DEVELOPMENT OF ADAPTIVE ASSEMBLY PROCESSES

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Adaptive assembly and manufacturing system (AAMS) reach intelligence and adaptation capability through the close interplay between four areas: electronics, mechanics, control and software engineering. The paper deals with the AAMS in order to accomplish enhanced adaptability to unstable environments through increased sensing capability and comprehensive control logics, able to self-optimize manufacturing performance and to realize intelligent and adaptive behaviour in assembly processes. In addition, the paper discusses with development trends of adaptive assembly processes.

KEYWORDS
adaptive assembly processes, development trends, sustainable production, advanced industrial engineering, virtual commissioning

1 INTRODUCTION

The adaptive assembly has, for example, very close to the intelligent product. The assembly can be adapted to production and material requirements of the product. The system can be adapted to the production (ideal quickly). The adaptive assembly allows changing the production operations, or the parameters (product size, roughness etc.).

Manufacturing is the dominant sector of the European economy and it exerts a strong technology pull on research and innovation, so the EU depends strongly on the dynamism of its manufacturing industry. The competitive and sustainable reaction to such changes and challenges requires a transformation of Industry.

An intelligent product is a physical and information-based representation of an item, which possesses a unique identification, is capable of communicating effectively with its environment, can retain or store data about itself, deploys a language to display its features, production requirements etc., is capable of participating in or making decisions relevant to its own destiny [McFarlane 2002].

Tecnomatix platform is a standard PLM commercial product. In the Department of Industrial Engineering, we have huge experience with this software platform. With the help of these tools, we can verify the synergy between design and management tools, and then perform some experiments with their use. The aim is to link PLM systems with real automation. For example, the automaker Mercedes through virtual commissioning has built a completely new assembly hall. Before starting the actual operation, the reliability algorithms and control systems fully was verified in the virtual space. This has brought great savings in time because the programmer can in a virtual environment reflecting the reality of control systems without being required to do on real devices.

Moreover, in the industrial practice is verified the operation of control systems mostly in the real application. The project of virtual commissioning is one of the solutions using Tecnomatix platform from Siemens and individual project planning tools such as Process simulate, Process designer, etc. that we will form to our mini factory. Real control systems are linked to the virtual space of the OPC server or other communication protocols and are verified their functions.

With Tecnomatix assembly simulation and validation, you can use virtual assembly to simulate and validate your assembly sequences, including all required human and machine interaction. When you use assembly planning tools to digitally validate production systems, you can reduce tool installation time and minimize system try-out costs. This ability to digitally optimize assembly processes and validate assembly feasibility can also significantly increase productivity [Siemens 2016].

Optimizing the assembly process upfront, prior to the start of production, results in right-first-time manufacturing plans and improves time-to-volume-production. You can reduce your overall planning process time, shorten production setup, achieve faster ramp-up and deliver high-quality products right the first time.

Control engineering is critical for the achievement of system performances and for logic specifications [Isermann 1997]: complex control logics must be developed in a short time on previously designed electro-mechanical hardware. In practice, the control system development is generally carried out only during the final stages of the design process. It is often realized directly on the assembled system and it still continues during the production ramp-up phase (commissioning) [Reinhart 2007].

The mechanical engineer is the engineer, who can do a wide range of concept and design of manufacturing systems, construction, industrial engineering and management. Control engineer is basically a programmer, either PLC, C ++ and he know creating a control code for example code of decentralized management etc.

This paper is structured in the form of four main sections, where are demonstrated concepts contributing to the development of AAMS in order to accomplish enhanced adaptability to unstable environments through increased sensing capability and comprehensive control logics, able to self-optimize manufacturing performance and to realize intelligent and adaptive behaviour in assembly processes. In section 2 a literature survey is presented for supporting the analysis of new knowledge in adaptive assembly and virtual commissioning. In section 3 a detailed explanation of the problem is given. In section 4 our method for mechatronic design of adaptive assembly system is proposed and the required tools are described. Section 5 reports the case study of adaptive assembly. Finally, a short summary and an outlook are given in the conclusion (section 6).

2 LITERATURE SURVEY

An objective of this research is a visible contribution to realizing the vision of an adaptive assembly and manufacturing system while simultaneously reducing the demand for losses as well as increasing the efficiency of resources in assembly processes.

Future manufacturing and assembly systems must enable product and process innovations and rapid changes performing cost-effective flexibility and adaptability to environment variations and changes.

The adaptive behaviours defined by the control logics are then physically performed by electro-mechanical hardware, previously designed. Mutual interactions between adaptive behaviour control logics and electro-mechanical hardware should be accurately evaluated, since they often causes commissioning time delays and imperfect optimization of the adaptive manufacturing systems [AberdeenGroup Inc. 2006].

Adaptive manufacturing systems can be regarded as complex mechatronic systems. According to Burmester et al. [Burmester 2008], these systems continuously perform three actions that are shown in Fig. 1.

Figure 1. Three actions of adaptive manufacturing system

Concluding, automation industry asks for novel engineering methods focused on mechatronic design of adaptive manufacturing systems. Such methods are requested to introduce the design and validation of control logics during the first steps of the mechanical and system design, in order to mediate conflicting requirements and to exploit synergistic solutions. This approach should aim to enhance the role of behavioural simulation in engineering, to virtually explore all the solution spaces of the mechatronic systems design variants [Pellicciari 2009].

In most case studies of automation technology application, the story typically revolves around the selection of a new technology to solve a production or cost issue. But as supply chains grow increasingly connected through use of specific technologies, it has become more common for manufacturers to switch technologies at the request of a customer [Greenfield 2013].

As pointed out by Bradley, mechatronic systems [Bradley 2000] are technical systems combining technologies applied in mechanical and electrical engineering as well as in computer science. Future mechatronic systems are expected to be composed of interacting systems rather than isolated solutions for individual devices. Networking and ever increasing local computational power will enable sophisticated mechatronic systems, which will not merely feature more advanced digital control, but also include rather complex software coordination and information management capabilities. To handle the resulting complexity, each single unit of such composite systems must be able to react autonomously and flexibly to changing environmental settings.

The adaptation capabilities may range from online parameter adaptation [Zouriktuev 2008] to structural adaptations [Cao 2007]. These methods need the creation of a knowledge base where processes are mathematically modelled in their detailed behaviour and the related parameters are sensed [Isermann 1997].

