CONFERENCE ON PRODUCTION SYSTEMS AND LOGISTICS
CPSL 2020

1st Conference on Production Systems and Logistics

Bio-inspired Factories of the Future

Arvid Hellmich[1], Brandon Sai[2], Marian Süße[3], Martin Schreiber[4], Torben Wiese[1], Steffen Ihlenfeldt[1], Thomas Bauernhansl[2], Matthias Putz[3], Gunther Reinhart[4]

[1]*Fraunhofer Institute for Machine Tools and Forming Technology IWU, Dresden Germany*
[2]*Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Stuttgart Germany*
[3]*Fraunhofer Institute for Machine Tools and Forming Technology IWU, Chemnitz Germany*
[4]*Fraunhofer Research Institution for Casting, Composite and Processing Technology IGCV, Augsburg Germany*

Abstract

The biological transformation of added value is seen as one of the key aspects in applied research. Bio-inspired methods and technologies will affect factories of the future and enable them to cope with changing boundary conditions and the rising necessity of sustainability. This results in a higher demand for flexibility and transformation ability of the comprised production systems.

To elaborate topics like these, Fraunhofer initiated strategic collaborative research projects. The current project aims at developing aspects of the biological transformation, whereof organic bio-inspired factories is one. Different research focal points were identified as enabling technologies on different levels of the well-established automation pyramid. The paper highlights the aspects "facility layout planning", "behavioral modeling of production systems" and "skill-based controller programming" as enabling technologies. Solution approaches for the addressed aspects are discussed and future steps towards a flexible and sustainable production are shown.

Keywords

Biological Transformation; Production; Factory Planning; Behavioral Models; Controller Programming

1. Introduction

Over the last years, research activities in manufacturing have been mainly focused on the digital transformation, an evolution, driven by the motivation to achieve higher efficiency and interconnectivity – not an agenda for more sustainability. This is where biological transformation comes in – a process that describes the increasing technological utilization of materials and principles from nature to establish a sustainable economy. [1] With the goals of the digital transformation the requirements on how a system has to operate are defined. But only with the biological transformation the activities' purpose is clearly named. Hence, digital transformation and biological transformation are complementary strategies. Each is necessary, but neither is sufficient in itself. They must, therefore, be reasoned out and pursued in combination. [2,3]

In fact, biological transformation can help to achieve the sustainable development goals set out by the United Nations (SDGs), which serve as a reliable benchmark against which to measure sustainability. In terms of manufacturing the biological transformation addresses the SDG No. 9: "Industry, Innovation and Infrastructure" and SDG No. 12: "Responsible Consumption and Production". [3]

DOI: https://doi.org/10.15488/9685 publish-Ing.

For SDG No. 9 the adaptation of biological principles can play a key role in making technological systems and infrastructure more resilient. In addition, the use of natural resources is a prerequisite for releasing global industry from its dependence on materials based on fossil fuels. SDG No. 12 addresses a responsible consumption and production. The replacement of fossil fuels by renewable biological materials, and the establishment of closed-loop material cycles, will make a significant contribution towards reducing industry’s carbon footprint. Using biological processes and biomimetics can help make manufacturing processes more efficient and, thus, reduce the consumption of raw materials. Similarly, the application of biological principles can reduce logistical requirements and a setup of industry at particularly impacted locations. [4]

In this paper, versatility and adaptability of nature is focused. Abilities which are highly required either by changing boundary conditions or by the rising necessity of sustainability.

2. Adaptability of nature in different areas of production

In order to achieve a change towards biological inspired and sustainable production, all aspects, starting from the factory layout down to the education of workers have to be transformed. Therefore, the vision of a biological bio-inspired factory is introduced as a role model (Figure 1). Here, stationary production resources such as forming machines, casting machines or rolling mills form the centered element of a factory in analogy to a cell nucleus. All other means of production (resource input, energy supply, cutting and assembly cells and shipping stations) are flexible in quantity and situated radially around the nucleus. Here, the analogy of a biological cell becomes visible, since they are also flexible e.g. in mitochondria based on the purpose of the biological cell (muscle cell, skin cell, …).

