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INTEGRATION OF MACHINE OPERATORS WITH SHOP FLOOR CONTROL SYSTEM FOR INDUSTRY 4.0

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Abstract

Research focused on integration of machine operators with information flow in manufacturing process according to Industry 4.0 requirements are presented in this paper. A special IT system connecting together machine operators, machine control, process and machine monitoring with companywide IT systems is developed. It is an answer on manufacture of airplane industry requirements. The main aim of the system presented in the article is full automation of information flow between a management level represented by Integrated Management IT System and manufacturing process level. From the management level an information about particular orders are taken, back an on-line information about manufacturing process and manufactured parts are given. System allows automatic identification of tasks for machine operator and particular currently machined part. Operator can verify information about process and tasks. System allows on-line analyzing process data. It is based on information from machining acquired: machine operator, process and machine monitoring systems and measurement devices handled by operator. Process data is integrated with related order as a history of particular manufactured part. System allows for measurement data analysis based on Statistical Process Control algorithm dedicated for short batches. It supports operator in process control. Measurement data are integrated with order data as a part of history of manufactured product. Finally a conception of Cyber-Physical Systems applying in integrated Shop Floor Control and Monitoring systems is presented and discussed.

Keywords

manufacturing, Industry 4.0, man/machine interaction, integration, process monitoring, shop floor control, integrated IT systems, integration of monitoring systems, Cyber-Physical Systems.

Introduction

Industry 4.0 revolution is driven by technology and IT development as well as grooving competition, where market fully determines success and principles of work. All manufactures have realized that they absolutely need more and more automation also in the area of data processing. Recently we can observe that, according to Industry 4.0 idea, the important area of research is focused on automation of data acquisition and processing in manufacturing process monitoring and control [1]. The capability of precise supervisory system which integrates individual process characterization will result in higher productivity, machine tool effectiveness and better final product quality [2–4]. An efficient process monitoring system is strictly required to identify the actual production conditions and to collect data for further big data analysis [5]. In most of manufacturing environments human employees carry out as machine tools operators, however they are not strictly integrated with company information flow [6]. They don't have on-line information supporting production process from sophisticated data processing. From the management point of view there is a lack of on-line information about process, part and machine. Companies see that there is a requirement to integrate on-line machine operators, process and machine monitoring systems with advanced data processing [7]. New important direction of research is development of Cyber-Physical Systems (CPS). CPS will connect high, easy to use computer capacity with solutions necessary to implement in production environments, like sensors, Real Time systems, etc. [8]. Cyber-Physical Systems application will allow to change philosophy of information flow and its processing in manufacturing systems.

The paper presents the idea and conception of implementation the specialized IT system based on computer panels dedicated for machine operators. The system will allow people to stay in touch with advanced IT systems operating on the management level, like Enterprise Resource Planning (ERP), process data management and product life cycle management systems. The possibility of permanent and stable access to production support systems like: CAD/CAM, instruction, quality management, etc. is useful for shop floor stuff. Integrated Management Systems can be on-line informed about any operation/action done by individual machine and its operator. Also the integration of manual measurement system for work pieces geometry measurement is developed. The human operator equipped with digital measurements instruments devices becomes an effective part of production monitoring system. Developed system allows also for integration of information from various locally implemented process and machine monitoring systems. Proposed solution of automated data exchange and management in the future should take advantage of Cyber Physical Systems implementation. It would allow flexibility improvement and implementation cost reduction.

Integration of information flow in the production systems

Integration of information management in the time of Industry 4.0 is necessary for taking advantage of sophisticated data analysis. It will play a crucial role in production management and will strongly influence on efficiency of whole production process. In the time of stock reduction and operation in Just in Time requirements a supply chain strict integration on the base of B2B IT solutions is needed. Usually it is based on special IT interfaces connecting company information systems. It allows for quick, automated exchange of data about performed orders, manufactured parts, quality demands, delivery data, etc. [9]. Company responsible for final product integration can receive information about particular parts delivered by suppliers. Usually exchanged data contains information important from management point of view. It would be very useful to have also information directly from the production process like: production status, quality control, manufacturing history of the part. Current company ERP/MRP IT systems allows for management of orders data. Usually they are not connected with machine control systems or specialized monitoring systems dedicated for acquisition of data directly from manufacturing process. Company IT systems don't allow for on-line data acquisition from manufacturing process. Usually a general data about production process is collected by machine operators, production leaders or other technical stuff in the form of paper reports [10]. Some of such a data can be later put into the company IT systems. However, there is no possibility to do it on-line. A consequence of it on the company management level and in the companies cooperating in supply chain is lack of on-line information about production process and orders realization. The next problem is impossibility to collect more detailed information about produced parts.