Rapidly changing demand and mass customization require highly flexible and adaptive manufacturing systems. Manufacturing operations have evolved in order to keep up by organizing themselves into smaller units of specialized production processes that are combined in different ways to create different products. Human workers are integral in the manufacturing systems and they too must be flexible and adaptive [Yew 2016].

Flexibility has become one of the most useful and necessary tool in today's competitive markets. Manufacturing flexibility is widely recognised as a critical component to achieving a competitive advantage in the marketplace [Jain 2013].

Virtual reality (VR) assembly tools create an immersive VR environment with 3D representations of a product, the human operator and the work environment. Advanced 3D human-computer interaction (HCI) interfaces are used to simulate the manual assembly process [Ng 2013].

Grid technology has been recognised as a promising paradigm for the next generation manufacturing systems. Researchers have attempted to apply grid technology to product design, manufacturing resource integration and sharing, enterprise management, enterprise collaboration, resource optimal allocation and scheduling, and to enable the digitalisation of enterprise information as an implementation methodology [Tao 2011].

For example, the companies IBM and NVIDIA continue to be in lock step in bringing its latest GPU technology to the cloud [Fuochi 2016].

An effective design of such complex systems requires interdisciplinary knowledge and advanced software tools. PLM platforms enable engineers to concurrently design a product and its manufacturing process, thanks to CAE (Computer-Aided Engineering) and CAM (Computer-Aided Manufacturing) tools embedded in CAD (Computer-Aided Design) 3D environments.

Traditional Product Lifecycle Management (PLM) solutions focus mostly on the product data management and design house-keeping aspects to maintain complete and consistent product information during product R&D. Thus, PLMs are not necessarily keen on supporting quick-to-market and mass-customization. Research overcomes the current PLM deficiency by enabling the Modularized product Design for Assembly (MDfA) and Collaborative Design Process (CDP) [Trappey 2008].

CAE and CAM tools allow by now the validation of very complex mechanical behaviours. The CAE systems are used as analytical, computational and simulation capabilities in the field of engineering. For instance, the robustness testing components, testing their strength, thermal stress, and flow and kinematics simulation related to the casting and making components. They are mainly used for decision support design teams in the sectors of automotive, aerospace and shipbuilding. The aim is reducing the cost and time of product development, increased security and durability of production components. In any case, the CAE systems are able to verify the design of computer simulation without performing tests of a physical prototype.

3 PROBLEM DEFINITION

With the level of automation increases the complexity of the production facilities and thus is associated with the problematic commissioning. For reducing the time required for the implementation of new facilities, but also on existing facilities is appropriate to apply the methods and technologies of the Digital factory (DF). Digital factory is a virtual image of the real production that shows the production processes in a virtual environment. DF is mainly used for planning, simulation and optimization of the production of complex products. Digital factory concept is based on PLM systems based on conventional CAD/CAM systems.

According to CIM (Computer Integrated Manufacturing) data reputable agency the implementation of the Digital factory achieves significant benefits:

- cost savings through better use of resources of 30 %,
- cost savings achieved by optimizing material flows 35 %,
- reduction of the number of machines, tools and workplaces by 40 %,
- total manufacturing production growth of 15 %,
- reduce time to market for new products by 30 %. [Ceit group, 2016]

An example of comparison between conventional production line and technologies of the Digital factory is shown in Fig. 2.

Figure 2. Example of then and now manufacturing (real vs. virtual production) [Ceit group 2016]

Generally, it deals with the creation and management of virtual model of an existing or planned system (equipment, production and assembly lines, and layout). Terms of an efficiency of engineering processes are mainly about design and simulation. This concept, where we have a virtual model of replicating real, but it is possible and desirable to also be used for visualization and especially for emulation system. The visualization is focused on the current online data in a virtual system. On the other hand, the emulation allows interface of real control algorithms emulsified in a virtual system that can respond to real data from the process. Emulation in the pre-production stage of the process automation is referred to as Virtual Commissioning. The concept of Virtual Commissioning is particularly suitable to verify the functionality, reliability and safety of programmed control algorithms in a virtual environment. While in normal deployment of automated or robotic system, the phase of programming and commissioning begins only when the physical hardware is created, using Virtual Commissioning is possible to skip the stage of the production system and move to the designing of a model in a CAD/CAM. From this point of view, Virtual Commissioning with regards to Industry 4.0 are directly related to PLM systems and connects the virtual with the physical world.

One of the most popular PLM systems implemented the concept of Virtual Commissioning is Tecnomatix from Siemens. Tecnomatix enables interconnection real managing hardware (PLC) with a virtual system in the tool Process Simulate. Department of Industrial Engineering at the University of Zilina built the future development of AGV logistics systems on the concept of Virtual Commissioning. CAE are systems that simulate design solutions before starting the real production. These systems belong to the range of (CIM) software tool and support the engineering work in the developmental stages of design.

The integration between mechanical, electronic and control software simulations is a field of many recent researches [Kanai 2007], [Shen 2005]**.** In their works Ferretti et al. [Ferretti 2004] evaluated some important requirements for a virtual simulation environment: multi-domain simulation, modular modelling and software reuse, build-in model libraries and customization, reliability and efficiency of numerical simulation, integration with CAD, interfaces for pre- and post-processing, simulation paradigm and object orientation.

Mechatronics is a dynamic, multidisciplinary subject combining three engineering fields: mechanical, electrical and software engineering. This highly integrated approach creates smart, inventive and ever more efficient solutions for a wide range of high-tech engineering problems. Adaptive manufacturing systems achieve intelligence and adaptation capabilities through the close interaction between mechanics, electronics, control and software engineering. The mechatronic design of intelligent manufacturing behaviours is of paramount importance for the final performances of complex systems and requires deep integration between mechanical and control engineering that is shown in Fig. 3.

