ABSTRACTS

WEDNESDAY, MAY 7

Arndt Lüder (Otto von Guericke University Magdeburg)

Mechatronical engineering of production systems and its new challenges (also) for mathematical research

Recent changes in market and technology conditions have forced production system owners within developed countries to rethink architecture and engineering of production systems. One widely considered approach to cope with these challenges is mechatronical thinking. Production systems become mechatronically structured and will be engineered exploiting mechatronical engineering processes. This new way of structuring and planning bears new problems to be solved. Within the engineering process, models of different engineering phases have to be handled consistently. During the use of the production systems, new ways of collaborative planning and control are required. For both problem fields, mathematical methods can (and shall) be developed supporting the solution of these problems. Here, the talk will give first indications on open issues.

Daniel Wolff (inpro, Berlin)

Digital factory goes blue – energy and resource efficiency aspects

It is a current challenge in manufacturing industry to increase energy productivity while at the same time avoiding negative effects on classical productivity objectives, such as output, availability and operational robustness. A strategic objective that is more and more recognized in industrial manufacturing is to systematically save energy related cost and to generate competitive advantages by the rationalized use of energy and reduced CO2 emissions. Aside from the energy oriented planning of products, processes and resources must be optimized regarding energy and resource use at the early stage in the production systems lifecycle. Here, significant potential results from applying the existing principles, methods & tools of the digital factory to an energy oriented production system planning, extended to the production planning scheduling in the operative stage. The talk lines out potential fields for action and discusses challenges for the current concepts of the digital factory, based on innovative approaches from the automotive domain.

Luca Ghezzi, Aldo Sciacca (ABB Italy S.p.A., Vittuone)

Applications of computational mathematics to industrial products and processes: the case of ABB

After introducing ABB as a company active in the field of power and automation technologies, examples are presented of mathematics applied to its products and industrial processes. First, the numerical simulation of low voltage electric arcs is shown as a multi-physical, multi-scale, initial boundary value problem. Then, constrained optimization problems, including discrete, combinatorial cases, are discussed as models for very diverse applications to production and industrial operations. Main solution approaches and algorithms are shortly recalled. Finally, possible future trends in mathematical research, with reference to industrial applications, are outlined, based on present needs and open issues on the business side.

Tamás Kis (Institute for Computer Science and Control, Budapest)

Production planning and scheduling in the digital factory

In the talk we give an overview of some R&D projects in the theme of production planning and scheduling. Along to tour, we highlight some of the main challenges and also summarize the lessons learned.

Zoltán Horváth, János Jósvai (Széchenyi István University, Győr)

Scheduling of production lines in automotive factories with the modeling, simulation and optimization technology

Scheduling of production lines with many jobs and machines is one of the most serious task of an automotive factory. Several commercial software products serve decision makers on the production in their job providing them with simulation and some optimization tools. However, even the state-of-the-art software tools has serious limitations, in particular those for the optimization. For supporting the scheduling decisions of engine producing segments, Audi Hungaria Motor Ltd, Győr and the Széchenyi István University formed cooperations to make simulations of real production lines and their supply chains and do research for making optimization methods better. We remark that these lines are among the largest engine production lines of vehicle industry over the world. In this talk we present our achievements in simulation, modeling and optimization for the scheduling of large production lines. Namely, we made contributions as follows:

- validated models and their simulations using Siemens' software Plant Simulation for real production lines and their material supply,
- optimization under Plant Simulation via built in genetic algorithms,
- set up of mathematical models of different levels (i.e. by considering more and more physical features of the lines) and implementing corresponding solvers of the type of black-box heuristics and MIP (mixed integer programming),
- fast computational optimization of the large scale problems in the mathematical models (several heuristics and MIP solvers) with interface from and to Plant Simulation,
- applications to real lines of industry.

The main conclusion was that solvers for some MIP models converge fast for large scale problems as well and give optimum in industrial cases.

This is a joint lecture with Sándor Kálmán (Audi Hungária Motors Ltd.).