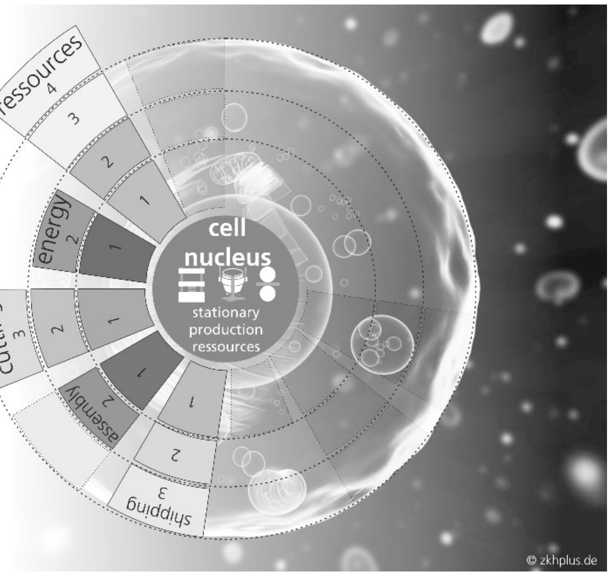

Figure 1: Vision of a bio-inspired factory of the future

Biological bio-inspired factories comprise different kinds of manufacturing units. Besides stationary machines, a large number of highly flexible units such as robot cells or adaptable storing devices enhance the process chains. The stationary units can remain more or less unchanged, when a factory layout is transformed e.g. to a more bio-inspired variant. However, the position and also the manufacturing or storage task of flexible cells can vary in wide ranges. This requires

- completely new design solutions,
- new ideas of power, air and information supply,
- new IT solutions in interlinkage and information distribution,
- new optimization paradigms in Facility layout planning as well as production optimization,
- new approaches of supervision and condition monitoring as well as
- a new paradigm of PLC programming.

In the following paragraphs, three aspects are selected and specific approaches towards the introduced biological bio-inspired factory layout are introduced: Facility factory planning, Behavioral modeling and PLC (programmable logic controller) programming. While in the segments of factory planning and production optimization adaptability approaches are proposed, the skill-based PLC programming represents one of the necessary enabling technologies.

2.1 Facility layout planning

The biological transformation incorporates several characteristics or tools of nature which are applied in technology. Not only is the contribution of each of these tools measured economically, but also with regard to its ecological and social impact. Hence, the development, clearance, use and demolition of a production plant is characterized by growing complexity, since a contribution to the above mentioned SDGs becomes a necessity. During this process, layout planning must provide the basis for sustainable factories and existing processes. Algorithms and software solutions require adjustments.

Planning facility structures or layouts is part of distinct phases in the standardized and well-defined factory planning procedure, described in the guideline VDI 5200 [5] of the German Association of Engineers. Therefore, developing factory layouts can be seen as a part of the concept planning phase and detailed planning phase of factories. Several authors like Müller [6], Pawellek [7] or Wiendahl [8] describe more specific procedures and detailed sequential steps for layout elaboration.

The general scheme may be separated into the following phases; first, structuring and dimensioning is conducted based on the required machines and production plants in order to achieve the previously defined system performance. Hence, the necessary area for all production elements is calculated. Second, several versions of rough layouts are developed, evaluated and discussed. Third, with the stepwise implementation of restrictions more detailed designs are created and finally one fine layout for the implementation is generated. The following Figure 2 illustrates the phases of the planning process and specifies the referring steps for layout planning.

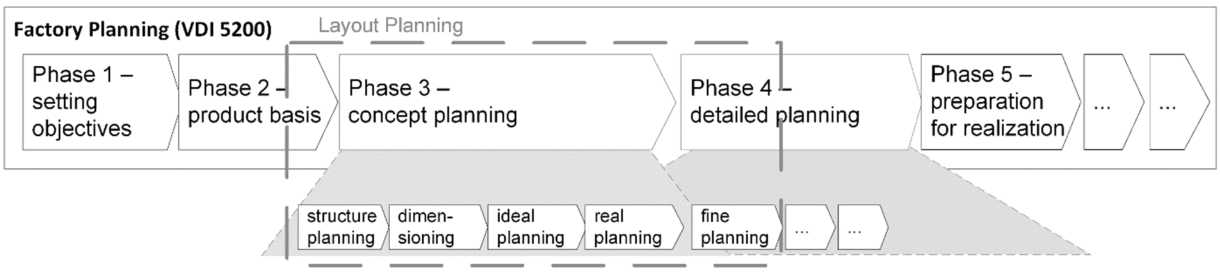

Figure 2: Delineation of factory planning and layout planning processes (based in VDI 5200)

During ideal planning and real planning, optimization of the arrangement plays a major role to find an optimal or at least good solution regarding distinct target criteria (e.g. material flow or transport costs). This accounts for both greenfield as well as brownfield planning cases. In mathematical optimization and operations research different formulations of the facility layout planning problem occurred during the last decades and diverse scientific research on algorithms and solution methods has been conducted. Depending on the circumstances and boundaries, further specification into different subcategories (e.g. dynamic facility layout problems or multi-floor facility layout problems) exists. A structured overview with according solution methods is given by Anjos and Vieira [9], Drira et al. [10] and Ahmadi [11]. In complexity theory the non-deterministic polynomial-time hardness (NP-hardness) characterizes a class of problems as possibly intractable, i.e. their solution requires an exponentially growing amount of time with increasing problem size and it is still a part of research if these problems can be solved in polynomial time [12]. Because of their complexity, facility layout problems are often characterized as NP-hard [9]. Therefore sophisticated heuristics are applied to generate improved solutions in an appropriate amount of time. As an example, Tuzkaya et al. [13] compare meta-heuristic approaches for generation of facility layouts.

