IDIOM methodology extension and its application to HEV optimization

Designing and developing mechatronic products is a challenging task, independent of the new concept being an evolutionary or revolutionary design. In order to decrease time-to-market, it is crucial to avoid late design changes.

The IDIOM methodology therefore focuses on early phase product design, facilitating easy and swift comparison of various design ideas by optimizing the concepts for desired design objectives, such as mass or energy consumption. The methodology and tools are based on a linear systems approximation. This means that the dynamic system models that represent the design concepts must be based on linear differential equations. The reason for this is that the need for very quick evaluations and optimization does not allow for time expensive numerical simulations. Thanks to the linear representations of a closed loop system, its behaviour can instead be found through solving algebraic equations.

In order to model and optimize a hybrid electric powertrain, the current IDIOM software framework has to be extended in the following directions.

1. The component library needs to be enlarged with models for battery, clutch, internal combustion engine, and potentially other components of the drivetrain. The current IDIOM models employ scaling laws to relate load torque to volume. To the new application of optimizing HEVs, we must further develop similar scalable models for energy losses and other objectives of interest. The equations governing the dynamic behaviour need to be linear differential equations. The energy loss model is preferably convex to enable convex optimization. The models shall also be implemented in the existing framework software package, where they have to be properly validated and verified.
2. The current methodology needs to be extended to be able to split the load of the drive cycle into a part for the combustion and the electrical drive train. This can for instance be achieved by a top-level optimization strategy, however, it is important to keep the overall computational effort to a minimum and as a consequence smart ways of doing so have to be investigated.   
   If necessary, the algorithm for controller synthesis has to be changed, here again, with the overall goal of swift concept estimation in mind.
3. The optimization method must include total energy or fuel consumption as a primary objective function. State-of-the-art methods for energy minimization include dynamic programming and convex optimization. The two optimization methods are not yet included in the IDIOM method and tool. Efficient implementation of dynamic programming and convex optimization algorithms is interesting and challenging research questions on its own.

We plan to take the prototype vehicle developed for the Shell Eco-marathon competition as a validator. Our research results will be applied to this vehicle to improve its efficiency. Hopefully our design will be implemented on the vehicle next year to gain better result in the competition.

A possible outline of the individual course activities could like as follows.

* Pre-study: Learn about IDIOM methodology and get some experience with the toolset, including the modelling approach of existing components.
* Pre-study: Literature study to investigate models for the desired relations of a specific component. Literature study on HEV design and optimization.
* Intermediate reporting within the research group on pre-study findings.
* Conceptual phase: Explore a multitude of possible ways of finding the targeted extension (both modelling-wise as well as methodology-wise). Develop proper models of the prototype HEV and apply various optimization technologies.
* Intermediate presentation within the research group and selection of possible ways forward.
* Solution phase: Develop the most promising idea(s). Summarize new designs that will improve the fuel efficiency of the HEV prototype.
* Presentation, reflection, discussion and conclusion phase.

# Contact Persons

* Support on IDIOM methodology and the development of the software package: Daniel Frede, Fariba Rahimi.
* Support on HEV configuration and optimization and control technologies: Lei Feng, Mikael Hellgren.
* Support on the HEV prototype: Mikael Hellgren.

# Reading Materials

* Daniel Malmquist, Daniel Frede, and Jan Wikander, Holistic design methodology for mechatronic systems, *Proceedings of the Institution of Mechanical Engineers, Part I, Journal of Systems and Control Engineering*, 228(10): 741-757, 2014.
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