Az elért eredmények rövid ismertetése:

The results achieved in the fourth year of the project are summarised according to significant aspects of Cyber-Physical Production Systems (CPPS), as formulated in the proposal. Some other important achievements related to the project are also enumerated.

1. Cooperative production systems

Based on the crowdsourcing concept, a new distributed manufacturing method was developed where companies can share their manufacturing resources depending on their demand and capacity. The specific objective is to manage a network of manufacturers who can dynamically re-configure and share their resources within a pre-registered community and analyse how the cardinality of the federation influences both the cooperation and the global and local production key performance indicators (KPIs).

The approach follows the decentralized control paradigm of Industry 4.0: agents are heterogeneous decision makers, which act autonomously and have different KPIs to optimize like financial (e.g., total cost), manufacturing (e.g., overall equipment effectiveness) and supply chain (e.g., service level, fill rate). Agents may also have preferences about which partners to choose for collaboration. The Collaboration Platform (CP) facilitates cooperation among the agents by functioning as a market for matching resource requests and capacities. Agents can offer their free capacities or request capacities when they have surplus or shortages; the CP helps to find suitable offers for each request. Due to the potential complexity of the agents' preferences, the goal of the request-offer matching is not to find an optimal solution for the requesting agent, but to offer some feasible alternatives. The novelty of the concept is the combination of the agent-based control, the matching algorithm and the digital simulation of the distributed production systems and the collaborative IT platform.

2. Identification and prediction of the behaviour of dynamic systems

A new correlation-type finite-sample system identification method was developed which can construct non-asymptotic, distribution-free confidence regions for parameters of various stochastic dynamical systems. The new method is called SPCR (Sign-Perturbed Correlation Regions) as it can be seen as the combination of the previously developed SPS (Sign-Perturbed Sums) and LSCR (Leave-out Sign-dominant Correlation Regions) algorithms.

SPCR also guarantees exact significance levels (i.e., exact confidence probabilities) for multi-dimensional parameters, like SPS, but has the computational simplicity and flexibility of LSCR. For example, it can work with ARX (autoregressive exogenous) models without the need to generate alternative perturbed output trajectories, similarly to the LSCR method.

The flexibility and the power of the approach was demonstrated by estimating the parameters of a (linear) ARX model given that the observations were generated by a bilinear (hence nonlinear) system. It was shown that the resulting confidence regions are exact with respect to the best possible ARX parameters and they include a nominal correlation estimate.

Numerical experiments also support the favourable topological properties of the regions, such as they are connected and bounded, and the strong consistency of the proposed algorithm, namely that the constructed confidence regions shrink around the best parameters, therefore asymptotically they cannot contain any false parameter values, with probability one.

3. Robust planning and scheduling

Motivated also by international industrial requirements, a method based on mixed-integer linear programming and advanced search heuristics has been developed for the joint optimization of product design and the assembly process, as well as for the application of the result in strategic level production and capacity planning.

The decision-making workflow focuses on tolerance allocation in product design, and assembly resource configuration in process and production planning. First, in a tolerance allocation model of the product tolerance values are sought that warrant feasible product geometry, required functionality and minimal production costs. Second, an assembly resource configuration sub-problem is solved to assess how the different design variants can be produced most efficiently on existing assembly lines considering capability and capacity constraints, or alternatively, what investments should be made into new capabilities or even new assembly lines on a finite horizon. The decomposition approach consists of solving first multiple instances of the tolerance allocation sub-problem to generate a portfolio of design alternatives; then, assembly resource configuration selects a design alternative for each product and matches it to assembly resources in the most efficient way. The proposed method was investigated also in an industrial case-study. Compared to earlier models of design for manufacturing and assembly (DfMA), the new approach is able to capture the synergies of producing a family of products in a multi-product assembly system, striving for minimal total costs on a long horizon.

The method was published after international patenting.