In industrial planning projects heuristic schemes like the triangle method of Schmigalla or circle method of Schwerdtfeger serve as well-established approaches for the creation of rough layouts or block layouts [7,6]. On the one hand, they generate quick arrangements for an ideal layout based on simple rules which provide transparent results. On the other hand, the development of innovative layout structures is limited and the applicability gets reduced when restrictions are increased. In addition to that, current and ongoing improvements in information technology are not exhausted with these heuristics.

However, a large gap between scientifically investigated approaches and applied layout optimization heuristics can be determined. As shown by Lohmer et al. [14] software tools for a factory layout design only comprise greedy heuristics, the actual potential of optimization approaches in realistic environments is still unexploited. Furthermore, layout development and design is mostly tied to rectangular concepts and building structures which leads to efficiency potentials of innovative and nature-inspired concepts.

Different concrete approaches for the adoption of bio-inspired designs for factory layouts were developed by Tinello and Winkler [15,16]. They investigated their applicability for diverse use cases and production environments. Some of their findings are compared in the following table:

Table 1: Comparison of advantages for different biologically inspired layouts

Honeycomb	Nautilus	Spiderweb
– Minimal circumference for same space compared to triangles or rectangles	– Reduces required space for transport	– Reflows besides main production flow can be handled easily
– Basis for efficient material flow with centrally focused section	– Material flows are reduced compared to established heuristics in factory planning	– Basic structure can be easily expanded

Besides these advantages it should be pointed out that these concepts highly contribute to an improved changeability of factories since nature-based structures are intrinsically built for an adoption towards changing circumstances and comprise efficient ways for necessary growth processes. Referring to this, Tinello and Winkler show that some of the procedures for biomimetic layout development are more complex compared to the already mentioned and well-known heuristics. [15]. It becomes obvious that the presented, nature-oriented shapes are still limited to the stage of an ideal layout which means that investigation regarding their efficiency and applicability has only been conducted for an earlier planning stage with less restrictions. Thus, several further steps for examination become apparent.

With reference to the aforementioned bio-inspired factory, several analogies of the structure and mechanisms in eukaryotic cells could be derived in order to generate creative as well as efficient planning results. As an example the cytoskeleton of organic cells serves as a solid and robust structure and likewise provides enough flexibility for cells to adapt their internal partitioning. Hence, specific ways to model, assess, compare and finally implement biomimetic factory layouts on such principles are necessary. As already indicated with the biologically inspired layouts in Table 1, this necessitates further development of heuristics and analytic optimization methods that are based on additional shapes besides rectangular grid structures.

Resuming investigation of bio-inspired layouts is conceivable in advanced planning phases (e.g. real planning) taking further restrictions into account. This implies the adoption of different legal requirements and norms or prevailing supply infrastructure. A third point of further examination is the transfer of scientifically investigated and tested approaches into appropriate software tools. Therefore, the evolution of existing software tools as well as the development of new software solutions for planning engineers is imaginable.

The fourth, but not less relevant aspect is the investigation of ecologic criteria and their consideration in layout planning. With reference to material flows, the energy demand (e.g. of automated guided vehicles) may already be a relevant aspect. As soon as the ecologic reflection is extended towards further aspects of lifecycle assessment-based impact categories, their quantification and optimization in factory planning stages has to be considered. Hence, aspects like biodiversity, land use or transformed area could become relevant target criteria in factory layout design.

2.2 Behavioral modeling of production systems

The complexity of modern productions systems is increasing. In addition, achievements in development are more frequently while the time span between them decreases. As a consequence, the role of the human in manufacturing is changing. Formerly, the focus was on adding value, mostly by handcraft. Today, in modern plants the role is to ensure a smooth running of the automated production system, i.e. the role of human has been changed towards production optimization. [17] In terms of optimization, the overall equipment effectiveness is becoming the most important benchmark with targeting the elimination of losses in the process. However, due to the continuously increasing complexity, this task is also slowly becoming more difficult. Therefore, intelligent systems which help to eliminate losses are required. Not just for identifying losses, but for identifying the root cause and its possible impacts. In analysis there are different approaches with different goals. For explanation, a promising approach is the diagnosis. In diagnosis, the main concept incorporates a reference, for systems with lower complexity, a single value can be sufficient to represent a goal. The difference between the target and actual value delivers the optimization action and the explanation inherently. For systems with higher complexity, a single value is hardly sufficient, therefore, a behavior model can be used as a reference, with the only change that the systems normal behavior is the new reference.