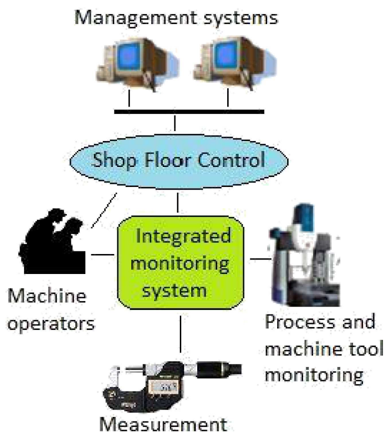

Fig. 1. The concept of information flow and operators integration in manufacturing system.

Enabling direct access to production and process data requires connecting into company IT systems special dedicated systems allowing monitoring of machine operation, process performance and transferring information from machine operators. In the process production a dedicated SCADA systems can be directly used [11]. They allow for acquisition of monitoring data from machine control systems and sensors. Signals usually are low changeable so SCADA systems based on PC operation systems like Widows can perform them directly. In the discrete production, like machining, and especially milling or cutting, monitoring applications have to be much more complicated [12].

Machine control systems based on CNC idea (Computer Numerical Control) have to calculate with extremely high accuracy a tool path and according to it control machine drivers. Monitoring of process and machine parameters requires acquisition of data with high and very often extremely high frequency [13, 14]. This situation requires cooperation of monitoring systems with relatively complicated CNC control systems. Monitoring data acquisition and processing have to work according to the Hard Real Time constrains [15]. The general idea of integration of information flow and integration of machine operators in manufacturing system is presented on the above scheme of Fig. 1.

Integrated monitoring system for manufacturing process

Integration of data flow in the discrete production is more and more important. In the presented research the system dedicated for airplane industry was developed. The aim of the system is to allow for integration of data exchange between machine tools, production process, machine operators and company integrated management systems.

The system is based on earlier originally developed at Warsaw University of Technology multilevel model of Integrated Monitoring System. This model describes five levels (Fig. 2). The first closely connected with machine and process concerns sensors responsible for signal acquisition. In the second level are dedicated applications responsible for signals processing. Usually they have to operate under Hard Real Time constrains. In the developed system on the first level are implemented force and Acoustic Emission sensors responsible for acquisition of signals for process condition monitoring. In the future a machine and part temperature measurement can be added. On that level are implemented also measurement devices for parts geometry dimensions control and barcode scanners. On the second level of the developed system operates Real Time computer cards for processing of monitoring data.

The third level of the model concerns systems of further data processing, problems detecting and decision taking. On this level in the developed system operate applications responsible for performing data from manufacturing parts identification and geometry measurement done by machine operator. On the fourth level operates IT system that integrates all data from monitoring of various machines and processes. On that level description of orders is transferred from ERP/MRP integrated system. To every particular order is added a special data tree. It describes product structure and particular parts produced in singular batches. In the data tree are saved monitoring data, taken decisions, operators remarks and all important information. In this way it is possible to verify all steps of manufacturing process. It forms history or particular product production process.