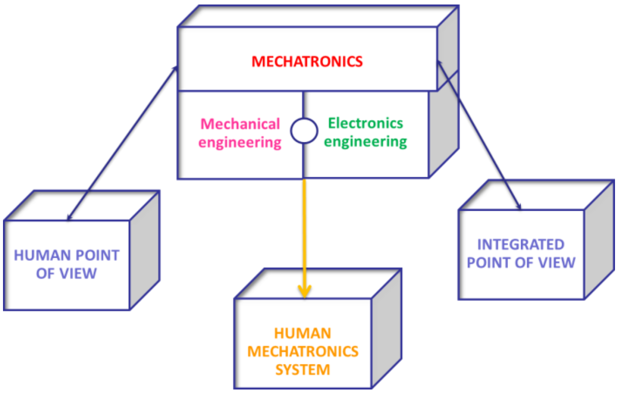

Figure 3. The request for integration of mechanical and electronics engineering

Therefore, the research questions in this context are following:

Human

- What is easy for people to use?
- What makes people happy?
- How could it be helpful to people?

System

- What is necessary to resolve problems?
- What is the optimum combination of product and service?

This research question is based on two hypotheses:

- ***Hypothesis 1:*** The best challenge to solve with Virtual Commissioning is the request to embed all the product and process knowledge possessed by the mechanical engineers into the control system development, simultaneously, to enable the mechanical engineers to evaluate the real mechatronic and dynamic performances of the assembly manufacturing system designed and the adaptive behaviours formulated, so to involve control engineers into the earlier mechanical design.
- ***Hypothesis 2:*** Virtual reality and modern pattern recognition system as a support tool in the assembly process are important enablers for measuring, controlling and improving adaptive assembly.

Holistic approaches to design and operate modern green production systems are required to cope with those challenges adequately. To analyse production systems with respect to economic, ecological and energy objectives, a specific set of data is necessary as an informational basis. The definition of input and output flows is a prerequisite to determine required economic, ecological and energy information on production systems [Micieta 2013].

Common industrial practice very often follows a sequential process (Fig. 4A) hiding synergy, [AberdeenGroup Inc. 2006]. Mechanical engineers manage the design process because they are generally the most expert on product and process know how, they are able to deploy the manufacturing system layout (developed through CAD, CAE tools) and to define the knowledge base that will rule all the mechatronic adaptive behaviours [Isermann 1997]. Mechanical engineers identify the adaptive behaviours to realize and then plan custom adaptive strategies. The system is then progressively developed in its mechanical hardware and provided with the necessary mechatronic modules.

In common practice, control engineers are marginally involved in the manufacturing system early design and layout development. Control engineers are really involved just in the final stages where they are asked to develop control strategies to accomplish the cycles specifications, previously defined by mechanical engineers (the product and process know how experts) and to program all the mechatronic systems. In fact the real complex control logics will be really designed in detail by control engineers only during the last stages of the manufacturing system development, or even during final commissioning [Reinhart 2007].

This common practice often experiences a lack in communication between mechanical, electronic and software engineers about the product/process knowledge base with subsequent delays and not optimized manufacturing operations.

In any case, the control engineers have only reduced possibilities to operate changes in the mechanical layout to optimize the control and the final performances of the adaptive manufacturing system. The drawbacks of this common practice are evident and well-studied [Burmester 2008] especially when the logic behaviours and control strategies become complex and sophisticated. On the other hand it must be underlined that it is fundamental to focus on the creation of the knowledge base that rules the process behaviour and this can be effectively carried out only by the product and process know-how experts, the mechanical engineers. Then, the state of the art of mechatronic manufacturing system design suffers the need to integrate the control engineering activities into the early stages of the design. This is fundamental to validate and optimize the mechatronic systems choices and mechanical layout design variants with the real performances of the software and control systems, really evaluating the real adaptive behaviour and cycle performances of the mechatronic system.

New Virtual Commissioning tools are now available: they provide behavioural simulation environments where software control algorithms can be evaluated on virtual prototypes without waiting for the manufacturing system assembly (Fig. 4B), then virtually emulating the commissioning process. Virtual Commissioning provide then interdisciplinary environments where mechanical and control engineering activities can finally communicate and where their synergistic contribute can be numerically evaluated.

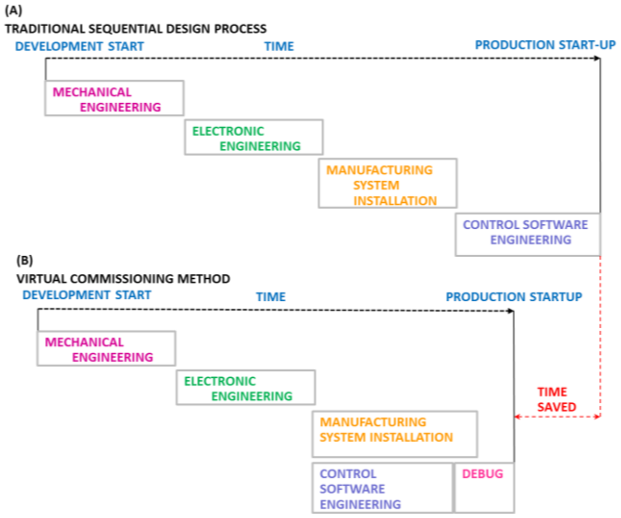

Figure 4. Traditional sequential design process vs. virtual commissioning method [Pellicciari 2009]

4 DESIGN METHOD

4.1 The use of Augmented Reality (AR) in the assembly process

Augmented reality (AR) is a combination of the real world with the virtual environment. Among the limitations of virtual reality in the assembly process may be classified:

- complexity and computational complexity of virtual reality,
- calibration of virtual reality,
- collision detection,
- lack of feedback - directly experience and perception of reality.

Nowadays, most research in the field of augmented reality is directed to the use of real-time capturing video that is digitally processed with adding computer-generated graphics.

The resulting image, which occurs by mixing video with capture digital content can be displayed on HMD (Head Mounted Display – the display placing on the user's head) or on the monitor.

The use of augmented reality in the assembly process (Fig. 5) eliminates the need for additional installation procedures. A worker in his view sees not only the actual physical assembled parts but at the same time the structure in virtual form, which is displayed him by assembly process. There are several software programs to create augmented reality, for example Metaio Unifeye Design, BuildAR, Artista or DART.

