the production process level requires hierarchical integration on machine level and over that on process level. Integrated data has to archived. Data can be processed to obtain information about whole process efficiency and product quality.	Input data in the form of digital signals informing about identified problems and taken decisions in local monitored objects. Output data in the form of multilayer data structures.
V	Data exchange with management syst.	Exchange of data between integrated monitoring systems and IT management systems. Data can be sent as a complete data structure or answers on singular requests.	Large data files or data objects with whole integrated data structures or singular answers on requests.

An important problem in integration of monitoring systems is keeping of a data collected from various devices and software applications. Data describing status of monitored process, machine or work piece and taken decisions transferred from various monitoring devices should be ordered according to product and manufacturing process structure.

Studied were various solutions based on graphs theory. As a result, an eight layer data tree reference model was proposed (Fig. 8). Each layer is responsible for keeping of a particular data. Every kind of data is saved in dedicated, clearly described level of the model. Monitoring data saved at the lowest levels is joined to upper levels. They describe explicitly a moment of a machining when monitoring data was registered as well as part, product and order it relates. The first level contains data from monitoring. It can be raw data directly acquisitioned from sensors, or in the case of high frequency of probing, like in the case of Acoustic Emission, an information prepared by dedicated subsystems, based on Real-Time applications or in future on Cyber-Physical-Systems. The second level allows for saving decisions taken during processing of monitoring data. The third level keeps information about monitored parameters. The fourth level allows to distinguish monitoring area. The fifth level describes specific manufacturing process treatment performed on the work piece surface by one tool with particular set of parameters. The sixth level saves information about manufacturing operation performed on one machine by different tools on different surfaces. The seventh level saves information about particular work piece. The last level assigns information to particular product the can contain number of machined parts. Proposed model allows for ordering information obtained from distributed monitoring devices. Data is arranged in logical, hierarchical structure assigned to structure of manufacturing process and product. Proposed model can be simplified. According to current needs number of levels can be reduced by leaving out information that are not needed in particular systems.

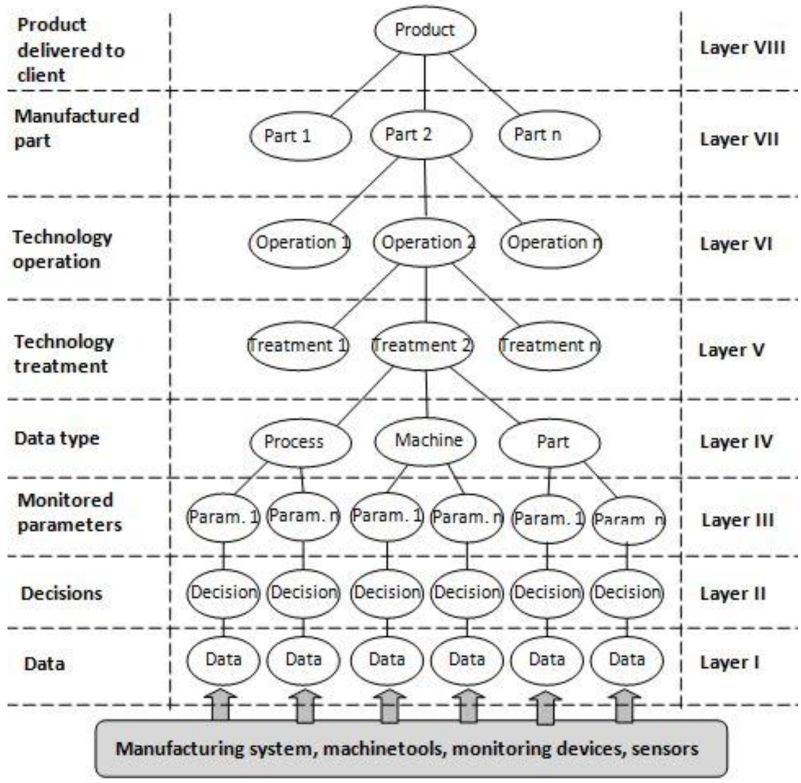

Fig. 8. Multilayer reference model of monitoring data based on order, product and process structure

5. DEMONSTRATOR OF INTEGRATED MONITORING SYSTEM

Proposed conception of the integrated monitoring system and developed models are verified in laboratory conditions. Demonstrator of integrated monitoring system was built. It has a multilayer structure based on proposed multilayer model. Every layer is responsible for performing specific tasks, appropriately to proposed model. The core of the system is based on multiagent technology. Applying this technology into applications connected with monitoring was already tested by some researchers [7],[12],[13]. Multiagent technology was chosen to build demonstrator because of its flexibility, intelligent algorithms easy application and openness on reconfigurations. Multiagent system is based on intelligent objects – agents that cooperate in performing systems tasks. Every agent can independently solve its tasks using own algorithm [14]. The goal of the whole system is realised by cooperation of particular agents. Type of cooperation depends on implemented cooperation algorithm. According to it the system can be heterarchical, partly heterarchical or hierarchical [20]. It is easy to reconfigure system by adding or removing agents. A graphical interface of demonstrator, database and system responsible for data management has been built on the base of client-server technology (Fig. 9). The demonstrator is built according to model requirements with distinguished layers responsible for different tasks. The lowest one currently simulated, will be based on a specialized monitoring applications working according to hard Real-Time constrains. It is with PLC controllers responsible for acquisition of signals directly from sensors.