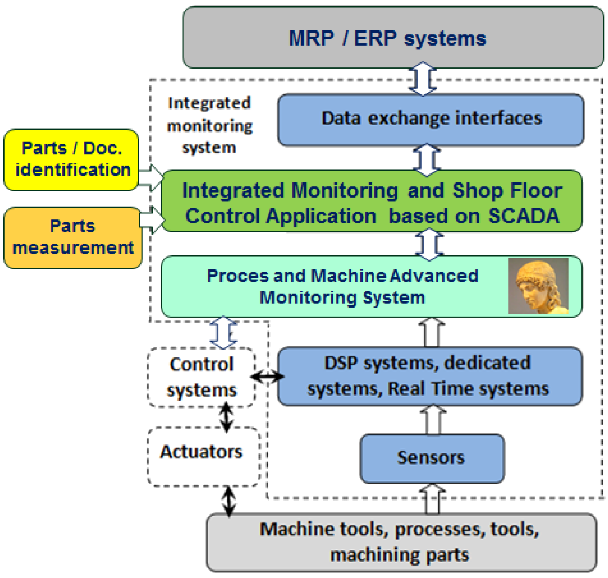

Fig. 2. Model of the integrated monitoring system developed in the research project.

Man-machine cooperation

Most of manufacturing systems containing CNC machines are controlled by human operators. Effective communication with machine operator is a crucial problem for integration of information flow. Research in this direction are an answer on problems and requirements signalized by number of companies. Also CNC machines suppliers are going in the direction of better communication with operator [16]. Some systems supporting CNC control are developed.

An example of such a solution can be a CELOS system produced by DMG/MORI SEIKI integrated with CNC control system. It can present information about orders and technical data of process and designee. Operator can enter data that can be sent directly to Shop Floor Control system (Fig. 3).

As earlier researches show, human cooperating with machine have a significant influence on overall system performance. It depends on human decisions. The significance of such decisions is higher than it was in the past because of more complex and costly production systems [18]. In such a situation, the efficient utilization of manufacturing equipment via proper man-machine interaction is necessary. In earlier research a behavioral man-machine cooperation model has been developed [19]. Also a sociotechnical problem in the case of automation of information flow is important. It can be very useful for operators, but it can also be destructive for their effectiveness and works motivation [20]. All of those aspects have been taken into account during integrated system development.

Fig. 3. System CELOS produced by DMG/MORI SEIKI integrated with CNC control system SIEMENS 840D Powerline (left) and Mitsubishi MAPPS V (right) [17].

Information flow in the system

Described system developed during research project plays a supportive role for operators, what is coherent with demands presented by other researchers [21]. A general data from ERP system about orders is presented as well as data about process and quality requirements. There are used also paper orders, that are easier to read by operator. Barcodes system is used for allowing operator quick finding in the IT system a data about particular work. Every document have a special barcodes, that can be scanned by optical scanner. Barcodes are used also for parts identification. Process monitoring data is entered to the system automatically. Process condition and machine monitoring data are on-line processed and key data is saved in the structure based on data tree. Work piece geometry and dimensions are measured manually by operator, but data is automatically transferred to the systems. Advanced algorithms for measurement data processing are used to inform operator about process correctness. Collected data forms a history of a particular part manufacturing.

System configuration and operator panel

During development of the system experiences from earlier research on Shop Floor Control system has been used [22, 23]. The system contains number of modules: local SQL database, system core responsible for data processing, machine and process monitoring modules, and operator modules (Fig. 4). Operator module is responsible for measurement devices and bare code scanners handling and related data processing. Control decisions are taken by operator supported by information presented on easy to use PC panel installed in the front of the machine next to CNC control system. A communication within operator is as much automated as it is possible.

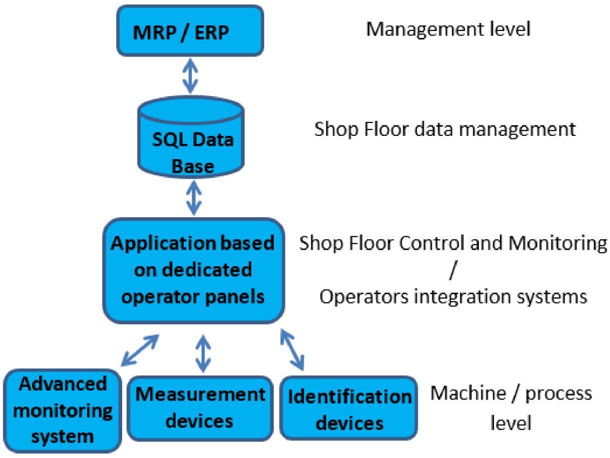

Fig. 4. Software configuration of the developed systems.