Felix Damrath (Daimler AG, Ulm), **Anton Strahilov** (Rücker EKS GmbH, Weingarten)

Energy considerations in Virtual Commissioning

1) Introduction
2) Virtual Commissioning as phase of the plant engineering process
3) Further potential of Virtual Commissioning
4) Energy considerations of electric and pneumatic components
5) Summary and outlook

Ulrich Schmucker (Fraunhofer Institute for Factory Operation and Automation, Magdeburg)

About some mathematical aspects of virtual product development

Increasing demand for custom products and functions, shrinking time-to-market and mounting cost pressure are making it necessary to overhaul and improve the product development process radically. This especially applies to complex mechatronic units such as robots and manufacturing equipment. The Fraunhofer IFF has developed a complete toolset for the virtual development and testing of mechatronic systems. It enables users to verify and optimize every essential geometrical and functional feature before a prototype is built. This paper introduces the basic components of the Fraunhofer IFF's virtual product development system. One key feature is its automated generation of physically correct Modelica models directly from CAD drafts. The mathematics behind this feature is described for mechanical multibody systems with serial, tree-shaped, parallel and closed kinematic loop structures. Modeled mechanical systems of experimental electric cars are also presented as examples. Since the standard Modelica solver Dymola has some drawbacks, the Fraunhofer IFF developed a special approach to simulate modular robot systems with any structure and degrees of freedom. Once again, systems' direct and inverse kinematics and dynamics are automatically calculated directly from CAD drafts. This paper also presents the algorithms employed to automatically calculate a robot's working envelope. Since energy is the common denominator of multiphysics simulations, the models can be used in conjunction with real time simulations to optimize energy consumption. A robot with an energy recuperation system is presented as an example. Finally, current challenges to the refinement of virtual product development systems and methods of resolving them mathematically are examined.

Rikardo Bueno (Tecnalia Research & Innovation, San Sebastian)

The factories of the future roadmap

'Factories of the Future 2020': Roadmap 2014-2020 and its relation to mathematics

The 'Factories of the Future' public-private partnership (PPP) under Horizon 2020 is centred on the priorities of 'Factories of the Future 2020', an ambitious and far-sighted strategic multi-annual research roadmap produced by EFFRA. 'Factories of the Future 2020' is the basis for research call topics and the overall direction of research in the 'Factories of the Future' public-private partnership under Horizon 2020

The roadmap was developed over a period of 24 months through working meetings including discussions with the European Commission within the 'Factories of the Future' public-private partnership Ad-hoc Industrial Advisory Group (AIAG) and close consultations with representatives of companies and RTOs organised in other related European technology platforms.

The 'Factories of the Future' PPP identifies and realises these transformations by pursuing a set of research priorities along the following research and innovation domains:

- Advanced manufacturing processes
- Adaptive and smart manufacturing systems
- Digital, virtual and resource-efficient factories
- Collaborative and mobile enterprises
- Human-centred manufacturing
- Customer-focused manufacturing

Each of these domains embodies a particular aspect of the required transformations towards the factories of the future. The research and innovation activities undertaken within the domains will focus on a concrete and measurable set of targets, described as manufacturing challenges and opportunities:

- Manufacturing the products of the future: Addressing the ever changing needs of society and offering the potential of opening new markets
- Economic sustainability of manufacturing: Combining high-performance and quality with cost-effective productivity, realising reconfigurable, adaptive and evolving factories capable of small scale production in an economically viable way
- Social sustainability of manufacturing: Integrating human skills with technology
- Environmental sustainability of manufacturing: Reducing resource consumption and waste generation

Addressing these challenges and opportunities is at the core of what the Factories of the Future PPP is determined to achieve. Achieving the identified transformations requires a coordinated research and innovation effort, where manufacturing challenges and opportunities are addressed by deploying technologies and enablers identified as advanced manufacturing processes and technologies, mechatronics for advanced manufacturing systems, ICT, manufacturing strategies, knowledge-workers and modelling, simulation and forecasting methods and tools.

Jens Korell (Project Management Agency Karlsruhe)

Research topics factories of the future 2015

The HORIZON 2020 Work Programme “Nanotechnologies, Advanced Materials, Biotechnology and Advanced Manufacturing and Processing” contains the Call for FoF – Factories of the Future. The FoF Topics for 2015 will be presented.