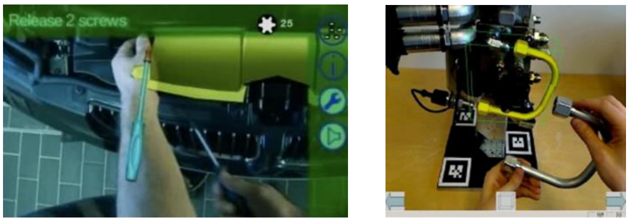

Figure 5. The use of augmented reality as a support in assembly [Woollaston 2014]

Design of the adaptive assembly and manufacturing system should be taken into account two dimensions:

Dimension 1: Input to new assembly system (planning of new structure)
The methodology provides the support for detailed processing of existing practices from the viewpoint of the effectiveness of assembly processes in the design stage (cooperation mechanical and control engineering for Virtual Commissioning).

Dimension 2: The implementation of restructuring (adding, changing, and reducing)
Using the tools of industrial engineering allows you to search the potentials of improvements in existing factories. To ensure the long-term sustainability of production is required to be able to control of assembly processes *(the use of Digital factory).*

4.2 *The modern pattern recognition system as a support tool in the assembly process*

In the industry are mainly used 3D camera systems operating on the principle of scanning the profile of line illumination on moving objects. The advantage of this principle of acquiring 3D information about objects is achieved high speed scanning profiles and subsequent processing speed of the information obtained. Smart cameras can be deployed in a variety of industries (Fig. 6).

Figure 6. The use of intelligent smart cameras as a support in assembly [Binasova 2016]

4.3 *Virtual Commissioning tools*

We propose a design method based on virtual simulations since conceptual design stage. Instead of using Virtual Commissioning tools only to validate control logics, we used them also to create, model and share the product and process knowledge base, to search for new solution spaces and to evaluate the behaviour resulting from the interaction of mechanical, electronic and software design solutions. Then, control logics and software design phase can start coarsely in the early design process and be strictly integrated with mechanical engineering. We developed the method specifically aiming at adaptive manufacturing system design. For this reason we evaluated Virtual Commissioning tools focused on PLC controls, and we chose to use Tecnomatix from Siemens.

Tecnomatix is a comprehensive portfolio of digital manufacturing solutions that help you realize innovation by synchronizing product engineering, manufacturing engineering and production. The Tecnomatix process design (Fig. 7) and management solution allows design and manufacturing engineers to concurrently develop product and process planning definitions [Siemens 2016].

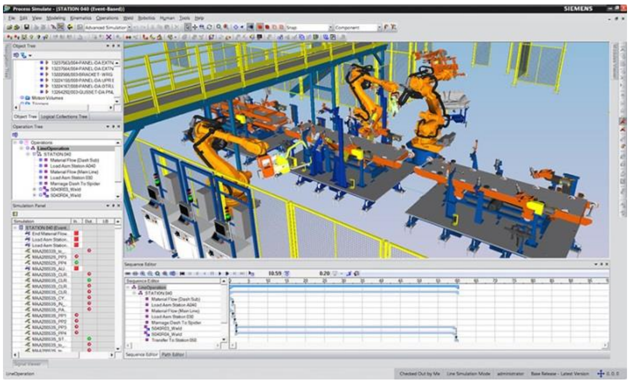

Figure 7. Example of Process Designer - module for design of production processes [KPI 2016]

This tool integrates, as part of a PLM platform, different domain activities within a common virtual environment. Mechanical engineers can now become really aware of the actual structure and behaviour of the device they design. In this way both the mechanical and control engineers can use the same tool in a user friendly environment to develop a mechatronic virtual prototype where they can effectively explore all the solution spaces and then proceed to a real final optimization. We believe the greatest challenge to solve with Virtual Commissioning is the need to embed all the product and process knowledge possessed by the mechanical engineers into the control system development and, at the same time, to enable the mechanical engineers to evaluate the real mechatronic and dynamic performances of the manufacturing system designed and the adaptive behaviours formulated, thus to involve control engineers into the earlier mechanical design. Actually, the knowledge base, developed for the adaptive and self-optimizing behaviour of mechatronic systems is just a small part of the whole product or process knowledge at the foundation of the knowledge base algorithm calculated.

4.4 *"Pick by" systems in the assembly process*

Use of augmented reality in the assembly increases human performance and reduces the time required to meet the mounting tasks, reduce waste and reduces the cognitive workload. In this context of improving the quality of the assembly processes are used "Pick by" systems. The group "Pick by" includes systems:

- Pick by Light (Fig. 8),
- Pick by Voice,
- Pick by Vision,
- Pick & Work.

Figure 8. Example of "Pick by light" system [Dematic 2016]

5 CASE STUDY

5.1 *Final Virtual Commissioning*

The design process of the state of the art adaptive manufacturing systems is mainly focused on the identification of adaptive behaviours opportunities and their knowledge base creation. For this reason, Virtual Commissioning tools represent a strategic advantage in validating and selecting solutions really actionable with robust mechatronic solutions inside the cycle time specifications. Early virtual evaluation of conceptual design solutions for the adaptive manufacturing system is shown in Fig. 9.

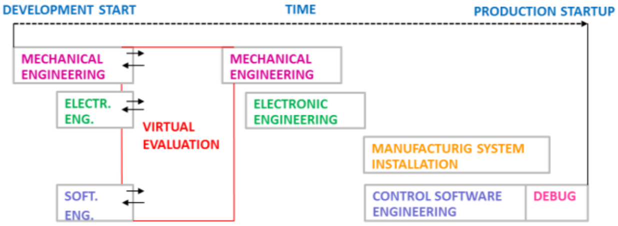

Figure 9. Early virtual evaluation of conceptual design solutions for the adaptive manufacturing system

A good example of a modern approach to design and testing logistics and assembly systems supporting virtual reality and simulation solutions is developed by CEIT (Central European Institute of Technology, Zilina, Slovakia), tradename is CEIT Table (Fig. 10) well analysed by [Gregor 2013].

The users can simply moving your hand to change the project of logistics concept of assembly system. The system automatically evaluates the length of material flow, transit times, transport capacity and a number of other parameters. The team (mechanical and control engineers, planners, manufacturing engineers, industrial engineers etc.) can show especially quickly in their view, which option is the best, even in a 3D environment.

Already in the phase of deployment of machinery and equipment we can eliminate any collisions that in 2D environment may not be reflected.