The next layer is based on sensor agents. They are responsible for management of data and information acquisitioned from particular sensors. Sensor agents using dedicated intelligent algorithms should identify problems and undertake decisions about proper actions. In future this part of the system could be based on Cyber-Physical-Systems technology with implemented sensor agent. Next level of the demonstrator application is based on machine agents.

They are responsible for integration and processing of information from various sensor agents. Machine agent can integrate also agents responsible for identification systems allowing identification of work pieces and order documents. It can be based on barcode scanners or other technology. It is necessary to know identification number of particular machined work piece. Monitoring data from its machining should be assigned to that number. Integration of data from various measurement devices used by machine operator can be done at that layer. It will allow to integrate machine operators tasks with the company IT system. The next level of the integrated monitoring system is a system agent that integrates various machine agents. Advanced, further processing of monitoring data and information can be done on that level. The last layer is an interface with company management system that in demonstrator is simulated by SQL data base.

6. INDUSTRIAL APPLICATION OF INTEGRATED MONITORING SYSTEM

Industrial application of integrated monitoring system is currently being developed. It is based on proposed multilayer reference model and experience from demonstrator testing. System built for industrial company mostly is based on commercial solutions and dedicated software applications. Important part of the system is a monitoring module that currently is focused on process condition monitoring. It will allow for acquisition of data from several sources, its processing and problems diagnosis. Industry computer and Real Time software based special system named Adonis will be used [11]. It allows for advanced data processing and special features describing monitored process condition automatic selection. System is based on original intelligent algorithms developed at Warsaw University of Technology [11]. Adonis allows for more sophisticated and more precise description of machining process condition than commercial solutions. Machine tool condition monitoring will be added in the developed system as well. It will be based on data acquisitioned by sensors built in the machine and transferred by Profibus network from machine control system.

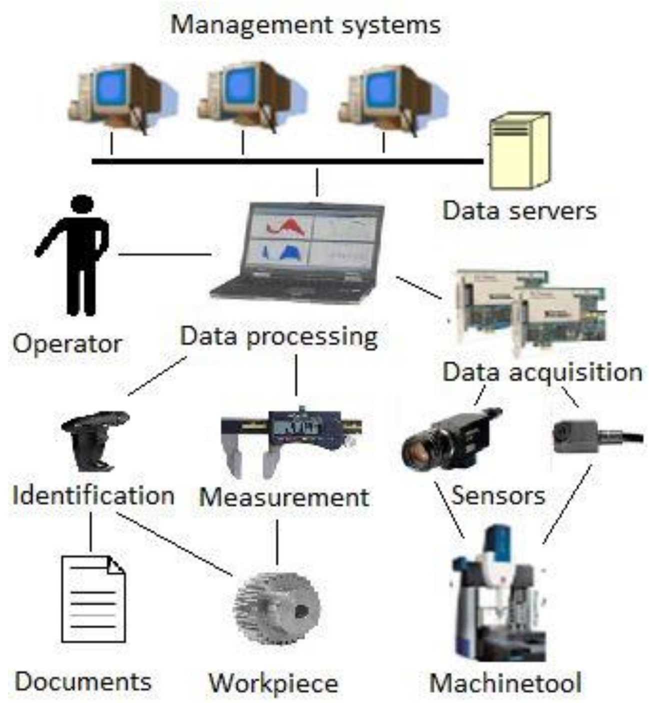

Fig. 9. General concept of the integrated monitoring system dedicated for production company

Integrated system will have also two other modules. One responsible for work pieces and production documents identification. Second responsible for acquisition data from measurement devices. Both of them will allow for supporting machine operator by automation of information flow. Together with special graphical interface presenting monitoring data as well as orders data transferred from management and CAD/CAM system it will allow for integration of machine operator with company IT systems. General concept of the integrated system is presented in the Fig. 9.

7. CONCLUSION

Growing complexity and sophistication of products combined with growing global competition demands quick development of production systems. Reserves in work organisation are nearly all utilised. Currently, there is time for quick development of manufacturing processes, machines and systems. Development of advanced IT technology, computer systems and data processing changed management of the production process, companies and supply chain. The coming breakthrough in development of Cyber-Physical-Systems will open new areas for advanced and easy to do integration of physical process and data processing. At the same time significant advancement in process and machine condition monitoring systems dedicated for discrete production can be visible. However, most of developed solutions are dedicated for monitoring single process or machines. There is a lack of advanced systems that would allow for integration of standing alone sophisticated monitoring systems with widely used highly developed IT management systems. There is also a lack of practical solutions allowing for integration of information flow between machine operators, machining process and company IT systems.

Researches presented in the paper are focused on a novel concept of monitoring systems integration development. The reference models of system integration and data storage were proposed. Integrated monitoring system demonstrator based on multiagent technology was developed to test proposed idea. On the base of reference models and experience from the demonstrator evaluation the test application for real discrete manufacturing system is developed. It is an answer to the needs of industry for development of IT solutions that will allow to integrate information flow in production process. The integration of various standalone monitoring applications, data from machine control systems and automation of information exchange with machine operator is the goal of the curried research project.

The concept and tested applications of integrated monitoring system presented in the paper can be a kind of reference solution for manufacturing companies equipped witch CNC machine tools and other not fully automated machines. Integration of monitoring systems, machine control, measurement devices and identification of work parts and production documentation allow for automation of data exchange between process level, machine operators and management IT systems. The developed approach enables an on-line data transfer to and from ERP/MRP systems. It offers real integration of information flow between management level, machine tool, machining process and operator. Monitoring data can be used for an on-going production control, optimisation of production process and collection of manufacture history of particular parts.

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