THURSDAY, MAY 8

Simone Göttlich (University of Mannheim)

Modeling of material flow problems

Material flow systems are usually divided into a microscopic and a macroscopic model scale. On the one hand, macroscopic flow models are used for large scale simulations with a large number of parts. On the other hand, microscopic models are needed to describe the details of the production process. We present an overview of models for material flow problems ranging from detailed microscopic models to macroscopic models based on conservation laws. Numerical simulations are presented on all levels of the hierarchy and validated against real-data test settings. The investigation of optimal control problems arising in this context is also discussed.

Jörg Raisch (TU Berlin)

Optimal control of High-Throughput-Screening systems in a dioid framework

High-Throughput-Screening (HTS) has become an important technology to rapidly test thousands of biochemical substances. HTS plants are fully automated systems containing a fixed set of resources performing, e.g., liquid handling, storage, reading, plate handling and incubation steps. All operations which have to be conducted to analyse one set of substances are combined in a so-called batch. In order to compare screening results, the single batch time scheme, i.e., the sequence and timing of activities for one batch, is usually required to be identical for all batches. In previous work, we proposed a method to determine a globally optimal (in the sense of achieving maximal throughput) solution for the resulting scheduling problem. However, this optimal schedule is generated off-line and can therefore not react appropriately to unforeseen disturbances and delays. To handle these in a systematic manner, we have investigated methods to enhance a given off-line schedule by appropriate feedback. It turns out that the resulting feedback synthesis problem is (non-benevolently) nonlinear when considered in standard algebra. However, formulating the problem in a suitable dioid algebra provides a linear representation. A dioid is an idempotent semiring, with the so-called (max,+) algebra being the most well-known example. We will discuss why a different dioid, commonly referred to as $\mathcal{M}_{in}^{ax}[\![\gamma, \delta]\!]$, is particularly suitable to model HTS problems. We will also discuss how to analytically determine a feedback control law which will start all activities as late as possible without violating the overall aim of throughput maximisation and will therefore implement a closed-loop just-in-time policy.

This is a joint work with Tom Brunsch (TU Berlin) and Laurent Hardouin (University of Angers).

Fredrik Edelvik (Fraunhofer-Chalmers Centre, Gothenburg)

The virtual paint shop

The paint and surface treatment is a complex area in automotive manufacturing characterized by multi-phase and free surface flows, multi-physics, multiscale phenomena and large moving geometries. This poses great challenges on mathematical modeling and simulation. The current situation in the automotive industry, and industry in general, is therefore to rely on individual experience and physical validation for improving these processes. We present a new and very efficient method that makes it possible to include detailed simulations in the production preparation process and off-line programming of the paint robots. The simulation framework that has been developed together with Volvo Car Corporation, AB Volvo, Scania CV, and General Motors NA, is based on novel algorithms for coupled simulation of air flows, electromagnetic fields and paint droplets.

Klaus Dreßler, Joachim Linn (Fraunhofer ITWM, Kaiserslautern)

Simulation for assembly-oriented design and digital validation of cables and hoses

Standard software tools currently used in industry for design, digital mock-up and virtual assembly can only handle *rigid* CAD geometries. However, there is an increasing demand for a realistic simulation of *deformations of slender flexible structures*, possibly in real time (i.e.: *at interactive rates*). Typical examples of such structures from automotive industry are tubes, hoses, single cables, or wiring harnesses collecting many cables within a compound structure.

The theory of *Cosserat rods* provides structural models that are suitable for physically correct simulations of deformations of such slender flexible objects by *stretching*, *bending* and *twisting*. In computational mechanics, such models are usually discretized via nonlinear finite elements, which are taylored to provide very accurate simulation results, but are technically rather complicated, and computationally far too demanding for fast simulations compatible with an interactive modification of the boundary conditions.

The kinematics of Cosserat rods are closely related to the *differential geometry of framed curves*, with the differential invariants of rod configurations corresponding to the strain measures of the mechanical theory. Therefore, one may utilize ideas from the *discrete* differential geometry of framed curves to construct discrete Cosserat rod models which behave qualitatively correct even for arbitrarily coarse discretizations, provide a fast computational performance at moderate accuracy, and thus are suitable for interactive simulations.