Figure 10. Example of "Pick by light" system [Gregor 2015]

We can use also the mobile information system based on augmented reality technology that is shown in Fig. 11.

Figure 11. Augmented Reality Mobile Information System [Bajana 2015]

5.2 *Adaptive assembly process*

First prerequisite of adaptability is a functional modularity of assembly system, which is often the condition for rapid reconfiguration of assembly system. Modularity is a sufficient condition for reconfiguration, but assembly system can be reconfigurable, unless it does not fulfil the conditions of modularity. The individual elements of the assembly system must be designed so that from a technical (hardware, mechanical, energy), as well as from a software site (control) were able to cooperate and communicate.

The resulting modularity of assembly elements allows scalability and adaptability of the whole assembly system. Adaptive assembly systems use a wide range of advanced technologies. Individual elements of the assembly system are equipped with small, powerful computers, so-called Embedding Intelligence to extend their functionality and autonomy. The ability to mutual communicate is supported by a new generation of Wireless sensor networks utilizing intelligent information infrastructure, Internet of Things and cloud services.

Adaptive assembly systems require clear identification of all objects (static and dynamic) that are located in the assembly system. In every time and in every place to be each assembly unit clearly identified. This requirement is especially necessary at a solution where assembly activities are controlled by the specified product. In this dynamic environment will create a lot of randomness and the needs of alternative strategies to solve transportation and manipulation, which will require permanent reprogramming of available resources. For uniquely identify of objects are most often using RFID technology (Radio Frequency Identification technology).

The features of adaptive assembly systems can be simply defined as the ability to be autonomous, active and quickly adapt to sudden and unexpected changes that arise in their area and are beyond the originally defined system functions. Adaptive assembly system must therefore possess the ability to change its structure, its functions and its capacity. These abilities ensure a rapid, cheap and easy way to adapt to change. One of the new technologies (supporting the adaptability of systems) is a technology of reconfiguration. It allows changing the structure of systems to adaptation functionality and capacity of the system to changing requirements of the system environment.

We propose an engineering method for the mechatronic design of adaptive assembly systems which fully integrates the Virtual Commissioning environments in the design and development process (Fig. 9), setting up behavioural models and simulations that will be intensively used to virtually explore all new solution spaces interactively since earlier system design and concept validation stage. The design of adaptive manufacturing system architecture is shown in Fig. 12.

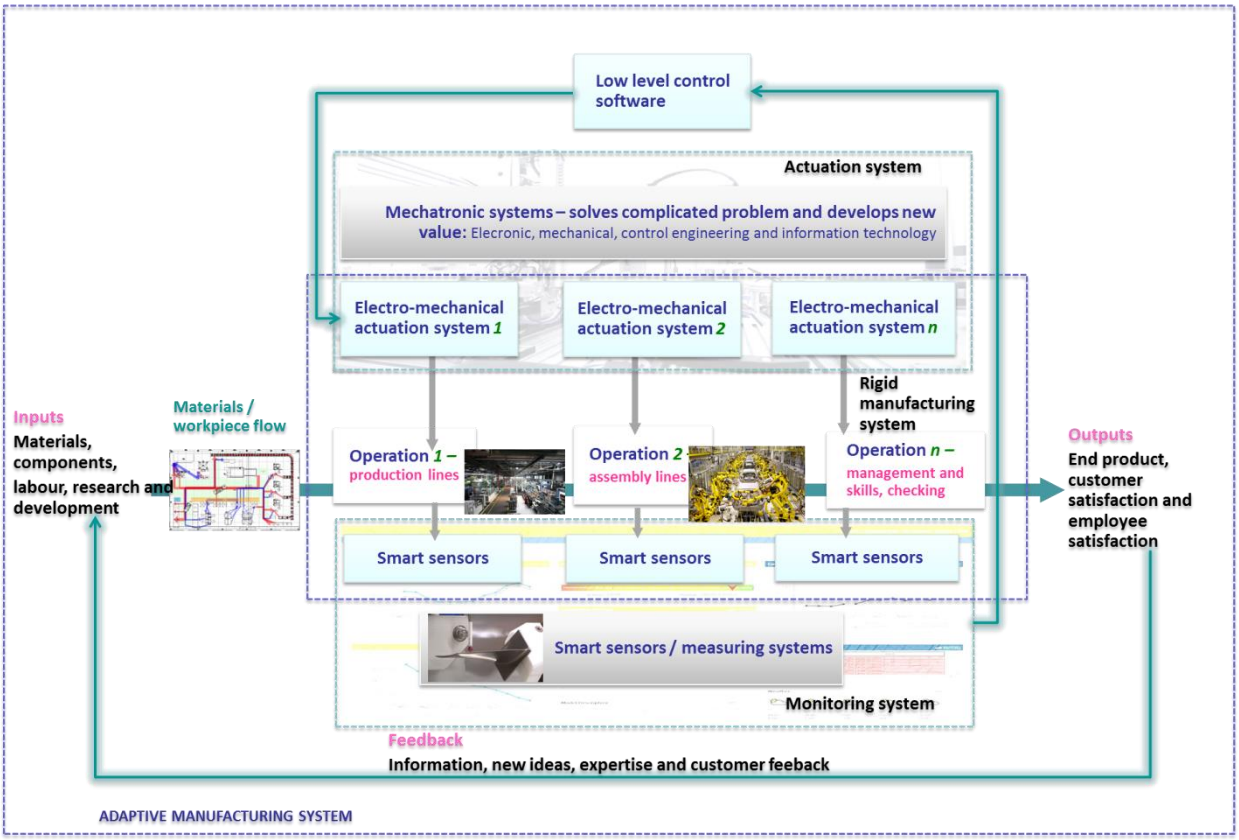

Figure 12. Adaptive manufacturing system architecture - the approach of integrating technical control system and action system

