Automotive Research Center
A U.S. Army Center of Excellence for Modeling and Simulation of Ground Vehicles led by the University of Michigan

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ARC Collaborative Research Seminar Series
Fall 2010

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If you wish to attend the seminar remotely, please contact William Lim (choonhun@umich.edu) for teleconference details.

September 24th

October 8th

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September 24th, Friday (9:30-11:00am)
University of Michigan, Duderstadt Center, Room 1180

TARDEC Thrust Area Leaders Drs. Paramsothy "Jay" Jayakumar, David Lamb and Mark Brudnak will discuss their research goals.

October 8th, Friday (9:30-11:00am)
University of Michigan, Computer Science and Engineering (CSE) Building, Room 1690

Combined SOFC/Gas Turbine Cycle Systems: Analysis and Optimization
Dr. Jing Sun, University of Michigan, Naval Architecture & Marine Engineering

Abstract: Combining solid oxide fuel cell and gas turbine (SOFC/GT) system is a promising concept for future clean and efficient power generation. An SOFC/GT system exploits the complementary features of the two power plants, where the GT recuperates the energy in the SOFC exhaust stream and thereby boosting the overall system efficiency. Through model based transient analysis, however, it is shown that the intricate coupling dynamics make the transient load following very challenging. Power shutdown has been observed when the load change is attempted. Our recent work focuses on modeling, dynamic analysis, and control design for the turbo-charged SOFC engines with the goals to understand the dynamic capabilities and performance limitations the system for military APU applications. Two distinct SOFC/GT configuratons are investigated: one is a single-shaft design with the compressor and turbine mounted on the same shaft as the power generator; another is a dual-shaft design with two turbines, namely one drives a compressor and another is a free power turbine driving a generator. Recent results on modeling, dynamic analysis, and system optimzation will be dscussed.

High Energy Density Asymmetric Supercapacitors
Paul Rasmussen, Priyanka Pande, and Levi Thompson, University of Michigan
Department of Chemical Engineering and Hydrogen Energy Technology Laboratory

Abstract: Batteries are the principal energy storage devices used for military and commercial applications. While these devices can have energy densities exceeding 100 Wh/kg, this energy is difficult to fully access in pulsed and high power applications due to the relatively slow kinetics associated with their redox processes. Supercapacitors (or ultracapacitors) are based on very fast and highly reversible processes and offer a unique combination of high power densities (5-10 kW/kg) and modest energy densities (2-5 Wh/kg). These devices are typically included in a hybrid configuration to manage short, high power pulses, thereby, minimizing stresses on the primary energy storage device (e.g. battery or fuel cell). Currently available supercapacitors are very well suited to handle pulses of up to a few seconds. To achieve broader application, capacitors will have to efficiently manage longer pulses which translates to higher energy densities. This talk will describe our development of materials and device concepts for asymmetric supercapacitors. These devices hold promise for achieving higher energy

fills important gaps in the energy-power space.

October 29th, Friday (9:30-11:00am)
University of Michigan, Duderstadt Center, Room 1180

Sampling-based RBDO using the Dynamic Kriging Method and Stochastic Sensitivity Analysis
Ikjin Lee, *KK Choi (PI), and Liang Zhao, The University of Iowa*

This study presents how to carry out RBDO when surrogate models are used to represent true performance functions. The Dynamic Kriging (D-Kriging) method is used to generate surrogate models, and stochastic sensitivity analysis is introduced to compute sensitivities of probabilistic constraints with respect to the design variables, which are the mean values of the input independent or correlated random variables. To apply the D-Kriging and stochastic sensitivity analysis for the sampling-based RBDO, which requires the Monte Carlo simulation (MCS) to evaluate probabilistic constraints and their sensitivities, this study proposes new efficiency and accuracy strategies such as a local window for surrogate model generation, sample reuse, local window enlargement, filtering of constraints, and an adaptive initial point for pattern search. Since the D-Kriging can accurately approximate true responses and there is no approximation in the estimation of probabilities, the sampling-based RBDO can yield very accurate optimum design. In addition, newly proposed strategies help find the optimum design very efficiently. Numerical examples verify that the proposed sampling-based RBDO can find the optimum design as accurate as existing methods. However, for large scale engineering applications, the sampling-based RBDO may not be as efficient as existing methods, which implies that it is desirable to be combined with parallel computing. Furthermore, the sampling-based RBDO code is ready to be applied to any disciplines since the stand-alone version of the code is ready.