The manual creation of behavior models is a tedious process and represents the bottleneck in the development of approaches for intelligent diagnosis. For the modeling itself, much expertise is required and all interactions in the plant have to be known. Additionally, not all physical effects can be captured and modeled in detail. [18,19]

To achieve adaptability, i.e. to be flexible, in production optimization the modeling of the systems behavior has to be automated. In addition, the system itself has to be autonomous [1]. Thus, whenever circumstances are changing the system has to adjust. Even if the circumstances and boundaries are set, the system has to learn continuously to provide the optimization target. Hence, the algorithm for diagnosis has to have the following characteristics:

- Online algorithm: Because the modeling is based on observation, its characteristics defines the main requirements of the algorithm. As an observing or reading system, the input has to be processed piece by piece in a serial fashion, i.e. in the order that the input is fed to the algorithm, without having the entire input available from the start.
- Passive algorithm: While passive learning algorithms have to cope with a given set of observations to learn the model, active learning algorithms can ask for additional observations, if needed.
- Fault data: Because the systems has to learn live during the production, fault-free data cannot be expected.

The main task in the automated modeling of a systems behavior is the extraction of a noised core sequence. Different approaches, either model-based or data-driven have been designed to fulfill this assignment.

One promising approach comes of the field of theoretical computer science and discrete mathematics. An automaton is a construct made of states designed to determine, if the input sequence should be accepted or rejected. An automaton has a finite set of states which are used to assess if the current state or transition from one state to another is receivable. With this construct a sequence, i.e. a behavior, can be defined. [18] Another model-based approach comes along with the Hidden Markov Model (HMM). A statistical Markov model in which the system being modeled is assumed to be a Markov process with unobservable (i.e. hidden) states.

In simpler Markov models, the state is directly visible to the observer, and therefore the state transition probabilities are the only parameters, while in the hidden Markov model, the state is not directly visible, but the output, dependent on the state, is visible. [20]

Possible data-driven approaches can be either modeled with a recurrent neural network (RNN) or an autoencoder. An RNN is a class of artificial neural networks where connections between nodes form a directed graph along a temporal sequence. This allows for temporal dynamic behavior. An autoencoder is an artificial neural network that learns to copy its input to its output. It has an internal (hidden) layer that describes a code used to represent the input, and it is constituted by two main parts: an encoder that maps the input into the code, and a decoder that maps the code to a reconstruction of the original input. [21]

Performing the copying task per se would be meaningless, and this is why usually autoencoders are restricted in ways that force them to reconstruct the input only approximately, prioritizing the most relevant aspects of the data to be copied.

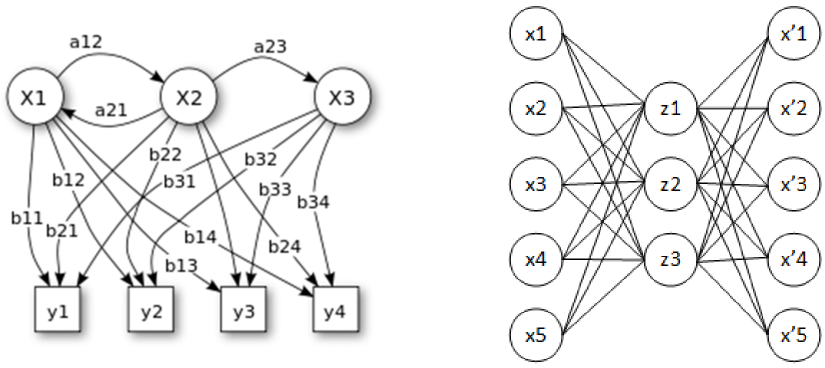

Figure 3: Structure of a hidden Markov model (left); Structure of an autoencoder (right)

Regarding nature, a self-optimizing system is the goal. To achieve this goal, a first step towards adaptability has to be made, which requires that a system is able to observe the actual and target value, i.e. the actual and normal behavior. Therefore, it is necessary to continue research in automated behavior modeling. The mentioned approaches deliver possible and promising solutions.

