Exploring new Applications for Modern Taylor Series Methods to Solve Stiff and High-Order Systems

AKTION project 76p11 2016-2017

Final Report

Involved partners: **Brno University of Technology (BUT)**
Vienna University of Technology (VUT)

Project duration: 2016-07-01 to 2017-10-31

Abstract
The presented project is the third AKTION project on the topic of Modern Taylor Series Methods (MTSM), carried out by the teams at the Brno University of Technology (BTU) and Technische Universität Wien (VUT). It focused on broadening the application scope of the MTSM to industrial applications in various domains, thereby also deepening the international cooperation between the two partner institutions. Moreover, the involved young researchers and PhD candidates could use the opportunity to gain international, interdisciplinary experience, both in social as well as in scientific terms.

Main outcomes of the project:

- Scientific and personal collaboration between the BUT and VUT project teams has been fostered and expanded, resulting in a sustaining and fruitful experience and building up a professional academic and scientific network between the BUT and VUT participants.
- The Modern Taylor Series Method (MTSM) has been expanded to tackling new applications. New tools and new functionality has been developed and tested in this new application context, covering efficient problem representations, stiff and high-order systems, the tackling of discontinuities, as well as other mathematical applications of the MTSM idea, for example in multi-dimensional integration problems.
- Relevant properties, requirements and constraints of industrial research applications have been collected and discussed, and the applicability of the MTSM and tools have been discussed.
- The participating Ph.D. students of both teams have actively driven scientific discussions during the exchange visits, thereby confronting their research work with an interdisciplinary perspective. Inspiration and factual feedback on their work helped them to improve the quality of their related research, as well as speed up their progress.
- Specialized guest lectures (with associated ECTS credits) were given by the visiting researchers at the respective host organizations. Active dissemination work (wide audiences at exchange round meetings and guest lectures as well as joint publication activities) carried the project's benefits out beyond the boundaries of the directly involved project participants.

1. Overview on Exchange Activities
The following exchange activities have been held:

Date / Activity	Venue	Visitors (duration)
18th-22nd July 2016, Kickoff	@ Vienna	5 participants from BUT at VUT
29th-30th August 2016, Coordination & Discussion	@ Brno	5 participants from VUT at BUT
2nd Oct. 2016, Coordination	@ Vienna	Prof. Kunovsky
28th Sep. 2016, Coordination	@ Vienna	Prof. Kunovsky
28th Oct. 2016, Coordination	@ Vienna	Prof. Kunovsky
11th Nov. 2016, Coordination	@ Vienna	Prof. Kunovsky
25th Nov. 2016, Workshop	@ Vienna	4 participants from BUT at VUT
13th Dec. 2016, Coordination	@ Vienna	Prof. Kunovsky
29-30th March 2017, Workshop	@ Brno	9 participants from VUT at BUT
25-28th April 2017, Workshop	@ Vienna	4 participants from BUT at VUT
19th-23nd June 2017, Workshop	@ Vienna	6 participants from BUT at VUT
18th October 2017, Final Workshop	@ Vienna	5 participants from BUT at VUT

The AKTION project setting is thereby characterized by a strong interdisciplinary perspective which is rooted on one side in the continuous exchange activities held, on the other side in the involvment of three different institutes, individual research perspectives, as well as the participation of several professors, post-docs, and PhD candidates with a wide range of scientific background.

2. Scientific Contents and Proceedings
With the goal of extending the Modern Taylor Series Method (MTSM) to various application domains and to tackle the specific problem structures and peculiarities found therein (stiffness, high order, nonlinearities, discontinuities), a broad and vivid scientific discussion has been organized, spanning several workshop meetings over the project duration. The participants related the general concepts of the MTSM to their research problems, incorporating an interdisciplinary perspective into their work in the process.

Upon project kickoff, the work groups exchanged their respective project-relevant background, the existing MTSM tools and technology. Throughout the project, possible ways of applying the MTSM to solve various application problems have been thoroughly discussed and developed. The MTSM thereby was seen as general methodology applicable to function approximation, numeric integration of differential equations, integral relations, or even algebraic implicit problems. The broadness of applications and formulations can be seen by the following collection of topics given as short talks and discussion items at the March 2017 workshop:

Student: Elvira **Thonhofer**
Topic: ***Traffic network control***
Abstract: Based on a macroscopic traffic model, where vehicular traffic is treated like a compressible fluid, control strategies are developed. Different approaches to both (hierarchical) control algorithms as well as optimization goals are investigated. Simulation based testing is currently underway, testing in real-live urban traffic networks is anticipated.