In our talk, we present this geometry based discretization approach for flexible 1D structures, with a focus on applications in assembly simulation of cables and hoses from automotive industry.

Chantal Landry (Weierstrass Institute, Berlin)

Automatic reconfiguration of robotic workcells

Manufacturing companies have by now reached a high degree of automation. To ensure their competitiveness, production lines must be as efficient as possible. A major point in this quest of efficiency lies in the automatic reconfiguration of the workcells that compose the production lines. Given the number of industrial robots in the workcell, the Computer Aided Design data of the workpiece and the location of tasks on it, the cell is optimally configured when the time taken to complete all the tasks is minimized. For that purpose, one needs to efficiently assign tasks to the robots and to find the fastest collision-free trajectory between the task locations. In this talk, we will discuss an automatic configuration that is based on the effective combination of discrete optimization techniques, time-optimal motion planning and collision detection checking.

Wolfgang Welz (TU Berlin)

Combinatorial optimization aspects of robot tour planning

In welding cells a certain number of robots performs spot welding tasks on a workpiece. The tours of the welding robots are planned in such a way that all weld points on the component are visited and processed within the cycle time of the production line. During this operation the robot arms must not collide with each other. On the basis of these specifications we show an approach, how such a problem can be solved with discrete optimization methods. This leads to a Vehicle Routing based problem with additional scheduling and timing aspects, induced by the necessary collision avoidance. It is then solved as an Integer Linear Program by Column Generation techniques. In this context we adapt a version of the Shortest Path Problem with Time Windows, so that it can be used to solve the pricing problem with collision avoidance. To boost the performance of this crucial part of the process, several problem dependent improvements can be applied to the pricing as well as the primal heuristics.

Konstantin Palagachev (Munich Aerospace/University of the Federal Armed Forces Munich, Neubiberg)

Switched system optimal control problems with applications to robotics

We consider Optimal Control Problems given by Switched Systems (SSOCP), i.e. systems operating between different subsystems or phases. The sequence of the phases might be known or unknown. In case the sequence of phases is known a priori, a time-transformation technique leads to a standard optimal control problem. In the second case decision variables have to be introduced into the problem, obtaining in such a way a mixed integer nonlinear problem. The design of effective control policies is far more complicated in the second case. Our approach for solving the SSOCP is to model the whole problem as bilevel optimization problem. On upper level, we have a job shop scheduling problem, i.e. a problem in which certain procedures whose sequence is unknown have to be executed. The parameters of the upper level problem are themselves solution of a lower level optimal control problem. In order to solve the problem numerically, “discretize-then-optimize” technique is adopted. Thus, the initial infinite dimensional problem is approximated by finite dimensional mathematical program, which is solved by iterative method. At each iteration, the lower level nonlinear mathematical program has to be solved by standard sequential quadratic programming method, and sensitivity analysis has to be performed on the optimal solution. Those sensitivities provide a linear and quadratic term for the upper level mixed integer quadratic program, which is solved by branch and bound. Thus a search direction for the lower level is obtained and the process is repeated until suitable stopping criteria is reached. In order to test the methods, optimal control problems involving interactions between robots are considered.

Josef Prinz (inpro, Berlin)

Simulation and optimization of the transfer of thin flexible metal sheets in forming presses

New manufacturing technologies and the further development of the machine and system technology on the one hand increase the production flexibility, but on the other hand also lead to more complex control programs and commissioning processes. Together with changed product characteristics, this means a challenge for the planning and design processes in the digital factory. As an example, the transport of thin and flexible metal sheets in transfer presses is presented. The trajectory and the transport speed should be individually optimized so that the maximum productivity is obtained. On the other hand should the deflection of the components caused by the motion and by the configuration of the holding system, cause no collisions and cause no damage. Efficient methods for deformation analysis must be developed, as these calculations are embedded in press line simulation systems and interactive configuration tools.

