Estimation of Longitudinal Velocity and Road Slope in Hybrid Electric Vehicles using an Adaptive Kalman filter
Introduction

- Partners:
  Chalmers University, Tongji University and AAM

- What?
  On line velocity and slope estimation for hybrid vehicle

- Why?
  Slip control for an AWD hybrid electric vehicle

- How?
  Sensor fusion

\[ v_x = \omega R_r \]

\[ v_x = v_{x,0} + \int a_x \, dt \]

This work

- Slipping
- Noise
- Initial value \( v_{x,0} \)
- Bias

Kalman filter
Estimation Methods

Kalman filter

Velocity estimation using acceleration \((a_x)\) and four wheel speeds \((v_{\text{meas}})\)

\[
\dot{x}_k^- = \Phi_{k-1} \dot{x}_{k-1}^- + \Psi_{k-1} u_{k-1}
\]

\[
P_k^- = \Phi_{k-1} P_{k-1} \Phi_{k-1}^T + Q_k
\]

\[
K_k = P_k^- H_k^T (H_k P_k^- H_k^T + R_k)^{-1}
\]

\[
\dot{x}_k^- + K_k (z_k - H_k \dot{x}_k^-)
\]

\[
P_k^- = (I - K_k H_k) P_k^-
\]

\[
\hat{v}_x^- (k) = \hat{v}_x (k - 1) + a_x (k) \tau
\]

Slope compensation

\[
\omega_{\text{sel}} R \hat{v}_{x,k}
\]

Over-slip adaption

Wheel speed selection

\(\hat{x}\) - Estimation state variables vector
\(u\) - Input variables vector
\(z\) - Measurement variables vector
\(R\) - Measurement error covariance matrix
\(Q\) - Prediction error covariance matrix
\(P\) - Estimation error covariance matrix
\(K\) - Kalman filter gain matrix
Algorithm Overview

- Yaw Rate
- Steering Angle
- Wheel Speeds (x4)
- Electric Motor Torque
- Long. Acceleration

Transformation → Whl. Vel. at CoG (x4)

Over-slip Detection → Over-slip Flags (x4)

Slope Estimation → Slope Compensated Acceleration

Best-Wheel Selection → $v_{x,\text{bestW}}$

Velocity Estimation AKF → $\hat{v}_x$
Test Vehicle

Modified Saab 9-5 – P4 Hybrid

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Wheel Radius (R_r)</td>
<td>328.5 [mm]</td>
<td>Peak power (motor)</td>
<td>50 [kW]</td>
</tr>
<tr>
<td>Steer Ratio</td>
<td>15.7</td>
<td>Peak torque (motor)</td>
<td>106 [Nm]</td>
</tr>
<tr>
<td>Front Axle to CG (l_f)</td>
<td>1362 [mm]</td>
<td>Max speed</td>
<td>15000 [rpm]</td>
</tr>
<tr>
<td>Rear Axle CG (l_r)</td>
<td>1475 [mm]</td>
<td>Gear ratio (motor)</td>
<td>11.3</td>
</tr>
<tr>
<td>Total Mass of the Vehicle</td>
<td>1987 [kg]</td>
<td>Peak power (engine)</td>
<td>110 [kW]</td>
</tr>
<tr>
<td>Vehicle Track (Front/Rear)</td>
<td>1583/1585 [mm]</td>
<td>Peak torque (engine)</td>
<td>240 [Nm]</td>
</tr>
</tbody>
</table>

RT3000 GPS/Inertial Unit

Electric drive unit

High Voltage Battery

DC/AC Inverter
Estimation Parameters (off-line)

- Wheel Radius
  Coast down, GPS, Wheel Speed
- Steer Ratio
  Parking, Steer angle, Wheel angle
- Sensors
  Standstill, $a_{meas} = 0$, $\omega_{meas} = 0$...
  Straight Line, $\phi_{meas} = 0$, $\delta_{meas} = 0$...

Test Result – Start on Ice
Test Result – Circle, Ice

Velocity Estimation [m/s]

SL

Slope [%]

Time [s]
Acceleration/Braking on Ice

![Diagram](chart.png)
Outcome

- Conference paper “Robust Estimation of Longitudinal Velocity and Road Slope in Hybrid Electric Vehicles using an Adaptive Kalman Filter” presented in a plenary session at the 23rd IAVSD Symposium on Dynamics of Vehicles on Roads and Tracks at Southwest Jiaotong University, Qingdao, China (2013)
- Journal paper “Longitudinal velocity and road slope estimation in hybrid electric vehicles employing early detection of excessive wheel slip” which is accepted for publication in Vehicle System Dynamics: International Journal of Vehicle Mechanics and Mobility.
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