Optimal Energy Management of a PHEV Using Trip Information

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Project ID # VSS068
Project Overview

Timeline
- Start: September 2011
- End: September 2012
- Status: 40% complete

Barriers
- Cost of testing advanced technologies through multiple vehicle builds
- Risk aversion of OEM to commit to unproven technologies
- Constant advances in technologies

Budget
- FY2012 - $250K

Partners
- NAVTEQ (Map data)
- Argonne’s Transportation Research and Analysis Computing Center (TRACC) (traffic modeling)
The objective is to use destination knowledge, GPS, road profile and current traffic to establish the optimal energy management of a short-range PHEV

- Predict speed profile of the trip ahead:
  - to provide the controller relevant information about the trip
  - to benchmark control strategies using trip information on the predicted speed profiles

- Develop PHEV control strategies taking advantage from trip information
- Demonstrate and quantify the benefits of trip information on PHEVs energy efficiency

Relevant to the VT Program goals: enable highly efficient cars and reduce both energy use and greenhouse gas emissions
Milestones

Quarter 1
- Choose a mapping service with extensive road information
- Create a cycle generator
- Create “alternative” control strategies that takes into account trip information
- Run study to compare alternative PHEV control to standard PHEV control

Quarter 2
- Publish Results

Quarter 3

Quarter 4

Current Status
Approach
Real-World User Story Modeled in this Study: Driver Selects Destination, Vehicle Runs Optimally

Driver

Current Localization
Final Destination

HMI

Global Positioning System (GPS)

Traffic Situation/Forecast

Traffic Management Center

Trip Information
- Distance
- Road profile (grade, lights, etc.)
- Trip sections (Urban, Interurban, etc.)
- Congestion Level on Each section
- Speed limits

Route Estimation

Optimization Unit

Road schedule

Optimal Parameters for Controller

Vehicle Control Unit
Approach
User Workflow Using ADAS RP\(^{(1)}\) and Autonomie®

<table>
<thead>
<tr>
<th>User Action</th>
<th>Tool</th>
<th>Action</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Define Trip</td>
<td>ADAS RP</td>
<td>Export Trip to CSV file</td>
<td>ADAS RP plug-in to export trip information</td>
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<tr>
<td></td>
<td></td>
<td>Define Vehicle and</td>
<td>Drive Cycle Generator (Process):</td>
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<td>Select CSV file with</td>
<td>- Trip data processing</td>
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<tr>
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<td></td>
<td>Trip Data</td>
<td>- Target speed generation</td>
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<tr>
<td>Run Vehicle Simulation and Analyze Results</td>
<td>Autonomie®</td>
<td></td>
<td>Vehicle Controller with Geographical Information Processor (Vehicle)</td>
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</tbody>
</table>

\(^{(1)}\) ADAS RP - Advanced Driver Assistance Systems Research Platform
Technical Accomplishments
ADAS RP Plug-in Allows Exporting Road Data

- ADAS = Advanced Driver Assistance Systems
- ADAS RP (RP= Research Platform) is a software framework to develop prototypes of applications that use positioning and maps.
- Includes NAVTEQ maps and traffic patterns
- The user can define a route by selecting the start and the end of the route
- A plug-in was developed for Autonomie® in C#:
  - Selects useful information for all links along the route
  - Formats the information
  - User can export the data in Autonomie (CSV format using the “Export cycle” button)
### Technical Accomplishments

**Raw Trip Data Is Processed**

1. **Stop scheduling**
   - Estimate wait time at traffic light
   - Estimate wait time at stop sign

2. **Division in Segments**
   - w/ or w/o traffic speed
   - If w/ pattern speed, in constant speed segments

3. **Target Speed**
   - No traffic speed: target speed = speed limit
   - w/ traffic speed = factor in stop time

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**Raw data**
- Expected speed
- Speed limit
- Traffic pattern speed
- Traffic lights and stop sign position
- Slope

**Processed data**
- Target speed for each segment
- Stop position and duration
- Grade

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Technical Accomplishments
Vehicle Speed Target Is Generated

- The trip is divided in segments with continuous positive speed:
  - No discontinuities within the segment
  - No stops within the segment
- For each segment, transitional speed target is computed, assuming constant acceleration and constant deceleration
- Output can be directly fed into a distance-based driver for whole vehicle simulation
Technical Accomplishments
Example of a Trip Simulation

**Chicago:**
Division Ave., between Ashland Ave. and State St. (2.2 mi, 16 min.)
Collaboration and Coordination with Other Institutions

- **NAVTEQ:**
  - Provided a free demo license of ADAS RP, including detailed road information for the whole United-States
  - Provided support to process their data
  - Future collaboration to use their web-based map tool (Nokia Maps)

- Argonne’s **Transportation Research and Analysis Computing Center (TRACC)**
  - Provided support on microscopic traffic simulation

- **OEMs:** discussions with R&D engineers
Proposed Future Work

- Drive cycle generation methods will be **tested** and **improved**:
  - Add speed fluctuations on longer sections, and congested highway driving
  - Compare generated drive cycle to **real-world** cycles (from GPS loggers, or database [e.g. Chicago drive cycles])
- Define **baseline PHEV** for study
- Define **control strategies** and test on simple examples using:
  - **Heuristic** optimization (e.g. use EV mode in low speed sections, rather than on highway)
  - **Optimization theory** (e.g. Pontryagin Minimization Principle)
- Implement **algorithms** in Matlab®/Simulink®
- Compare **trip-based control** to standard control (EV + CS)
Summary

- A **process** was created to generate a **speed schedule** (incl. grade and stops) anywhere in the USA
- A **PHEV control** using trip information will be designed.
- That control will be **compared** to standard PHEV control, and the benefits of trip-based control will be **quantified**
- This study will demonstrate that **trip information** can be successfully used to **improve PHEV energy efficiency**, and thus make PHEVs more successful
- The map-based speed target generation will have **numerous side applications**:
  - Green routing
  - Fleet fuel consumption estimation
  - Selection of optimal powertrains for specific routes
  - Etc.