Prediction of Roadway Surface Conditions Using On-Board Vehicle Sensors

Project Update

FHWA Road Weather Stakeholders Meeting
July 17, 2013

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Presentation Outline

• Brief Project Overview
• Friction prediction concept
• Experimental verification
• Data analysis plan
• Status
• What’s next
• Challenges & Potential Benefits
Project Overview

- Objectives
  - Determine whether existing on-board vehicle sensors can be used to predict changing road friction
  - Demonstrate integration with Connected Vehicle
  - Assess weather data available from vehicle network
- FHWA funded project
  - Gabe Guevara
  - Start: Dec. 19, 2012
  - End: May 18, 2014
- Test location – Virginia Smart Road, Blacksburg, Virginia
• Observations from instrumented vehicles on the Smart Road
• Micro-slip
• Macro-slip (used by on-board safety systems)
• Differential rotational rates of driven vs. non-driven wheels
• $\Delta$ differential with time
• Relative coefficient of friction tire-pavement
• Wind and grade are potential confounds
Experimental Methodology

- Operate instrumented vehicles on the Smart Road in various road surface and environmental conditions
- Monitor
  - Rotational rates of driven versus un-driven wheels
  - Distance traveled, weather variables, safety systems
- Determine rotational differential over time
- Predict relative friction values based on differential
- Compare to absolute friction measurements (e.g., GripTester)
  - At time of testing
  - Historical road friction data
Artificial Precipitation on the Smart Road
Experimental Vehicle

2008 Chevy Tahoe

Wheel rotation sensor
Vehicle Data Acquisition

- **Multiple Videos**
  - Machine Vision Eyes Forward Monitor
  - Machine Vision Lane Tracker
- **Accelerometer (linear acceleration, 3 axis)**
- **Gyroscope (angular velocity, 3 axis)**
- **GPS**
  - Latitude, Longitude, Elevation, Time, Velocity
- **Forward Radar**
  - Tracking of 32 targets
- **Cell Phone**
  - ACN, health checks, location notification
  - Health checks, remote upgrades
- **Illuminance sensor**
- **Passive alcohol sensor**
- **Incident push button**

- **Audio (only on incident push button)**
- **Turn signals**
- **Vehicle network data**
  - Accelerator
  - Brake pedal activation
  - ABS
  - Gear position
  - Steering wheel angle
  - Speed
  - Seat Belt Information
  - Airbag deployment
  - Etc.
Experimental Data - Vehicle

- GPS time and position — differential error correction at 20 Hz.
- Wheel rotation sensor pulse counts – all wheels
- Status of on-board safety systems -- ABS, ESC, and TSC from the CAN bus
- Brake activation and applied torque at all wheels
- Throttle – Requested and actual..
- Linear Acceleration – yaw, pitch, roll
- Angular acceleration – 3 axis gyroscope
- Laser trip – delineates pavement test section
- Weather variables -- temperature, atmospheric pressure, windshield wiper, and headlight activation, etc.
Laser System
Experimental Data – Test Site

• Pavement
  – Surface Temperature
  – Surface moisture

• Atmospheric
  – Wind
    • Speed
    • Direction
  – Relative humidity
  – Barometric pressure
  – Incident solar radiation
  – Precipitation rate
## Test Scenarios

<table>
<thead>
<tr>
<th>Condition</th>
<th>Air Temperature</th>
<th>Pavement Temperature</th>
<th>Pavement Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>35°F +</td>
<td>35°F +</td>
<td>Dry</td>
</tr>
<tr>
<td>B</td>
<td>35°F +</td>
<td>35°F +</td>
<td>Lightly wet</td>
</tr>
<tr>
<td>C</td>
<td>35°F +</td>
<td>35°F +</td>
<td>Very wet</td>
</tr>
<tr>
<td>D</td>
<td>28°F -</td>
<td>28°F -</td>
<td>Snow</td>
</tr>
<tr>
<td>E</td>
<td>35°F +</td>
<td>28°F -</td>
<td>Snow</td>
</tr>
<tr>
<td>F</td>
<td>28°F -</td>
<td>28°F -</td>
<td>Ice</td>
</tr>
<tr>
<td>G</td>
<td>35°F +</td>
<td>28°F -</td>
<td>Ice</td>
</tr>
</tbody>
</table>
Experimental Control

