Networking and Information Technology Research & Development: Input for Strategic Planning

Futurists, product planners, and government agencies envision new semi-autonomous vehicle, vehicle-to-vehicle, and vehicle-to-infrastructure capabilities that reduce fuel consumption, reduce congestion, improve air quality, and improve safety. Given this future, the automotive industry must have access to new engineering tools and methods that yield the productive development of these complex Cyber-Physical Systems at unquestioned levels of quality.

Our goal is to partner with NITRD and other collaborators to conduct research in robust methods for Cyber-Physical Systems development. Our particular experience is in automotive engine control and the following paragraphs expose critical aspects Cyber-Physical Systems development in the engine control context. Of course, the complexity and difficulty grow exponentially for the products and systems outlined above.

To reduce fuel consumption and emissions, improve vehicle performance, and meet higher customer expectations, the powertrain control system is becoming more and more complex. As a result of the increased complexity, the software has a structure composed of thousands of variables and tuning parameters with highly interacting functions. The software is becoming very difficult to develop and test and the cost for securing the highest quality is increasing exponentially. **Model-Based Development** (MBD) has been promoted [1], [2], [3] for several years to alleviate this scenario.

We envision an engineering framework to enable the introduction of MBD to production processes. Challenges related to three aspects of MBD are introduced in this position paper:

1) **Plant Modeling.**

2) **Verification and Validation (V&V)**.

3) **Visualization.**

Challenges and Research Needs

Plant Modeling: If we are to be successful, we must recognize that plant models are prerequisite for model-based development. These plant models must a) capture the "appropriate" physical phenomena and dynamics, b) be "sufficiently" accurate, and c) be "available" when dictated by the production process schedule. Given these requirements, we believe there is significant research and development opportunity to improve plant modeling processes, methodologies, and tools so that plant modeling can be considered a predictable and dependable production process.

In fact, toward this end, we are participating in the formation of a Plant Modeling Consortium. Our initial goal is to create a community to promote plant modeling research and development in the above context. Potential topics for consortium consideration include: a) plant modeling process definition and standardization, b) domain-neutral, conservative modeling methods and tools, c) statistical and machine learning modeling methods and tools, d) model simplification methods and tools, e) improved parameter identification methods and tools, f) integration of physical and statistical modeling methods, g) improved solvers for a-causal model formulations, and h) model confirmation & validation methods.

From our control domain perspective, we consider the behavioral / functional specification

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and verification of the embedded powertrain software to be a fundamental challenge. It is essential that we develop robust modeling methods that yield 'sufficient' plant models to support this control algorithm specification and verification.

Verification and Validation (V&V): Conventional V&V processes of powertrain control software rely on exhaustive experimental testing. However, continuously increasing complexity of modern powertrain control systems poses great challenges to the conventional processes. We list a few of the challenges in the MBD context:

Defining levels of abstractions and corresponding specification languages are needed for being able to develop more complex control systems and efficiently perform V&V [5]. For example, a Simulink model visually provides hierarchies, however it has all the details of a C-code. A higher level architecture abstraction that captures properties such as component interactions, real-time communication schedules and dependency structure are needed.

Ensuring semantics-preservation between architecture abstraction layers during the development process is a key challenge to develop high confidence control software. As we move down the abstraction layers, there are more details added to the design. The less abstract implementation must preserve the semantic properties of the high level model. If it is not preserved as in between simulation and experiment, the gap and its effect on robustness need to be analyzed.

There are many V&V methods, tools and platforms available or being developed. V&V processes need to be developed in every step of the control software development process including requirements management, control logic design, software implementation and integration and calibration. The process should efficiently use a comprehensive end-to-end V&V tool chain with confidence.

Visualization: It is rare to develop powertrain control software from scratch. This means that we have to cope with legacy software which has been incrementally expanded over time to add new control functions. Drastic changes are avoided as far as possible, since reliability of legacy software has been proven through market use. Thus legacy powertrain software tends not to be well structured as it increases with complexity and size. It is difficult to understand how the system works and how partial changes will affect the whole system. As control software keep growing, this is becoming one of the key issues in the design process and demand for visualization is increasing in this light.

Conventionally, understanding legacy control software starts with code reading to capture software structure, and then we infer system behavior. To help structural understanding, there already exist commercially available visualization tools. The difficulty we have in using these tools is that the graph representations given by these tools are still too complex and their interpretation is as painful as code reading. A mechanism for selecting what to show and what not to show is required.

Simulation is often used to understand dynamic behavior of the software. However, stimuli should be provided to excite important system behavior and this requires deep knowledge on the software and the system itself which we don't have without large investment.

Understanding control system from legacy code is time-consuming and human-dependent activity. Methodologies to capture and extract representative system properties while hiding unimportant details seem to be the key. We believe that tools that can support this activity will

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improve the productivity of development processes significantly.

References

[1] T. Ueda, A. Ohata, "Trends of Future Powertrain Development and the Evolution of Powertrain Control Systems," in Proc. 2004 SAE–Convergence Conference, October, 2004.

[2] A. Ohata, K. Butts, "*Towards a Concurrent Engine System Design Methodology,*" in Proc. 2005 American Control Conference, June, 2005.

[3] A. Ohata, "*Model-Based Development: Plant Modeling Environment,*" Vision of the Future Plenary Presentation, Fifth IFAC Symposium on Advances in Automotive Control, August, 2007.

[4] Plant Modeling Consortium Website: http://www.maplesoft.com/consortium/

[5] http://aadl.info/

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