Monitoring functions are performed automatically. Real-Time part of the system responsible for monitoring data acquisition and processing is implemented in separated computer. It works automatically without direct contact with operator.

Information from process and machine monitoring, as well as parts measurement is presented on the operator panel (Fig. 5). Data about order transferred from MRP/ERP, process data and design drawings from CAD/CAM systems are also available. System core module is also responsible for Shop Floor Con-

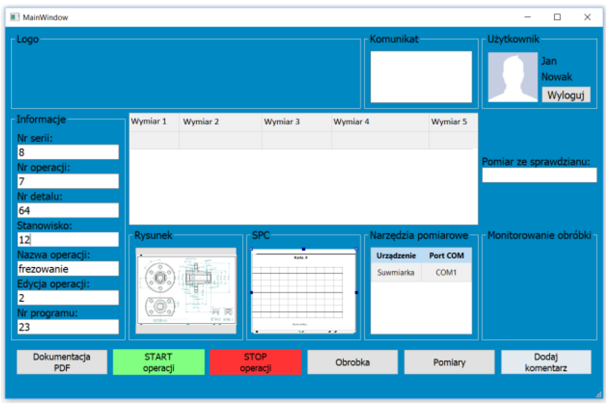

Fig. 5. The main window of operator panel – test version.

trol and have a dedicated panel. It allows for analyzing particular order performance as well machines, process and parts monitoring data. Additional data important for management level of the company like proposal of improvement can be added.

Process condition monitoring

Important part of the system is a monitoring module. Currently it is focused on process condition monitoring. Special computerized equipment was constructed for process data acquisition and for describing the actual condition of monitoring machine tool and machining process. The name of it is Adonis [24]. In the opposite of the commercial diagnosis systems, where the condition is measured as a signal growth, the new Adonis conception is based on actual, continuous, maximum/minimum and acceptable signal level analyzing. It is more sophisticated and can more precisely describe situation. As a research shows it is really useful for precise process condition prediction. Adonis system consists of several sensors able to follow different parameters. The first is the acoustic emission sensor (8152B121 made by Kistler) and the second cutting force sensor (Kistler 9017B) commonly implemented with vibration sensor PCB PIEZOTRONICS 356A16. All these sensors are connected to the computer fast data acquisition card equipped with numerical and analog inputs. The signal processing is performed with the basic frequency of 10 kHz. All information is processed by intelligent, neural-network based decision-making algorithm implemented in special software build in LabView programming environment. The important feature of developed system is possibility of connection to the machine tool CNC controller. Two ways communication is implemented: by digital lines of PLC and Profibus-DP interface. The essential information directly from numerical controller are acquired. It can be for example the rotating speed of main spindle, actual feed rate, realized block of technological program. An information about noticed critical situations, like unnormal vibration, tool brake, etc, can be send to CNC controller from monitoring systems. It will result immediate machine stop.

Work pieces identification and measurement

Important part of the system is work piece identification and measurement. In discrete production usually number of pieces are manufactured in the batch assigned to one order. Identification of every piece is done on the base of bare codes system.

Measurements are done by operator by electronic measurement devices. Data is automatically transferred to the system and processed by specially developed algorithm. It is based on SPC cards optimized to piece and small batch production performed in airplane industry. Operator has information about correctness of measured part and information about stability of machining process immediately [25]. The scheme of the system is show on the Fig. 6. On the Fig. 7 is presented view of one of the system windows.

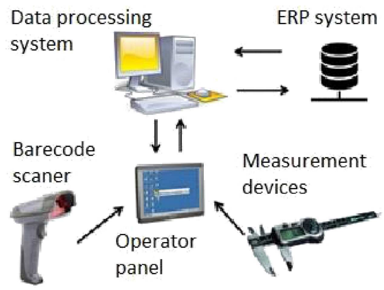

Fig. 6. The measurement system scheme.