Student: Elisabeth **Luchini**
Topic: ***A hierarchical MPC for multi-objective mixed-integer optimisation applied to redundant refrigeration circuits***

Student: Clemens Carl **Maier**
Topic: ***GearControl***

Abstract: This presentation will talk about the modelling of a hydraulic system (of an automatic gearbox) using nonlinear state space formulation. The system is considered large (with 16 states) and is stiff due to its physical properties, therefore requires small a sampling time (1µs) using Matlab/Simulink solvers. One main task in the associated project is to use this white-box model to identify its physical parameters from testbed measurements.

Student: Pablo Elias **Fuentes Sommer**
Topic: ***Ways to deterministic chaos through Torus destruction in populatio biology models***
Abstract: Analysis of the Rosenzweig Mac-Arthur model in population biology with bifurcation structures such as Hopf, limit cycle and torus bifurcations and deterministic chaos. Development of stochastic processes for the Rosenzweig MacArthur model.

Student: Janos **Kancsar**
Topic: ***Flatness-based feedforward control of PEMFC stack testbeds***
Abstract: To enable modular and transient testing of a PEMFC stack during development a highly dynamic testbed is needed. The testbed represents a coupled nonlinear MIMO system for which a model is presented and the model property of differential flatness is exploited to decouple the system and design a 2DoF controller.

Student: Lukas **Böhler**
Topic: ***Biomass combustion – parameter sensitivity of a heat exchanger model***

Student: Daniel **Ritzberger**
Topic: ***Emulating a perfectly matched layer using optimal control strategies***
Abstract: When approximating the solution of *unbounded* wave propagation problems, suitable boundary conditions have to be formulated for the PDE to minimize unphysical reflections at computational domain boundaries. Perfectly matched layers are regarded as the state-of-the-art technique to absorb spurious waves at the boundaries, but extensive transformations of the problem are typically required. As an alternative approach, which can be highly automated and does not need extensive analytic treatment and problem-specific transformations, optimal control strategies are presented to emulate the properties of a perfectly matched layer.

Student: Sebastian **Thormann,** Alexander **Schirrer**
Topic: ***Finite-Element modeling and dynamic simulation of string-/cable-/rope-structures***
Abstract: An overview on string/cable/rope modeling via finite elements and their dynamic simulation via numeric integration methods is given.

Vivid discussions on each topic and potential use cases, advantages and limitations of the MTSM in these application scenarios followed, and several test problems have been identified and studied together or in smaller groups.

This way, all participants could engage in interdisciplinary scientific discussions and concrete links to active research projects could be established. The findings could be incorporated into the participants‘ work as well as publication activities. Publications related to the project contents, specifically MTSM and directly related concepts, are listed below. These publications have directly benefitted from the project setting and the workshop discussions.

3. Project Team

By the beginning of the project, Dr. Marsalek and Ing. Raffai unexpectedly left the university and so they could not participate in the present AKTION project. Instead, in agreement with the AKTION office, the new group around Dr. Rozman and Doc. Zboril (BUT) entered the project. The involvement of the group around Prof. Kunovsky (BUT) and Prof. Kozek / Dr. Schirrer (VUT) remained unchanged.

Dr. Rozman is an assistant professor at BUT, focusing on the development of a walking Hexapod system and associated gait actuation and control system. Doc. Zboril is associated professor at BUT. His interest comprises artificial intelligence, especially agent and multiagent systems. He developed and implemented WSAgeNt system that works with agents as mobile codes for wireless sensor networks (WSN). This approach allows easier prototyping of such systems. When WSAgeNt platform exists on a WSN node then the agents can be interpreted there and they may temporarily extend functionality of the node as well as functionality of the whole WSN.

These new perspectives and associated contributions enriched the project teams‘ competency landscape, replacing the originally envisaged application domain of fluid problems.

4. Educational Impact

Nine junior Ph.D. students have been actively involved in the AKTION project. They could use the project framework to disseminate their research results, to assess their own and others' perspectives in the project's interdisciplinary perspective, and broaden their experience both scientifically as well as socially.

The exchange rounds were carried out with a broad audience – not only the project team members, but also researchers and students not in the project teams comprised the audience and joined the discussions. This way, a broad interdisciplinary exchange took place, reaching well beyond the boundaries of the project teams and thereby realizing an intensive exchange of ideas and broad dissemination.

