USER STORY

University of Waterloo Develops Award-Winning Fuel Cell Technology Using MathWorks Products for Model-Based Design

THE CHALLENGE

To re-engineer a sport utility vehicle to optimize fuel efficiency without compromising performance

THE SOLUTION

Use MathWorks products and Model-Based Design to design and test a fuel cell vehicle propulsion system

THE RESULTS

- Ease of communication
- Substantial design time savings
- Innovative technology

Challenge X, a competition sponsored by General Motors and the U.S. Department of Energy, challenges 17 North American student teams to re-engineer a Chevrolet Equinox so as to reduce emissions and fuel consumption without sacrificing vehicle performance or safety.

The University of Waterloo Alternative Fuels Team (UWAFT) won first place overall in the first year of the three-year competition with their fuel-cell-powered vehicle design. UWAFT also won The MathWorks Crossover to Model-Based Design Award for outstanding achievement in creating, simulating, and analyzing models for vehicle design and subsystem control.

"We were the only team to use fuel cells in the powertrain," says professor Roydon Fraser, UWAFT faculty advisor. "MathWorks software for Model-Based Design not only cut down on the time it took for our team to prototype and simulate our vehicle system designs, but also enabled us to establish the viability of the fuel cell technology."

THE CHALLENGE

The first year of Challenge X focuses on vehicle design. Participants must use Model-Based Design to complete powertrain design and testing within 10 months, and must submit five major reports.

The University of Waterloo team sought design software that would enable them to use Model-Based Design throughout the project—from requirements capture to implementation. The software must accelerate control strategy development by facilitating model reuse. It must also be quick to learn and enable team members to share work easily.

University of Waterloo demonstrating at Challenge X.

THE SOLUTION

"MathWorks tools enabled us to simulate various powertrains, develop accurate plant models, test control strategies, and validate the overall design," says UWAFT captain, Matthew Stevens.

The MathWorks provided training in MATLAB®, Simulink®, Stateflow®, and PSAT, a modeling program based on Simulink. "Having a product with a quick learning curve or that students were already trained in was critical to the team's success," Stevens comments. "MathWorks tools could be used for multiple stages in the design process, minimizing the number of software programs that students needed to learn."

UWAFT developed more than 400 PSAT simulations to compare fuels, technologies, and powertrain sizing. The Optimization Toolbox and a sophisticated Design of Experiments enabled them to understand the relationship between component size and vehicle performance and then determine the optimal powertrain.

They used Simulink to develop a plant model of the fuel cell power system, which included the engine, the battery, the fuel cell, and a DC/DC converter.

MATLAB, Simulink, Stateflow, and the Control System Toolbox enabled them to

develop the hybrid control strategy (HCS), which determines the amount of power coming from the fuel cell. MATLAB helped them to find the optimal appropriation of power between the fuel cell and battery over a specific drive cycle.

The DC/DC converter boosts the fuel cell voltage and controls the power from the fuel cell. SimPowerSystems was used to model the circuit, which was controlled by a PI controller. The team investigated the frequency response and stability of the circuit using bode plots and pole-zero maps in MATLAB. Simulation enabled them to verify correct operation, determine circuit efficiency, and calculate values and ratings of inductors and other components.

Because the fuel cell turns on and off, it creates a discontinuous function that is difficult to optimize using traditional methods. To find the optimal control benchmark, UWAFT therefore used the Genetic Algorithm and Direct Search Toolbox, which does not require the function to be continuous. They also used the Neural Network Toolbox to model the hydration of the membranes within the fuel cell stack.

The team used Real-Time Workshop® Embedded Coder to target UWAFT satellite controllers throughout the vehicle for on-target rapid prototyping using an embedded controller.

They are currently testing powertrain components, refining the vehicle control strategy, integrating the advanced fuel cell into the vehicle, and researching weight-reduction possibilities.

"We are definitely interested in using other MathWorks products throughout the competition, and hopefully in our future careers in many other projects," Stevens says.

> *"Without Simulink, I don't believe there would have been any way to develop executable specifications to the same level of detail or use Model-Based Design so extensively."*
>
> Matthew Stevens, University of Waterloo

THE RESULTS

- **Ease of communication.** The MATLAB and Simulink environment increased efficiency by enabling team members to easily exchange shortcuts and tips and to e-mail their models and results to each other for further work.
- **Substantial design time savings.** "Simulink in particular allowed UWAFT to use Model-Based Design to compare four different fuels and design a robust fuel cell sport utility vehicle and control strategy in less than 10 months, including training time—a truly incredible feat," notes Stevens. "Without Simulink, it probably would have taken us until the end of the three-year competition to complete the work required in the first year alone!"
- **Innovative technology.** "We believe that our end product will be the first student-designed fuel cell vehicle to provide performance competitive with today's vehicles while achieving the mileage and efficiency needs of the future," Stevens says.

To learn more about the University of Waterloo, visit **www.uwaterloo.ca**

APPLICATION AREAS

- Academia
- Automotive
- Model-Based Design
- Production code generation
- Simulation

PRODUCTS USED

- MATLAB
- Simulink
- Stateflow
- Stateflow Coder
- Real-Time Workshop
- Real-Time Workshop Embedded Coder
- Optimization Toolbox
- Control System Toolbox
- Genetic Algorithm and Direct Search Toolbox
- Neural Network Toolbox

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