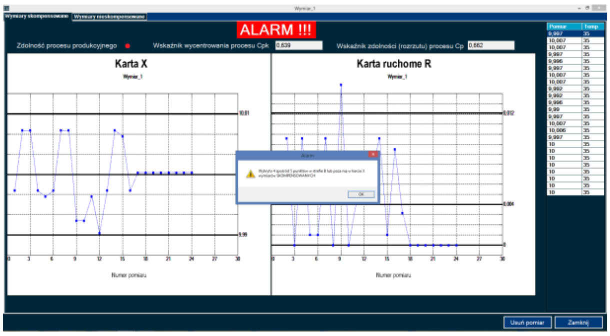

Fig. 7. View of the dimension window in stage of the alarm.

Measured data, trends and alarms are assigned to particular work piece belonging to particular order. Information about orders and parts are taken from ERP and process planning system. Collected data and operator decisions are a part of a history of manufacturing of a particular work piece.

Data integration base on multilayer reference model

Key part of the integrated monitoring system is data integration. Various parts of the system are responsible for acquisition and data processing.

Data have to be collected and archived in an ordered way for further advanced processing. In the described system a multilayer reference model was used. Eight level model was developed at Warsaw University of Technology together with multilevel model of Integrated Monitoring System. It allows for ordering data according to product and manufacturing process structure. Model is based on graphs theory and in this on data trees (Fig. 8). Every kind of data is saved in dedicated level of the model. Order and product structure data are coped from ERP system. Information about process and number of parts in a batch are added before manufacturing start. Data collected by the system and taken decisions are added to a multilayer model that is kept in system database. It forms a history of every work piece manufacturing, that can be further processed and exchanged in supply chain.

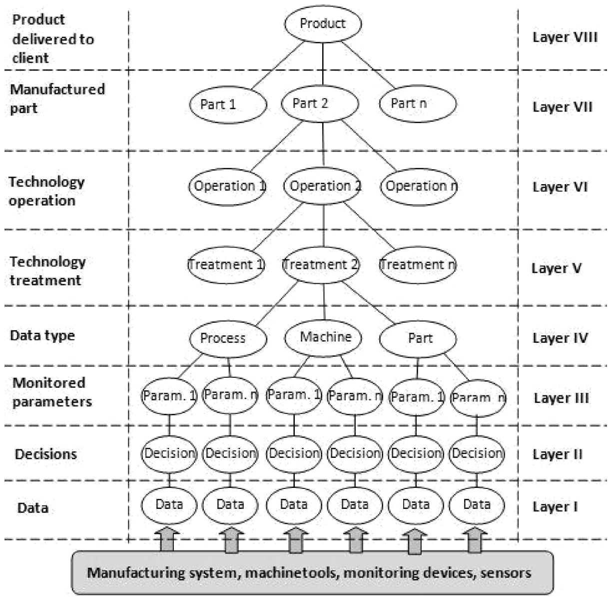

Fig. 8. Multilayer reference model of data integration for manufacturing process.

Further development direction

In the case of air plane company for which the research were performed, some measurement operations done by machine operator requires manual data entering. Most of them are precise pattern tests used for controlling some surfaces after machining process. There is also a need for remarks writing. In that way operator can give for example information for process planners about improvement suggestions or remarks about quality.

Implementation of voice command recognition system is considered to solve this problem. It should be much more useful that currently used keyboards and touchpad panels. Research will go into direction of testing various kinds of speech recognition software. It should allow operator for choosing various functions without using hands, that can be used for example for measurement. Significant problem in applying voice recognition system in the production area is high level of noise. Such a system will be tested to check possibility to filter noise from a shopfloor and recognize operator speech.

Cyber-Physical-Systems – potential area of further development

System presented in the paper have to work in production conditions close to machine tools, cutting process and other process like Electro-Discharge Machining that is characterized by high level of negative influences. IT systems operating in such conditions have to base on special production devices, computers and networks. More over highly changeable production process requires development of solutions that are very flexible and open for reconfiguration. In the presented research a standard production equipment has been used. High cost of such approach limit it to companies with high value added and complicated, costly production process. In the future application of a Cyber-Physical-Systems should allow for wider implementation of integrated monitoring systems by reducing its cost and increasing flexibility.