Moreover, the academic cooperation of the partners could further be strengthened. Then-PhD candidate Filip Kocina (BUT) could finalize his PhD studies during the project and successfully achieved his promotion to PhD, with Martin Kozek (VUT) being one of his opponents at the defense at BUT.

Finally, the involved senior researchers participated at the exchange rounds and gave guest lectures at the project partner's institutions. The following guest lectures have been given with a widened audience, organized as an integral component in ECTS-recognized lectures at these institutions:

Lecturer (home institution)	Guest Lecture Title	Held at
Prof. J. Kunovsky (BUT)	Modern Taylor Series Method for integration	VUT
Prof. M. Kozek (VUT)	Modeling and Control of Dynamical Systems	BUT
V. Šatek (BUT)	Analysis and integration of stiff systems	VUT
A. Schirrer (VUT)	Realtime emulation of complex, high-order system dynamics in a test rig	BUT

5. Conclusions

The third installment of the MTSM-themed academic cooperation between BUT and VUT has widened academic and scientific cooperations both in terms of the treated topics and application domains, as well as in terms of involved parties. Many applications have been reviewed for applicability, advantages and limitations of the MTSM in scientific computing, and new ties between the VUT research group and the involved research groups at BUT have been established. The involved junior researchers / PhD candidates benefitted from the interdisciplinary context fostered by the AKTION project setting, exposing their research to a broad scientific discussion, and generating ideas on MTSM applications beyond their respective research domains.

The involved PostDoc researchers have the perspective of leading their own laboratories and research groups in the near future and can carry the impressions of their involvement in the interdisciplinary, inter-universitary exchange setting of the AKTION projects into their future research endeavours.

Publications related to the project

2017 CHALOUPKA Jan, KOCINA Filip, VEIGEND Petr, NEČASOVÁ Gabriela, ŠÁTEK Václav and KUNOVSKÝ Jiří. Multiple Integral Computations. In: *14th International Conference of Numerical Analysis and Applied Mathematics*. Rhodes: American Institute of Physics, 2017, pp. 1-4. ISSN 0094-243X.

CHALOUPKA Jan, NEČASOVÁ Gabriela, VEIGEND Petr, KUNOVSKÝ Jiří and ŠÁTEK Václav. Modern Taylor series method in numerical integration: PART 1. In: *16th Czech-Polish Conference Modern Mathematical Methods in Engineering (3mi)*. Rybnik, 2017, pp. 263-273. ISBN 978-83-65265-14-2. ISSN 2391-9361.

KOCINA Filip, NEČASOVÁ Gabriela, VEIGEND Petr, CHALOUPKA Jan, ŠÁTEK Václav and KUNOVSKÝ Jiří. Modelling VLSI Circuits Using Taylor Series. In: *14th International Conference of Numerical Analysis and Applied Mathematics*. Rhodes: American Institute of Physics, 2017, pp. 1-4. ISSN 0094-243X.

KUČERA Radek, ŠÁTEK Václav, HASLINGER Jaroslav, POCHYLÝ František, KOKO Jonas and SASSI Taoufik. Numerical Modelling of the Stokes Flow with Threshold Slip Boundary Conditions. In: *14th International Conference of Numerical Analysis and Applied Mathematics*. Rhodes: American Institute of Physics, 2017, pp. 1-4. ISSN 0094-243X.

NEČASOVÁ Gabriela, KOCINA Filip, VEIGEND Petr, CHALOUPKA Jan, ŠÁTEK Václav and KUNOVSKÝ Jiří. Solving Wave Equation Using Finite Differences and Taylor Series. In: *14th International Conference of Numerical Analysis and Applied Mathematics*. Rhodes: American Institute of Physics, 2017, pp. 1-4. ISSN 0094-243X.

VEIGEND Petr, NEČASOVÁ Gabriela, KOCINA Filip, CHALOUPKA Jan, ŠÁTEK Václav and KUNOVSKÝ Jiří. Real Time Simulation of Transport Delay. In: *14th International Conference of Numerical Analysis and Applied Mathematics*. Rhodes: American Institute of Physics, 2017, pp. 1-4. ISSN 0094-243X.

2016 KOCINA Filip, KUNOVSKÝ Jiří, NEČASOVÁ Gabriela, ŠÁTEK Václav and VEIGEND Petr. Parallel solution of higher order differential equations. In: *Proceedings of the 2016 International Conference on High Performance Computing & Simulation (HPCS 2016)*. Insbruck: Institute of Electrical and Electronics Engineers, 2016, pp. 302-309. ISBN 978-1-5090-2088-1.