2.3 Skill-based controller programming

Automation of production means is currently mainly a technical development to increase production volume. As mentioned, for the introduced bio-inspired factory, state of the art construction principles, IT-solutions and automation paradigms have to be changed. Only if flexibility and transformation ability in hardware is regarded in combination with flexibility in designing the automation solution, IT and optimization, a true flexibility in manufacturing can be a reached. Different solutions in this manner are already under development, currently mainly with a focus on organization. In the following paragraph, the focus is laid on automation. Here, state of the art in programmable logic controllers (PLC), which are the common solution for e.g. robot cells, is a cyclic processing comprising the steps:

- input scan (reading all inputs and memory states)
- execution of a problem-oriented automation program (PLC-program) to generate output and memory values
- output update (writing values to outputs and memory)

The PLC program incorporates all necessary information to generate output signals based on the input and memory state. Therefore, the complete automation task is specified and transformed into the PLC program, which is usually developed, implemented, tested and maintained by an automation technician of the machine/unit manufacturer [22]. This approach is focused on the specific automation problem (problem-oriented) and can only handle changed conditions or tasks to the extent that they were already known to the programmer at the design stage and taken into account in designing the control program. Modification, adaptation or addition of command sequences, positions, process sequences is usually not possible. Conventional control programs are, therefore, structured individually and project-specific based on the automation problem (Figure 4, left). The effort required for programming, testing and commissioning control software is growing disproportionately with the increase in the scope and complexity of control functionality [23]. This mismatch is aggravated due to the fact, that machine users cannot initiate even slight adaptions of process chronology, such as reordering process steps, position changes, changes of loading aids etc.. Therefore, even minor changes to the program are costly and time-consuming because specialized commissioners are required.

Along with Industrie 4.0, initial approaches to modularize the control landscape, architecture and programming arise. One course of action is to simplify the task of programming PLC by transforming it to a parametrization action. Hence, the controller is not only equipped by a program to solve one specific complex automation task but with a large set of modular skills, covering all possible abilities of the manufacturing unit. Programming and teaching this skillset still requires an automation technician but is extremely flexible in further application and individual utilization. The transformation from the well-known but inflexible task-based programing to a skill-based parametrization requires a new point of view and a new definition of the automation procedure. At first, all possible skills of the flexible manufacturing unit such as handling, measuring, orienting, loading/unloading are regarded as jobs. All jobs consist of a sequence of skills, such as movement, opening/closing a gripper, call to a camera etc.. Hence, the skill “movement” is furthermore a combination of basic skills such a move linear or move circle (Figure 4, right). A rather complex robot path is composed from basic movement elements. An analogy to biology can be found when the DNA is regarded, where also very basic elements are combined to a highly complex information storage system.

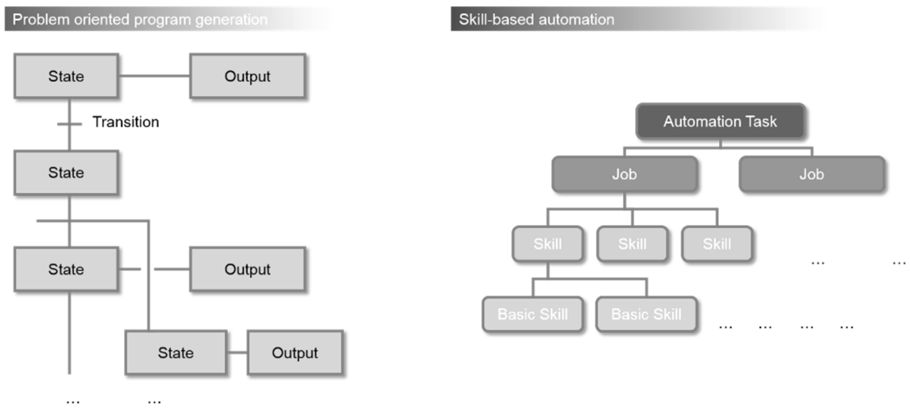

Figure 4: Transformation of problem-based to skill-based automation

The manufacturing cell is equipped with all hardware modules and a complete skillset. This skillset is taught and programmed by the automation technician but remains open for a variety of applications. After a basic commissioning and software test, the machine operator can combine the skills and jobs to an automated process sequence or adapt the given sequence to a new setting with support of a graphical user interface (GUI). Figure 5 shows such a GUI for a robot cell to manipulate, measure and stack up automotive parts. The cell consist of a KUKA robot and four stations, realizing different process steps. The left part shows the parametrized job list followed by a specification for each job. A visualization in the right part provides an interaction with the operator and visualizes the abstract robot actions, associated with the manufacturing layout and task. Here, the programming paradigm interacts with factory facility planning, when the state-actual model is incorporated in the GUI. In the middle part, control buttons allow for connecting with the PLC, downloading the program to the plc and running specific jobs.