Cyber-Physical-Systems (CPS), according to NSF definition, are engineered systems that are built from, and depend upon, the seamless integration of computational algorithms and physical components [26]. In reality it will be the next step of development of embedded systems. Such systems that will be similar to smartphones widely used in our life would be easy to program. CPS will offer high computing capacity connected with easily Real Time programming and high resistance on production distortions. High analytical capabilities, possibility of joining sensors, controllers and mechanical solutions with intelligent real-time computing of networked information should create new opportunities for systems integration. According to literature review next generation Cyber-Physical-Systems will be able to execute extraordinary tasks that are difficult to imagine today [27]. They will allow for easier and much cheaper implementation of systems dedicated for manufacturing. Adding new functionality impossible to apply today will be possible as well [28].

Conception of Cyber-Physical-Systems implementation in discrete production system was proposed (Fig. 9) as a potential area of integrate monitoring system development. CPS are defined as a systems involving the close integration of the cyber world and physical environments. They should allow for implementation most of devices connecting physical processes control, signals measurement and communication. Most of those devices have to work according to hard Real Time constrains. They have to process data and communicate with cyber systems, like integrated IT systems operating on management level (supply chain, MRP/ERP, Shop Floor Control, etc.). Development of CPS and its implementation in such a systems will allow for increasing its flexibility and functionality as well as reducing implementation cost.

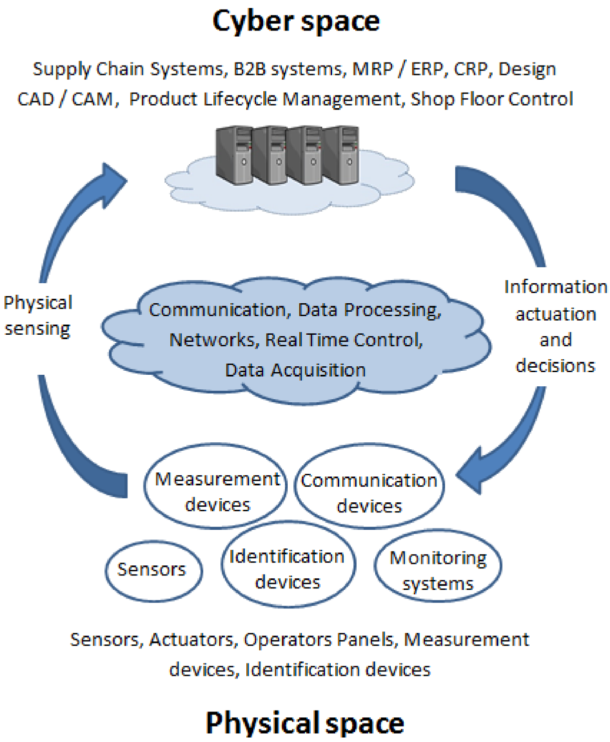

Fig. 9. Conception of the Cyber-Physical-Systems implementation in monitoring of discrete production process and integration of machine operators with Shop Floor Control.

Conclusions

Integration of the information flow in production became more and more important. Integrated management systems allow for easy and automatic information exchange between companies in supply chain. However, sill a problem is on-line monitoring of production process and collecting a product manufacturing history. Usually information and data on the shop floor level is collected in the form of paper reports prepared by machine operators, quality inspectors, area leaders, middle management stuff, etc. This situation have negative impact on performance and efficiency of whole production process. Technical stuff should focus on performing production tasks not preparing paper written reports. Moreover online information collection and processing is impossible on the base of paper reports. Solution for this situation is implementation of IT systems. In continuous production process systems based on SCADA solutions are usually implemented. However, in discrete production equipped in CNC machines functionality of those systems is not enough. This situation will force manufacturing companies to develop dedicated solutions for integration of information flow on the shop floor level.

The integrated monitoring system presented in the paper can be a kind of demonstrator for manufacturing companies equipped in CNC machine tools and other not fully automated machines, as well. A functionality focused on automated process condition and machine monitoring is connected with automation of information exchange between machine operator and IT system. System allows for 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. Moreover operator activity is supported by automatic documentation and parts identification and automatic entering data from measurement devices. Planed implementation of voice recognition module will open new area of operator communication with IT system.

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