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Report on the Doctoral thesis submitted to the **Czech Technical University in Prague, Faculty of Electrical Engineering**

Title: Scalable Scheduling Algorithms for Embedded Systems with Real-Time Requirements

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Branch of Study: Control Engineering and Robotics

The scope

This doctoral thesis deals with scalable scheduling algorithms for real-time embedded systems containing shared computational resources. It contributes to the design of optimal and heuristic scheduling algorithms utilizing Integer Linear Programming (ILP), Satisfiability Modulo Theory (SMT) and Constraint Programming (CP) formalisms and corresponding professional solvers. Considering the growing interest in embedded and cyber-physical systems that contain complex computational resources (including multi- and many-core processors, shared memories and interconnecting networks) and require accurate and real-time control and scheduling algorithms, the theme of the thesis is undoubtedly topical and definitely relevant for the author's field of study.

Goals of the thesis

The goals and objectives are clearly stated on page xi and their fulfilment is discussed in detail in Section 5.2. I have to confirm that all the goals were more than fulfilled.

Methodology and contributions

In particular, the thesis addresses the problem of scalability of scheduling in embedded systems with many shared resources and under various constraints, where the real-time aspect is a crucial objective. As finding time-triggered schedules is an NP-hard problem under the real-world conditions given in the thesis, an optimal solution can only be obtained for simple problem instances. The author has shown how scheduling problems (with various constraints in terms of timing) can be formulated in such a way that commonly used (ILP, SMT, CP) solvers can find optimal solutions for more complex instances than it was possible up to now. Moreover, three efficient heuristic algorithms were proposed to handle complex industrial-size problem instances in an acceptable time and quality. A detailed (mostly statistical) comparison of the optimal approaches and heuristic approaches is presented on a set of synthetic benchmark problems of different size and on several real-world applications from automotive industry. All the problems addressed in the thesis are rigorously formulated for appropriate solvers and the proposed algorithms are discussed in detail. The proposed methodology is correct, adequate and leads to efficient approaches capable of solving target problems.

Organization, style and language

The thesis contains all relevant parts; its length and the level of detail are appropriate. However, there is one exception. As the thesis relies on ILP, SMT and CP, I would expect a detailed introduction to these methods and corresponding solvers in the section describing the state of the art. References are complete and adequate. I found only a few minor typos in the use of English, but the Czech version of the abstract

needs additional proofreading. The clarity and style of writing are excellent, showing thus the author's experience and erudition in presenting the results of her research. I highly appreciate how Chapter 5 is composed. It contains not only a summary of problems, methods, results and contributions, but also several sections on user experience, portability and usage of the software utilized and created to produce the results. Finally, where is Fig 1.1 taken from? No reference is given!

Author's publications

The list of author's publications contains three articles in journals with an impact factor (one of them is still under review) and two conference papers. These papers have already attracted 35 citations in Google Scholar. The quality of publication venues is high, for example, IEEE Transactions on Computers is clearly one of the leading journals of the field.

Questions

1. Chapter 2.7 presents a non-deterministic heuristic algorithm, but there is no experimental evaluation of its behavior on selected problem instance (use-case) calculated from multiple independent runs. Does this heuristic produce (statistically) stable results?
2. The results are not compared against results of other authors because, as I have understood from the thesis, there are no relevant approaches available. But the algorithms presented in Chapters 3 and 4 are evaluated using problem instances generated by a tool developed by Bosch [65]. Does it really mean that the obtained results cannot be compared if there is a tool generating relevant problem instances?

Summary

This is a well-written doctoral dissertation presenting new scientific results in the area of scalable scheduling algorithms for real-time embedded systems containing shared computational resources. In addition to the rigorous formulation of problems and their algorithmic solutions I highly appreciate that the author did a lot of experimental work which confirmed the quality of proposed algorithms. The practical aspect of the thesis is clearly demonstrated by solving challenging real-world problem instances from automotive industry. In my opinion, the author of the thesis proved her ability to perform a high-quality research and achieve original scientific results. The thesis contains new and original results that have already been published. The thesis satisfies all requirements given on doctoral dissertations. Therefore, I **recommend the thesis for defense.**



Prof. Ing. Lukáš Sekanina, Ph.D.
Reviewer of the thesis