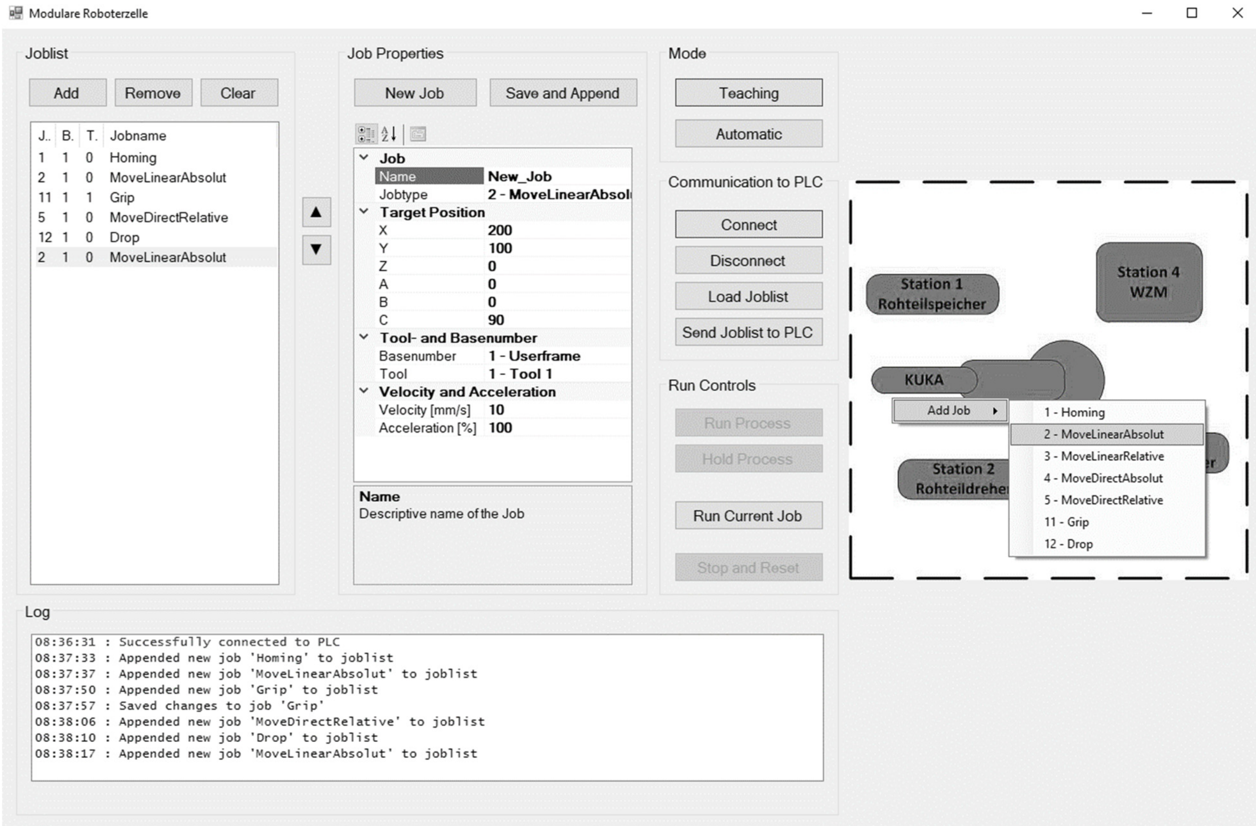

Figure 5: GUI of the skill-based automation for a flexible robot cell

The new parametrization paradigm uses flexible robot jobs, parametrized by a GUI and subsequently downloaded into the PLC. The program, job/skill parameters and the chronology of skills can be controlled, adapted and reorganized through a GUI. After basic commissioning of the complete skillset, no automation specialist is needed anymore. Job and process flow adaption and testing can be realized within a few minutes. Users without PLC or robot programming knowledge can implement changes and the risk of errors in programming is reduced.

Beside the mentioned robot cell for manipulating automotive parts, also a different robot cell for highly flexible utilization to load and unload machine tools was automated, based on the new parametrization paradigm.

3. Conclusion

Bio-inspired autonomous systems in manufacturing incorporate flexibility in hardware and software and adaptability in concepts. Both, flexibility and adaptability, were discussed in this paper. Promising approaches to achieve adaptability on different levels, e.g. facility planning and production optimization, have been pointed out and discussed. For facility planning specific ways to model, assess, compare and finally implement biomimetic factory layouts are necessary. In addition, ecologic criteria and their consideration in layout planning need further examination. Moreover, scientifically investigated and tested approaches must be transferred into appropriate software tools. For production optimization, intelligent diagnosis systems are needed. Their development is limited by the manual process of behavior modeling. Promising solutions have been discussed for both, model-based and data-driven approaches. On the lowest level of the automation pyramid a flexibility of controller planning is needed to enable adaptability in manufacturing. Therefore, a rethink of programming PLC is shown, simplifying the task of programming

PLC by transforming it to a parametrization action. Here, the controller is not only equipped by a program to solve one specific complex automation task but with a large set of modular skills, covering all abilities of the manufacturing unit.