Steen Markvorsen (Technical University of Denmark, Lyngby)

Hot wire cuttings for the building industries

The constructions of advanced architectural designs are presently very labour intensive, time consuming, and expensive. They are therefore limited to be applied only to some few prestige Projects and it is a major challenge for the building industry to bring the costs down and thereby offer the architects more variability in the (economically allowed) designs – i.e. to allow them to think out of the box. To address this challenge The Danish National Advanced Technology Foundation is currently supporting the BladeRunner project that involves several Danish companies and public institutions. The project aims to reduce the amount of manual labor as well as production time by applying robots to cut EPS-moulds for the concrete to form doubly curved surfaces. The scheme is based upon the so-called Hot Wire or Hot Blade technology where the surfaces are essentially swept out by driving an Euler elasticum through a block of EPS. This presentation will be centered around the mathematical challenges encountered in the implementation of this idea. They are mainly concerned with the rationalization of the architects' CAD drawings into surfaces that can be created via this sweeping and cutting technology.

Pavel Burget (Czech Technical University in Prague)

Simulation of idle-times energy savings on a welding line

The objective of this work is to enhance the models in a simulation study of a welding line with the ability to put the devices into a sleep mode in case no welding or movement operation is required. For this case, it relates only to the robots because in the real line no other devices possess the ability to be in standby or hibernate modes, in which they consume significantly less energy than in the operational state. For the simulation the Tecnomatix environment has been used, namely Process Simulate and Plant Simulation, in order to compare both models and assess the suitability of their use for real production lines. Preliminary measurements show that during weekends when no production is executed, more than 80 % of the energy consumed by the robots can be saved when the robots are hibernated. During work days a significant amount of energy can be saved if the robots are put into the standby mode during planned or unplanned pauses. Simulation in the digital factory framework checks out not only that the expected savings are achieved but also that the sequence of bringing the robots into the standby and back to operational modes are feasible. In this work the data from a real welding line are used to obtain the energy consumption of the robots in different modes in the simulation models. This work is done in cooperation with Škoda Auto.

Premysl Sucha (Czech Technical University in Prague)

Optimization of power consumption for robotic lines in automotive industry

These days not only throughput is a key-aspect of designing robotic lines, but also the energy consumption is getting more and more important as the cost of electricity was rising during the last decades. As a consequence it is not surprising that industrial companies are interested in finding energy efficient solutions. Lack of support of energy optimization in the existing software design tools is the reason why we were contacted by Škoda Auto to participate in this project.

In our work we propose a novel mathematical formulation of the energy optimisation problem for robotic lines. In contrast to the existing works our solution considers different trajectories of robots, gravity and order of robot operations from the global point of view. Moreover, our mathematical formulation takes into account the robot's power save modes (e.g. using brakes or bus-power-off if supported), to which the robot in a stationary position can switch after a transitional time, to save even more energy. The optimal solution to the problem is the one which is both the most energy efficient and meeting the desired production cycle time. As our approach is high-level, the point-to-point robot's movements for different speeds and trajectories have to be a priory simulated by an external tool and used as an input for our algorithm. Having had the line structure and data from simulations the problem can be solved using Integer Linear Programming. As the large-scale ILP problem is difficult to solve we proposed to decompose it into smaller independent sub-problems corresponding to individual robots using the Lagrangian relaxation method. However, the tightness of the resulting lower bound and performance of the method need to be investigated in the future research. The preliminary experiments on generated instances confirmed the correctness of the proposed model and revealed a high potential for reducing energy consumption of robotic lines.

FRIDAY, MAY 9

René Pinnau (TU Kaiserslautern)

The production of filaments and non-woven materials — the design of the polymer distributor

In this talk we discuss the different stages in the production of filaments and non-woven materials as well as the underlying mathematical challenges, which were investigated in the collaborative research project "ProFil". In particular, we are going to have a closer look at the very first stage in the process chain: the design of the polymer distributor. This yields a numerical shape design problem with state constraints. Finally, we are considering also the question of reachability of desired states.