Development of a High Fidelity Vehicle Energy Assessment Simulation and Implementation in the GT-Drive Framework
Dennis Assanis (PI), **Aris Babajimopoulos**, **Zoran Filipi**, *Dohoy Jung*, **Huei Peng**, *The University of Michigan*
Denise Kramer (PI), Mike Pozolo, TARDEC, CASSI Analytics

TARDEC'S CASSI group is engaged in the assessment of technology options for improving vehicle fuel economy of tactical vehicles under the Fuel Efficiency Demonstrator (FED) Project. More specifically, the M1114 High Mobility Multipurpose Wheeled Vehicle of at least 18,000 lbs gross vehicle weight (GVW) is being used as a baseline for developing concepts using the Gamma Technologies GT-Drive as the framework for performing vehicle fuel economy evaluations. While the commercially-available tool provides several default models for modeling engines, transmissions, drivers, electrical accessories, and power management strategies, its ability to be interfaced with Matlab/Simulink enables the user to readily implement more sophisticated models. The objective of this project is to develop and transition to TARDEC/CASSI a high fidelity vehicle energy assessment simulation under the GT-Drive framework. This seminar reports on our progress towards achieving the main objectives, i.e.:

1. Develop advanced engine brake performance and fuel economy maps
2. Develop advanced transmission models and associated control strategies
3. Develop hybrid electric system components and systems, including through-the-road coupled configurations
4. Develop advanced power management/control strategies

As a result of the above enhancements, the GT-Drive framework will be capable of simulating vehicle fuel economy and performance in a realistic manner, taking into account transient behavior and control system characteristics. It will be able to simulate various conventional and hybrid powertrain configurations. The use of forward-looking model architectures will provide the framework with a "real-world" causality ideal for control system analysis and design.

November 5th, Friday (9:30-11:00am)
University of Michigan, Duderstadt Center, Room 1180

Presented by **Thrust Area 1 - Dynamics and Controls of Vehicles**

Recursive Vehicle Mass Estimation: Methods and Experimental Results
Benjamin Pence, *Jeffrey Stein (co-PI), Hosam Fathy (co-PI), University of Michigan*

This presentation addresses methods and experimental results for real-time vehicle mass estimation for off-road vehicles. The presentation derives a base excitation model of the full vehicle ride dynamics which is critical for enabling mass estimation without knowing the terrain profile a priori. This base excitation model differs from the traditional full car ride model by treating the motion of the unsprung masses, instead of the terrain profile, as the model input. This model is combined with recursive

parameter estimation algorithms to calculate the estimated value of the vehicle's mass. Experimental validation was performed by applying the mass estimation methods to accelerometer data from a 2001 Nissan Altima. The vehicle drove over a variety of terrains while collecting the acceleration data. The results show successes, challenges, and opportunities which will be discussed in this presentation.

3-D Terrain Topology Modeling Techniques for Defense and Automotive Application
John Ferris (PI), *Virginia Tech*

For decades, researchers have been developing and applying mathematical models to terrain profiles so that they can be characterized and synthesized. The objective has been to identify the effects of terrain modeling on the resulting Ground Vehicle Reliability (GVR) prediction so that proper models of terrain and specifications for these terrain models can be developed. Ultimately, this will provide an compact representation of types of terrain, a standard to define the roughness of terrain for durability test schedule development, and a method to directly import measured terrain and synthetic terrain into Modeling and Simulation environments. Recent advances in terrain measurement technology have expanded the ability to measure terrain and have driven advanced techniques to characterize the terrain in terms of its effect on GVR. This proposal focuses on two aspects of this objective:

1. Terrain characterization, modeling, analysis and synthesis through the development of *TerrainSim* software
2. Validation and verification of these terrain characterizations on Ground Vehicle Reliability.

Expertise is garnered from the ARC and the U.S. Army TARDEC, as well as through the efforts of the *SAE Ground Vehicle Reliability Committee Task Force on Terrain Modeling. One of several means by which the tools and methodologies resulting from this work are transitioned to government and industry practitioners is through this SAE Terrain Modeling Task Force.* The fundamental problem being addressed is that terrain topology is a very rich and complex signal that has significant physical characteristics over a wide range of wavelengths. The richness of the signal is compounded by the fact that the terrain topology does not typically possess the statistical properties (such as homogeneity, Guassianity, and linearity) that allow the broad application of existing modeling techniques. The success of each technique is heavily dependent on the type of terrain data to which it is applied (highway to off-road) and the wavelengths being considered (sub-millimeter to kilometer). This complexity is magnified when considering entire terrain surfaces (3D), rather than terrain profiles (2D). Currently, a software tool developed to analyze and synthesize 2D terrain profiles, *TerrainSim*, implements an Autoregressive model to synthesize the terrain, several statistical analyses (including graphs) to identify the statistical properties of the terrain, and automatically generates a report including the result of all analyses. *TerrainSim* is the tool by which informed decisions can be made regarding appropriate model type and parameterization that are best suited for specific terrain types. The second part of this presentation leverages the outputs from *TerrainSim* for GVR studies, with the goal being to develop a consistent reliability prediction process for ground vehicles. Understanding the terrain characteristics that affect vehicle reliability and determining the vehicle design options that improve vehicle reliability for a given terrain will improve the simulation capability for ground vehicle dynamics, durability, reliability, and mobility assurance.