- Same driver for all test runs
- Cruise control (if more consistent than a driver)
- Tire pressure will be measured with a digital pressure gauge and adjusted as needed to ensure that each test session is conducted at the same inflation pressure.
- The tire size (circumference) will be measured and recorded prior to testing. This will be performed with a tape measure while the tire is elevated above the ground and after tire pressure has been adjusted. Changes in tire circumference will also serve as an indication of tire wear.
- Wind speed will be monitored at the test site and tests will not be conducted when excessive tail or headwinds are present. The proposed test cancellation threshold for wind speed is 16 km/h (10 MPH).
- The pavement within the test section will be kept clean.
- On-board safety systems such as ABS will be monitored to ensure they are not activated during testing.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Type</th>
<th>Measurement Method/Sensor</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle speed</td>
<td>Independent - control</td>
<td>Vehicle network, GPS</td>
<td>Control speed to be determined in initial on-road testing. Driver input constant through test.</td>
</tr>
<tr>
<td>Vehicle acceleration</td>
<td>Independent - control</td>
<td>GPS, linear accelerometers (longitudinal), network applied and actual throttle</td>
<td>Zero acceleration over test course</td>
</tr>
<tr>
<td>Vehicle change of direction (steering)</td>
<td>Independent - control</td>
<td>Network steering, GPS, linear accelerometer (lateral)</td>
<td>Zero vehicle direction change over test course</td>
</tr>
<tr>
<td>Distance traveled</td>
<td>Independent - control</td>
<td>Laser sensor and roadway mounted reflectors, GPS, network</td>
<td>A vehicle-mounted laser sensor will be used along with roadway markers to detect the start/stop of test section</td>
</tr>
<tr>
<td>Brake application</td>
<td>Independent - control &amp; monitored</td>
<td>Brake light switch, applied brake torque at each wheel</td>
<td>Driver will not apply brakes during testing. However, vehicle safety systems may so this must be monitored and recorded.</td>
</tr>
<tr>
<td>Road grade</td>
<td>Independent - control</td>
<td>Inclinometer, linear accelerometer</td>
<td>Monitored, recorded</td>
</tr>
<tr>
<td>Weather condition</td>
<td>Independent - monitored</td>
<td>Roadside weather station and in-vehicle sensors (where available)</td>
<td>Monitored, recorded. Temp., dew point, wind, light</td>
</tr>
<tr>
<td>Road condition</td>
<td>Independent - semi-control</td>
<td>Water presence, state, quantity, form (ice, snow)</td>
<td>Semi-controlled. See Table 1.</td>
</tr>
<tr>
<td>Activation/status of vehicle safety systems</td>
<td>Independent - monitored</td>
<td>Status from vehicle network</td>
<td>Monitored, recorded. Driving procedure adjusted to prevent activation.</td>
</tr>
<tr>
<td>Driven and non-driven wheel rotational displacement</td>
<td>dependent</td>
<td>Vehicle network (ABS sensors)</td>
<td>Measured for all 4 wheels independently.</td>
</tr>
</tbody>
</table>
Data Analysis Plan - Preliminary

- Single factor ANOVA across scenarios
- Factorial ANOVA and/or regression across other independent variables
- Power analysis – to determine no. of runs required (sample size) for test scenarios
Project Status

- Initial experimental vehicle instrumentation completed
- Data Collection Plan
- Pilot data collection
- Analysis of pilot data
- Modification of vehicle instrumentation and methods
- Preliminary Data Analysis Plan development
Path Forward

- Develop Data Analysis Plan
- Finalize methodology
- Run scenarios
- Data analysis
- Reporting
Potential Challenges

• Wheel rotation data resolution
• Data acquisition from CAN bus
• Effects of
  – Road slope
  – Acceleration/deceleration
  – Wind
• Correlation with absolute measures of road friction
• Value of “relative” friction prediction
Potential Benefits

• Lives saved, fewer injuries
• Decreased property damage
• Better application of limited winter maintenance resources
• Increased mobility
• Decreased adverse environmental impact
Questions – Discussion - Thanks

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