Markus Grebenstein (Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Wessling)

Compliant robots in automation: The impact of humanoid robotics on automation

Besides in fiction, Humanoid Robotics has been assumed to have hardly any impact on future automated production. Even robot suppliers struggled to find industrial applications for their recently introduced torque controlled robots. But current developments show that the producing companies themselves discovered these robots having a large potential to accomplish assembly tasks that have, up to now, been exclusively performed by humans. Furthermore, the anthropomorphic properties of these robots enable them to be collaborators rather than a replacement of human beings. By this, these robots are believed to provide the potential to develop a more human friendly and yet efficient production in future factories.

Based on the development of the DLR/KUKA LBR technology, this presentation gives an overview of the technology of torque controlled lightweight robots and its evolution toward human centered robotics as well as an outlook on future developments.

Martin Krüger (Fraunhofer Institute for Production Technology IPT, Paderborn)

Model-based design of self-correcting forming processes

Complex metal parts concealed in everyday devices, such as in plug contacts for electrical connection technology and pull-out rails for the furniture industry, are produced by forming processes. The challenges involved in the production of these metal parts lie in the time-intensive setup of the bending processes and compliance with the product requirements during production. The difficulties encountered in meeting the requirements for the quality and size accuracy of the final products in forming processes include the fluctuating properties of the semi-finished products and/or the machine behavior. Today, production processes are automated to a high degree. However, feedback control of core processes like punch-bending or continuous bending is not state of the art. Usually, machine operators have to set new process parameters manually on the basis of their experience if undesirable geometrical deviations appear. This contribution presents an approach for the design of self-correcting forming processes by means of suitable feedback control strategies. This approach is developed in the course of a project within the Leading-Edge Cluster "Intelligent Technical Systems OstWestfalenLippe". We try to transfer the well-etablished design methodology for mechatronic systems to the design of manufacturing processes. Hence, mathematical models of the process dynamics become a crucial part during design process. Our model assumes a workpiece to be built of a chain whose links are connected by spring-damping elements and torsional elements representing the material properties. Elastic as well as plastic deformations can be simulated. This model is accurate enough to design a closed-loop control which uses information of the current workpiece, e.g., opening dimension or applied force, for bending correction of next workpiece.

Xavier David-Henriet (TU Berlin/University of Angers)

About closed-loop control and observability of max-plus linear systems: Application to manufacturing systems

Max-plus algebra is a suitable setting to model synchronization and delay phenomena [3]. Among applications, it is used to model timed discrete-event systems, which represent, for example, the manufacturing system operations. Over the past three decades, many fundamental problems for max-plus linear systems have been studied by researchers, for example, controllability, observability, and model reference control. This talk will propose a survey about the recent developments about this specific control theory. Max-plus algebra is actually an idempotent semi-ring. Hence first, the talk will focus on the residuation theory [1] and the solving of equations in the semi-ring framework [2]. Then, how to model the manufacturing systems in this algebraic setting will be recalled. An assembly workshop will be considered as example. Then, applications for the controller synthesis [4] and the observer synthesis [5] will be presented. Among illustrations, it will be shown how to compute an optimal closed loop controller according to the just-in-time criterion for the assembly workshop previously introduced. It will be shown that controller is optimal in spite of disturbances such as machine breakdowns or disruptions in component supply.

References

[1] T. S. Blyth, *Lattices and Ordered Algebraic Structures*, Springer Verlag, 2005.

[2] P. Butkovič and R.A. Cuninghame-Green, On matrix powers in max-algebra, *Journal on Matrix Analysis and Applications*, 421(3):370–381, 2007.

[3] F. Baccelli, G. Cohen, G.J. Olsder, and J.-P. Quadrat, *Synchronization and Linearity: An Algebra for Discrete Event Systems.* New York: John Wiley and Sons, 1992. *http://www-rocq.inria.fr/metalau/cohen/SED/SED1-book.html*

[4] C.A. Maia, L. Hardouin, R. Santos-Mendes, and B. Cottenceau, On the model reference control for max-plus linear systems, *The 44th IEEE Conference on Decision and Control*, pp. 7799–7803, 2005.

[5] L. Hardouin, C.A. Maia, B. Cottenceau, and M. Lhommeau, Observer design for (max,plus)-linear systems, *IEEE Transactions on Automatic Control*, vol. 5, issue 2, pp. 538–543, 2010.