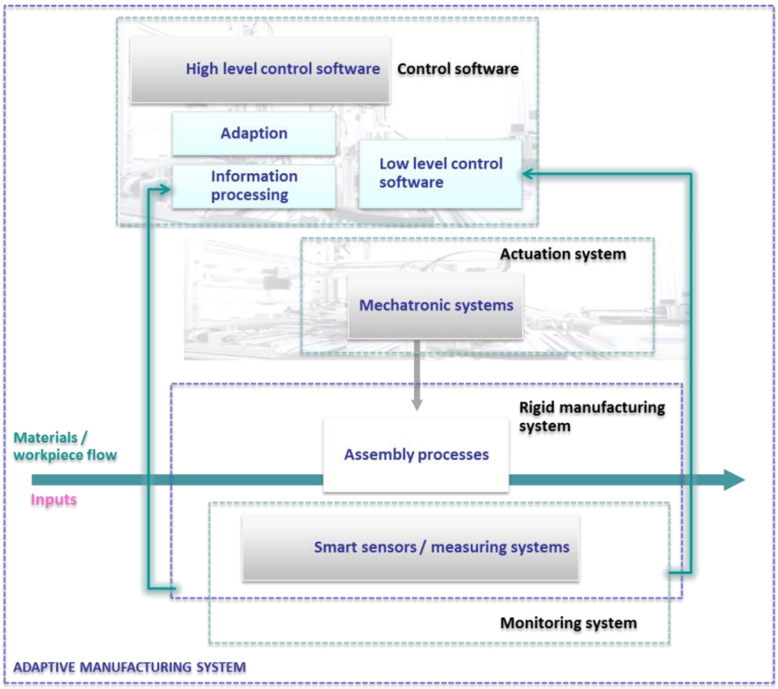

Figure 13. Adaptive assembly system

Adaptive manufacturing systems (Fig. 13) accomplish enhanced adaptability to changeable environments through increased sensing capabilities and complex control logics, able to self-optimize manufacturing performances and to realize intelligent and adaptive behaviours. The ability to quickly adapt operations, supply chains and products is essential to achieving manufacturing excellence in today's globally competitive markets. The enterprises that can quickly adjust to changing conditions and new market opportunities can "seize the moment" to gain competitive advantage and improve operating margins. Commissioning includes all functions of electronic devices, ranging from testing the sensors and actuators, various functions of production and distribution of electric drives through parameterization of frequency inverters and booster to test command exchange by application of the device such as control of welding or gluing.

The first phase of Virtual Commissioning ends with the ***test relevant manual features of equipment.***

This is followed by the ***implementation of automatic functions*** in accordance with simulated processes of equipment.

Then is continued ***optimization phase*** which provides the course of the designed device parameters such as cycle time and availability. In this respect, it plays an important role in the current documentation concerning the various stages of the commissioning process.

New features of adaptive assembly are:

- Holonic autonomous logistics management system in real time [Durica 2015],
- modular structure supporting reconfiguration (plug and produce),
- mechatronic systems and embedding intelligence, sensors and actuators of equipment (systems for internal shares),
- sensor technology for the surroundings of the assembly system (for external actions),
- simulation-emulation systems for decision support,
- standardized interfaces (mechanical, electrical, electronic, software, network etc.,
- learning system (prior to the event, in action after the event)
- knowledge base,
- base of best practices.

6 CONCLUSIONS

Current trends of adaptive assembly approaches help enterprises develop and launch new products more quickly. ***The main scientific contribution is*** the case study of the mechatronic design method showed an easier and more effective way to develop adaptive manufacturing solutions and the overview of development trends in adaptive assembly. A teamwork approach is used, with all areas involved in the project working on the project at the same time. ***The end result is that:***

- The new product is brought to the market much more quickly.
- The enterprise may be able to charge a premium price that will give a better profit margin and help recoup R&D (Research and Development) costs.
- There is less likelihood of a need to modify the product later due to unforeseen problems.
- A greater sense of involvement across business functions improves staff commitment to the project.
- This can therefore be a source of competitive advantage (first mover advantage) for the enterprise if it can get a reliable new product into the market and build brand loyalty before its competitors.

The two hypotheses introduced in section 3 can be confirmed:
According to our method, mechanical engineers must not develop the real control code but just define the nominal behaviour they need to perform the manufacturing process as desired. Then control engineers proceed to develop the final complete control logics integrating it with special cycle diagrams, safety, Human Machine Interface specifications, etc. ***(Hypothesis 1).***
Virtual reality, augmented reality and modern pattern recognition system are important enablers for measuring, controlling and improving adaptive assembly work with safety and precision ***(Hypothesis 2).***
Reconfigurable Manufacturing Systems (RMS) constitute a new class of systems characterized by adjustable structure and design focus. A system built with changeable structure provides scalability and customized flexibility and focuses on a part family, thus generating a responsive reconfigurable system. The flexibility of RMS, though really only "customized flexibility", provides all the flexibility needed to process that entire part family [Koren 2010]. Digitizing, modelling, simulation and emulation are used to understanding of comprehensive manufacturing processes and creation of new knowledge, which is used for optimization of real production systems [Gregor 2015]. Depending on the model, especially lightweight materials are used for the individual parts, for example, aluminum in the front end and chassis [Kohar 2014]. Intelligent manufacturing systems are socio-economic system with the ability to autonomously identify system changes and impulses from the environment, their causes and to use the obtained knowledge for self-learning, adapting and responding to all changes of the surrounding environment in a way similar to human response [Krajcovic 2013]. The main task of manufacturing system reconfigurability lies in hardware and software components changing [Micieta 2015] [Rakyta 2014]. Reconfigurable manufacturing systems are proposed as a solution to unpredictable fluctuations in market demand and market turbulence [Westkamper 2009]. Realising cost-effective energy efficiency potentials will be beneficial not only for individual energy consumers but also for the economy as a whole [Micietova 2014], [Dulina 2014]. The global market are imposing strong changing conditions for companies running their businesses, something comprising complex and large scale systems [Leitao 2013].

Virtual Commissioning environments offer engineers new opportunities for the design of complex intelligent behaviours and for the enhancement of the performance of adaptive manufacturing systems. Virtual Commissioning tools can be used to virtually explore new solution spaces for an effective mechatronic optimization. Therefore***, further research*** intends to specify the concept and to develop a demonstrator for using these methods by ***next case studies that other technology suitable for adaptive assembly (artificial intelligence, mobile robotics, smart containers, etc.) can be applied***.