Acknowledgement

The authors wish to acknowledge and thank Professor Reimund Neugebauer, President of the Fraunhofer-Gesellschaft, for his initiation and all involved Fraunhofer-institutes for the possibility of carrying out this research project. They also thank Dr. Sophie Hippmann, Head of Think-Tank, Dr. Miriam Leis and Ms. Petra van Heek for their continuous support. In addition, the authors thank Dr. rer. nat. Wolfgang Karl Hofbauer of Fraunhofer IBP, Dr. Malte von Ramin of Fraunhofer EMI and Dr. Bernhard Ellinger of Fraunhofer IME for their input .

References

[1] Bauernhansl, T., Brecher, C., Drossel, W.-G., 2019. Biointelligenz: Eine neue Perspektive für nachhaltige industrielle Wertschöpfung : Ergebnisse der Voruntersuchung zur biologischen Transformation der industriellen Wertschöpfung (Biotrain), 96 Seiten.

[2] Byrne, G., Dimitrov, D., Monostori, L., Teti, R., van Houten, F., Wertheim, R., 2018. Biologicalisation: Biological transformation in manufacturing. CIRP Journal of Manufacturing Science and Technology 21, 1–32.

[3] Fraunhofer Gesellschaft e.V., 2018. Biological Transformation and Bioeconomy. Fraunhofer Gesellschaft e.V. https://www.fraunhofer.de/en/research/current-research/biological-transformation.html. Accessed 8 October 2019.

[4] United Nations, 2015. Transforming Our World: The 2030 Agenda For Sustainable Development. https://sustainabledevelopment.un.org/post2015/transformingourworld/publication. Accessed 17 October 2019.

[5] VDI-Gesellschaft Produktion und Logistik, 2011. VDI 5200 Blatt 1 Fabrikplanung - Planungsvorgehen.

[6] Schenk, M., Wirth, S., Müller, E., 2014. Fabrikplanung und Fabrikbetrieb: Methoden für die wandlungsfähige, vernetzte und ressourceneffiziente Fabrik, 2., vollständig überarbeitete und erweiterte Auflage 2014 ed. Springer Vieweg, Berlin, 840 pp.

[7] Pawellek, G., 2014. Ganzheitliche Fabrikplanung. Springer Berlin Heidelberg, Berlin, Heidelberg.

[8] Wiendahl, H.-P., Reichardt, J., Nyhuis, P., 2015. Handbook factory planning and design. Springer, Heidelberg.

[9] Anjos, M.F., Vieira, M.V.C., 2017. Mathematical optimization approaches for facility layout problems: The state-of-the-art and future research directions. European Journal of Operational Research 261 (1), 1–16.

[10] Drira, A., Pierreval, H., Hajri-Gabouj, S., 2007. Facility layout problems: A survey. Annual Reviews in Control 31 (2), 255–267.

[11] Ahmadi, A., Pishvaee, M.S., Akbari Jokar, M.R., 2017. A survey on multi-floor facility layout problems. Computers & Industrial Engineering 107, 158–170.

[12] Leung, J.Y.-T., 2004. Handbook of scheduling: Algorithms, models, and performance analysis. Chapman & Hall/CRC, Boca Raton.

[13] Tuzkaya, G., Gülsün, B., Tuzkaya, U.R., Onut, S., Bildik, E., 2013. A comparative analysis of meta-heuristic approaches for facility layout design problem: a case study for an elevator manufacturer. J Intell Manuf 24 (2), 357–372.

[14] Lohmer, J., Klausnitzer, A., Lasch, R. Advanced scientific algorithms in digital factory design applications.

[15] Tinello, D., Jodin, D., Winkler, H., 2016. Biomimetics applied to factory layout planning: Fibonacci based patterns, spider webs and nautilus shell as bio-inspiration to reduce internal transport costs in factories. CIRP Journal of Manufacturing Science and Technology 13, 51–71.

[16] Tinello, D., Winkler, H., 2017. Überlegungen zur Übertragung bionischer Systemdesignmuster auf die Fabriklayout- und Materialflussplanung. Institut für Technische Logistik - Technische Universität Graz.

[17] Maier, A., 2014 - 2014. Online passive learning of timed automata for cyber-physical production systems, in: 2014 12th IEEE International Conference on Industrial Informatics (INDIN). 2014 12th IEEE International Conference on Industrial Informatics (INDIN), Porto Alegre RS, Brazil. 27.07.2014 - 30.07.2014. IEEE, pp. 60–66.

[18] Aho, A.V., Ullman, J.D., 2000. Foundations of computer science, C ed., 6.pr ed. Computer Science Press, New York, 786 pp.