November 12th, Friday (9:30-11:00am)
University of Michigan, Lurie Engineering Center, Level 3, Johnson Room

Presented by **Thrust Area 5 - Vehicle System Integration, Optimization, and Robustness**

Modeling, Design, and Control of Military V2MG2V MicroGrid Systems: The Design and Scheduling Problem
John Whitefoot, *Diane Peters, Abigail Mechtenberg, Anna Stefanopoulou, Panos Papalambros*

Abstract: Microgrids offer a way to integrate renewable and non-renewable energy resources with plug-in vehicles into a local electrical grid that can provide indepence from the electrical grid and reduce liquid fuel use. The optimal design of a microgrid will allow for perpetual support of critical loads when separated from the macrogrid while minimizing the capital equipment needed to provide this support. Thus, the optimal physical design of the microgrid is linked to its optimal operation: the scheduling of its energy generation and storage elements. We will present the problem formulation and modeling methods to design a microgrid for military applications. However, the high-level design and scheduling problem only considers long time-scale events (one hour to one year), thus the short-term dynamics of the resulting designs must also be evaluated by solving the regulation problem.

Modeling, Design, and Control of Military V2MG2V Micro-Grid Systems: The Regulation Problem
Tulga Ersal, *Changsun Ahn, Huei Peng, Ian Hiskens, Jeffrey L. Stein (University of Michigan)*

systems. Many micro-sources need to be integrated to the micro-grid through inverters and local control of inverters is important for regulating the power, voltage, and frequency in case of an islanding (i.e., disconnection from the main grid). Such regulation needs to happen at a much faster time scale than the design and scheduling problem, and preferably in a decentralized manner for a plug-and-play operation. A stable regulation is critical for the performance of the micro-grid. We will first introduce and motivate these regulation issues on a simple example from the literature. We will then show how the presence of EVs/PHEVs can help with the regulation problem. Finally, we will introduce another regulation problem, namely, the phase unbalance issue, and briefly highlight our ongoing efforts.

December10th, Friday (9:30-11:00am)
University of Michigan, Duderstadt Center, Room 1180

Presented by **Thrust Area 4 - Advanced and Hybrid Powertrains**

Preamble by Dr. Peter Schihl, Senior Technical Expert, U.S. Army TARDEC

Combustion Diagnosis from the Measured Crankshaft Speed Variation
Dinu Taraza, *Naeim A. Henein, Florin Mocanu, Elena Florea (Wayne State University)*

The motion of the crankshaft is determined by the torque exerted by each cylinder of the I.C. Engine and the torsional vibration excited by these torques. A good dynamic model of the crankshaft allows calculating the motion of the crankshaft when the cylinders' torqueses are known and, in reverse, to calculate the torques from the measured crankshaft speed variation. The reverse calculation is more sensitive to measuring errors and a very accurate dynamic model of the engine moving parts is necessary. Simplified methods to estimate the engine torque from the measured crankshaft speed variation could be also developed. In this presentation some of these methods are described in conjuncture with experimental results showing how the peak cylinder pressure and the ignition delay could be fairly well estimated in the case of a single cylinder diesel engine operate with two different fuels: ULSD (cetane number 46) and synthetic fuel S25 (cetane number 25). Using these procedures makes it possible to estimate fuel properties and adapt engine controls to operate the engine safely and efficiently.

Piston-Assembly Frictional Losses and Secondary Motions
Nabil G. Chalhoub *(Wayne State University)*

High power density Diesel engines are required to have good fuel economy, reduced levels of noise and oil consumption along with enhanced engine thermal efficiency and durability. These goals are strongly impacted by the intricate motion of the piston-assembly, which is commonly known to be the major contributor to the frictional losses in IC engines. This presentation focuses on the intricate dynamics of the piston-assembly, which involves piston secondary motions such as piston-slap and piston-tilting that affects engine noise and vibration, ring elasticity manifested by longitudinal and in-plane transverse deformations, ring tilting angles, interaction of the ring with the piston groove including ring floating configuration, impact problem, and constrained motion. This presentation will demonstrate, through animations, the dynamic behavior of the piston-assembly with an emphasis on the ring tilting, in-plane transverse deformation, and floating behavior within the piston groove, which are key phenomena affecting blowby of the cylinder gases and the consumption of the lubricating oil.

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