4. Fusion of real and virtual systems, human-robot symbiosis

The main motivation of the research in this year was creating ergonomic, gesture-driven, robot control methods. First, a high-level monitoring method was developed to capture the actual states of the robot and of the operators. The method was based on the digital twin (DT) of the workcell which was properly calibrated and whose actual status was matched time and again to that of the real system. Data from the digital twin (e.g., position and movement of the operator) could be used for human gesture recognition. A specific object hand-over scenario was carried out between the human operator and robot, controlled by gesture-based communication.

Robotic pick-and-place processes require the workpieces to be prepositioned and aligned to a fixed pose, but this lacks flexibility and efficiency. Our other research target was to generate robot motion in semi-structured environment, like picking up objects from random positions. Camera-based solutions are available for simple workpieces, but no generic solution exists for complex ones. The results of our research offer a universal software that determines the stable equilibrium poses of the workpiece from its 3D model, and renders its top view image. This image can be compared to that one captured by a single camera setup so as to determine the workpiece position and orientation in real-time for robotic applications. The results were validated by conducting drop test simulation series.

5. Biological transformation of manufacturing

We have participated in laying the foundations of a new strategic initiative of Fraunhofer as for the biological transformation of manufacturing.

Specifically, a new emerging frontier in the evolution of the digitalisation and the 4th industrial revolution (Industry 4.0) is considered to be that of “biologicalisation in manufacturing”, i.e. the use and integration of biological and bio-inspired principles, materials, functions, structures and resources for intelligent and sustainable manufacturing technologies and systems with the aim of achieving their full potential. A White Paper was conceived, discussing all main implications of this trend from the perspective of product design, manufacturing technology, processes and systems, supply chains and organisations. The drivers and influencing factors were also reviewed, in the context of significant developments in materials science and production engineering.

Recommendations were singled out targeting the manufacturing research community, policy makers, funding agencies, and those industries involved in the development of next generation manufacturing technology and systems. It was concluded that biologicalisation represents a new innovation frontier of digitalisation and Industry 4.0, with very strong application potential. Though, extensive R&D is required in order to gain its benefits.

Specific research was also initiated on the use of biologically inspired algorithms for controlling manufacturing cells producing biological material.

Some other aspects of the project

The paper Monostori, L.; Kádár, B.; Bauernhansl, T.; Kondoh, S.; Kumara, S.; Reinhart, G.; Sauer, O.; Schuh, G.; Sihn, W.; Ueda, K.: Cyber-physical systems in manufacturing, CIRP Annals – Manuf. Techn., 65/2, 2016: 621-641, is currently the second best cited paper of the journal from the year 2014 (among ca. 450 papers). (430+ Google Scholar cit.)

The paper Monostori, L.: Cyber-physical production systems: Roots, expectations and R&D challenges, Procedia CIRP, 17, 2014: 9-13, was the second best cited paper of the periodical from the years 2014-18 (among ca. 5600 papers). (580+ Google Scholar cit.)

In the broader topic of the project, a strategic national 5-years NKFIA project was launched on "Research on Prime Exploitation of the Potential of Industrial Digitalisation" in 2018. Consortium leader is MTA SZTAKI, partner is BME (2018-23).

Our research unit of machine learning will contribute to the "Mathematical foundations of Artificial Intelligence" NKFIH project (2018-21).

In the topic of biological transformation of manufacturing:

- The White Paper was presented in June 2018, at the strategy setting "Futuras in Res" conference of Fraunhofer.
- In August, 2018, a new collaborative working group of the International Academy for Production Engineering (CIRP) was formed (Vice Chair: L. Monostori).
- A joint, bilateral R&D project was started in 2018, commissioned by Fraunhofer. This use case of the broad-sweeping BIOMANU II project which is led by L. Monostori focuses on "Robust, Cooperative Manufacturing Systems and Supply Chains" and involves MTA SZTAKI and FhG IPT/WZL (Aachen) (2018-19).