Reducing waste in manufacturing enterprises helps reduce manufacturing costs, and helps keep our industries competitive [Staszewska 2013]. Advanced industrial engineering is focused on three main subgroups: industrial networks, adaptive production and digital engineering [Micieta 2014], [Binasova 2014]***. In the future, the project of Virtual Commissioning will start,*** where one of the solutions is that by Tecnomatix platform from Siemens, and individual project planning tools such as Process Simulate, Process Designer and the like, we create our mini factory***.*** Real control systems in it then we can connect with the virtual space via an OPC server or other communication protocols and verify their functionality. Tecnomatix platform is a standard PLM commercial product, with which we have extensive experience. With the assistance of these tools we can verify the synergy between design and management tools, and then experiment with their use. The adaptive assembly is currently one of the main research topics and the future goal of development engineers. The local solutions for assembly processes are nowadays directly implemented in industry. New, adaptive assembly concepts will be holistic; they will use agent control and the plenty of new advanced technologies. The main goal which is followed by adaptive assembly is the offering of effective services for dynamically changed production. As shown by the world statistics, confirmed by experts of University of Zilina, (Faculty of Mechanical Engineering, Department of Industrial engineering) new concepts of assembly increase efficiency of assembly processes. For example, the unit costs of mobile business robotic systems without human operators are 3-6 USD per hour of their work. Costs comparable activities are manned at 25-35 USD per hour worked. Solution benefits of adaptive assembly - a simple comparison of a direct cost saving of 80 to 90 % and also improved performance of at least 20 to 30 %.

Contemporary automatic assembly systems used in the automotive industry are implemented using a deterministic task approach. The throughput of such systems is controlled mainly by the quality of the piece parts and the tooling. Wear and uncertain part geometry are the major sources disturbing the process, and causing dimensional variations. As a solution to these dimensional errors an adaptive system is developed an active system, where the process state is monitored by a number of sensors and the measured information is used to adjust the process on-line. Performance of the system was evaluated experimentally indicating its ability to reduce in-process variation by approximately 50 %.

The main aim of this paper is the realization of the concept of education on the issues "Adaptive assembly - design and construction of the new product and process design and production start-up" with a direct impact on practice. Virtual Commissioning of production systems is a tool of the concept of Industry 4.0. The education will be focused mainly on the use of new technology for Virtual Commissioning of new systems into service - i.e. linking a virtual 3D model of the concept (e.g. assembly line) with real automation features (e.g. Simatic) to verify and debug PLC programs, including the concept at the time when that does not yet exist physically. It is a multidisciplinary problem that includes mechanical and electronic parts, including PLC programming.

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REFERENCES

[AberdeenGroup Inc. 2006] AberdeenGroup Inc. The Mechatronics System Design Benchmark Report. AberdeenGroup White Paper, Boston, MA, USA, 2006, [2016-06-17]. Available from < http://www.plm.automation.siemens.com/zh_cn/Images/aberdeen_-_the_mechatronics_system_design_benchmark_report_06-08-31_tcm78-4642.pdf >.

[Binasova 2014] Binasova, V. Energy-efficient manufacturing>. enterprise. Disertation thesis. University of Zilina. 2014, pp 150-155 (in Slovak)

[Bajana 2016] Bajana, J. ARMIS - Augmented Reality Mobile Information System. University of Zilina. 2016, Available from < https://www.youtube.com/watch?v=KHiog6KPRXY>.

[Bradley 2000] Bradley, D., et al. Mechatronics: and the design of intelligent machines and systems. Cheltenham : Stanley Thornes, 2000. pp 20-27. ISBN 0-7487-5443-1

[Burmester 2008] Burmester, S., et al. Tool support for the design of self-optimizing mechatronic multi-agent systems. International Journal on Software Tools for Technology Transfer, 2008, Vol. 10, pp 207–222. ISSN 1433-2787. Available from < http://link.springer.com/article/10.1007%2Fs10009-008-0067-0#page-1>.

[Cao 2007] Cao, Y., et al. Reconfigurable control structure for robots in assembly. Journal of Intelligent & Robotic Systems, 2007, Vol. 50, pp 419-439. ISSN 1573-0409. Available from < http://link.springer.com/article/10.1007%2Fs10846-007-9173-6#/page-1>.

[Ceit group 2016] Ceit group. Digital Factory. Zilina, 2016, [online]. 2016, [2016-06-17]. Available from < http://www.ceitgroup.eu/index.php/en/digital-factory>.

[Dulina 2014] Dulina, L. and Bartanusova, M. Ergonomics in practice and its influence on employees´ performance. Communications: scientific letters of the University of Zilina, 2014, Vol. 16, No. 3A, pp 206-210. ISSN 1335-4205

[Durica 2015] Durica, L., Micieta, B., Bubenik, P., Binasova, V. (2015). Manufacturing multi-agent system with bio-inspired techniques: Codesa-Prime. MM Science Journal. Prague, December 2015, pp 829-837. ISSN 1805-0476. DOI: 10.17973/MMSJ.2015_12_201543

[Fuochi 2016] Fuochi, A. IBM Cloud First to Offer Latest NVIDIA GRID with Tesla M60 GPU, Speeding Up Virtual Desktop Applications. 2016, [2016-06-17]. Available from < http://www-03.ibm.com/press/us/en/pressrelease/49787.wss>.

[Greenfield 2013] Greenfield, D. CAD Switching at Customer's Request. [online]. 2013, [2016-06-17]. Available from <http://www.automationworld.com/design-engineering/cad-switching-customers-request>.