[19] Kunze, M., Weske, M., 2016. Behavioural models: From modelling finite automata to analysing business processes. Springer, Cham, 279 pp.

[20] Rabiner, L., Juang, B., 1986. An introduction to hidden Markov models. IEEE ASSP Mag. 3 (1), 4–16.

[21] Goodfellow, I., Bengio, Y., Courville, A., 2016. Deep learning. MIT Press, Cambridge, Massachusetts, London, England, 1785 pp.

[22] Tiegelkamp, M., John., K.H., 2009. SPS-Programmierung mit IEC 61131-3: Konzepte und Programmiersprachen, Anforderungen an Programmiersysteme, Entscheidungshilfen, 4. Aufl. ed. Springer-Verlag, s.l., 400 pp.

[23] Möbius, V., 2009. Produktprozess im Computerzeitalter: Methodische Grundsätze zur Informationsbehandlung im Produktprozess und deren Anwendung auf die Entwicklung eines Steuerungskonzepts. Dissertation, Dresden.

Biography

Thomas Bauernhansl (*1969) has been Head of the Fraunhofer Institute for Manufacturing Engineering and Automation IPA in Stuttgart and the Institute of Industrial Manufacturing and Management at the University of Stuttgart since 2011 Prof. Dr.-Ing. Bauernhansl is author of many books and member of many scientific societies. Both the digital and the biological transformation of value creation are core research fields in his institutes.

Arvid Hellmich (*1982) is Head of the Department Technical Cybernetics of the Fraunhofer Institute for Machine Tools and Forming Technology IWU Dresden. After his PhD thesis in 2014 he is currently working in different projects on data acquisition and –analysis, function integration in industrial controller systems, intuitive controller programming and simulation of electromechanical systems.

Steffen Ihlenfeldt (*1971), studied at the TU Braunschweig and has been a member of the Fraunhofer Institute for Machine Tools and Forming Technology IWU in various positions since 1997 at. He received his Doctorate in 2012. Since 2015 Prof. Dr.-Ing. Steffen Ihlenfeldt has been called to the Position of Professorship for Machine Tool Development and Adaptive Control systems at the TU Dresden. In addition to his work at the TU Dresden he is currently Head of the Department for Cyber-Physical Production Systems at Fraunhofer IWU.

Matthias Putz (*1957) studied Mechanical Engineering at the St. Petersburg State Polytechnic University. He gained his Doctor's degree in 1986 in the Field of Machine Tool Construction. Professor Putz joined Fraunhofer IWU in 1994. Since 2000 he has had leading positions at the Fraunhofer IWU. In the year 2007 he obtained the Honorary Professorship at the Dresden University of Applied Sciences. Since April 2014 Professor Putz is Institute Director of the Fraunhofer IWU, responsible for the Scientific Field of Machine Tools, Production Systems and Machining and he has additionally been holding the Professorship for Machine Tools and Forming Technology at the Chemnitz University of Technology.

Gunther Reinhart (*1956) studied Mechanical Engineering at the Technical University of Munich and finished his PhD Thesis in 1987. He worked as Executive Employee for the BMW AG and IWKA. He is the Professor of Management Sciences and Assembly Technology at the iwb of the TUM together with Prof. Dr.-Ing. Michael Zäh since 2007. Since 2016 he is a Member of the Management of the Fraunhofer Research Institution for Casting, Composite and Processing Technology IGCV in Augsburg.

Brandon Sai (*1990) has been a Research Associate of the department of autonomous production optimization of the Fraunhofer Institut of Manufacturing Engineering and Automation IPA in Stuttgart and a doctoral student at the Institute of Industrial Manufacturing and Management at the University of Stuttgart since 2018. He is currently working on behavioral models of production systems.

Marian Süße (*1992) started working at the Fraunhofer-Institute for Machine Tools and Forming Technology IWU as a Student Assistant in 2014. Since 2017 he is working as Research Associate in the Department Factory of the Future where he is in charge of the Group for Factory Design and Simulation since 2018. In his research and PhD-Thesis he focusses on the development of methods for factory layout planning and layout optimization approaches as well as ecologic impacts of production systems.

Martin Schreiber (*1989) is a Research Assistant at the Fraunhofer Research Institution for Casting, Composite and Processing Technology IGCV since 2016. His research fields are production management, production planning and operations research. He is also specializing in simulation and optimization of production systems as well as knowledge generation using Machine Learning.

Torben Wiese (*1991) studied mechanical engineering at the TU Dresden. Afterwards he started working at the Fraunhofer-Institute for Machine Tools and Forming Technology IWU in 2016. He works as a Research Associate in the Department Technical Cybernetics where he specializes in programming and engineering of industrial controllers. His focus lies in the real time part, such as path planning, axis transformation, process model integration as well as data acquisition and data analysis.