[Gregor 2013] Gregor, M. et al. 2013. Reconfigurable Manufacturing. The solution for the frequent changes in demand.(in Slovak) ProIN – Productivity and Innovation, Vol. 14, No. 3, pp 38-41, ISSN 1339-2271

[Gregor 2015] Gregor, M., Krajcovic, M., Hnat, J. and Hancinsky, V. Utilization of genetic algorithms in the fields of industrial engineering. In: FAIM 2015: proceedings of the 25th international conference on Flexible automation and intelligent manufacturing: 23-26 June, 2015, Wolverhampton, UK. Wolverhampton: University of Wolverhampton, 2015. pp 380-386. ISBN 978-1-910864-00-5

[Isermann 1997] Isermann, R.: Mechatronic systems—a challenge for control engineering. In: Proceedigs of the American Control Conference, Albuquerque, New Mexico, USA, June 1997, DOI: 10.1109/ACC.1997.611932

[Jain 2013] Jain, A., et al. A review on manufacturing flexibility. International Journal of Production Research. Vol. 51, No. 19, pp 5946-5970, DOI: 10.1080/00207543.2013.824627

[Kanai 2007] Kanai, S., et al. A multi-disciplinary distributed simulation environment for mechatronic system design enabling hardware-in-the-loop simulation based on HLA. International Journal for Interactive Design and Manufacturing, 2007, Vo. 1, pp 175–179, ISSN 1955-2513, DOI: 10.1007/s12008-007-0020-6

[Kohar 2014] Kohar, R. and Hrcek, S. Dynamic analysis of a rolling bearing cage with respect to the elastic properties of the cage for the axial and radial load cases. Communications: scientific letters of the University of Zilina, 2014, Vol. 16, No. 3A, pp 74–81. ISSN 1335-4205

[Koren 2010] Koren, Y. and Shpitalni, M. Design of reconfigurable manufacturing systems. Journal of Manufacturing Systems. [online]. Elsevier, 2010, Vol. 29, No. 4, [2015-07-17]. Available from <

http://www.sciencedirect.com/science/article/pii/S0278612511000021>.

[Krajcovic 2013] Krajcovic, M. et al. Intelligent manufacturing systems in concept of digital factory. Communications: scientific letters of the University of Zilina, 2013, Vol. 15, pp 77–87. ISSN 1335-4205. Available from < http://www.uniza.sk/komunikacie/archiv/2013/2/2_2013en.pdf>.

[Leitao 2013] Leitao, P. Towards self-organized service-oriented multi-agent systems. Service Orientation in Holonic and Multi Agent Manufacturing and Robotics. Studies in Computational Intelligence. Vol. 472, Berlin Heidelberg: Springer, 2013. pp 41-56. ISBN 978-3-642-35852-4

[McFarlane 2002] McFarlane, et al. The intelligent product in manufacturing control In: Journal of EAIA (July) [online]. 2002, [2016-06-17]. Available from <http://citeseerx.ist.psu.edu/viewdoc/download?rep=rep1&type=pdf&doi=10.1.1.126.7221>.

[Micieta 2013] Micieta, B. and Binasova, V. Defining requirements for energy efficiency in manufacturing. DAAAM international scientific book 2013. Vienna: DAAAM international Vienna, 2013, pp 887-894. ISSN 1726-9687, ISBN 978-3-901509-94-0

[Micieta 2014] Micieta, B. et al. The approaches of advanced industrial engineering in next generation manufacturing systems. Communications: scientific letters of the University of Zilina, 2014, Vol. 16, No. 3A, pp 101–106. ISSN 1335-4205. Available from <http://www.uniza.sk/komunikacie/archiv/2014/3a/3a_2014en.pdf>.

[Micieta 2015] Micieta, B. et al. System for support the design and optimization of reconfigurable manufacturing systems. MM science journal. Prague, March 2015, pp 542–546. ISSN 1805-0476. DOI: 10.17973/MMSJ.2015_03_201502

[Micietova 2014] Micietova, A. et al. Study of Elastic Deformations in Hard Turning. Key Engineering Materials, 2014, Vol. 581, pp 176–181. ISSN 1662-9795

[Ng 2013] Ng L.X., et al. Integrated product design and assembly planning in an augmented reality environment. Assembly Automation, Vol. 33, No. 4, pp 345-359
[online]. 2016, [2016-06-17]. Available from <https://www.plm.automation.siemens.com/en_us/products/tecnomatix/manufacturing-simulation/assembly/>.

[Shen 2005] Shen, Q., et al. A cooperative virtual prototyping system for mechatronic solution elements based assembly. Adv. Eng. Inform. 19, 2005 pp 169–177

[Ferretti 2004] Ferretti, G., et al. Virtual prototyping of mechatronic systems. Annu. Rev. Control. 2004, Vol. 28, No. 2, pp 193–206

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[Pellicciari 2009] Pellicciari, M., et al. Engineering method for adaptive manufacturing systems design. International Journal on Interactive Design and Manufacturing. 2009, Vol. 3, pp 81-91, DOI 10.1007/s12008-009-0065-9

[Rakyta 2014] Rakyta, M. and Bubenik, P. Data mining technology and its benefits in business practice. In: Manufacturing systems today and tomorrow 2014, ed. Proceedings of the 8th annual international Conference, Liberec, 2014. Liberec: Technical university, pp 6-10. ISBN 978-80-7494-150-4

[Reinhart 2007] Reinhart, G. and Wünsch, G.: Economic application of virtual commissioning to mechatronic production systems. Prod. Eng. Res. Dev. 2007, Vol. 1, No. 1, pp 371-79

[Siemens 2016] Siemens. Assembly Simulation and Validation. 2016. Available from < https://www.plm.automation.siemens.com/en_us/products/tecnomatix/>.

[Staszewska 2013] Staszewska, J. The company Industrial towards the challenges of the twenty-first century. Krakow and Warsaw: Unique, 2013. ISBN 978-83-62314-80-5 (in Polish)

[Tao 2011] Tao, F., et al. A review of the application of grid technology in manufacturing (Review). International Journal of Production Research, 2011, Vol. 49, No. 13, pp 4119-4155. ISSN 0020-7543, DOI: 10.1080/00207541003801234

[Trappey 2008] Trappey, A.J.C. and Hsiao, D.W.. Applying collaborative design and modularized assembly for automotive ODM supply chain integration. Comput. Ind. 2008, Vol. 59, pp 277–287

[Westkamper 2009] Westkamper, E. and Zahn E. Wandlugsfahige Produktionsunternehmen. Das Sttuttgarter Unternehmensmodell. Berlin: Springer Verlag, 2009. ISBN 978-3-540-21889-0

[Yew 2016] Yew, A.W.W, et. al. Towards a griddable distributed manufacturing system with augmented reality interfaces. Robotics and Computer-Integrated Manufacturing, 2016, Vol. 39, pp 43-55. ISSN 0736-5845, DOI: 10.1016/j.rcim.2015.12.002

[Zouriktuev 2008] Zouriktuev, V.T.: Mechatronic machine-tool systems. Russ. Eng. Res. 2008, Vol. 28, No. 1, pp 69-73.

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