Torque Estimation in an Automotive Powertrain

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Objectives

- Build a realistic integrated powertrain model in Simulink to implement and compare several types of input estimator and adaptive observer to estimate unmeasurable variables, enabling advanced control strategies
- Assemble a physical test-rig emulating a scaled-down version of an automotive powertrain, to be used for Hardware-in-the-Loop (HiL) simulations for model validation and real world estimator implementation

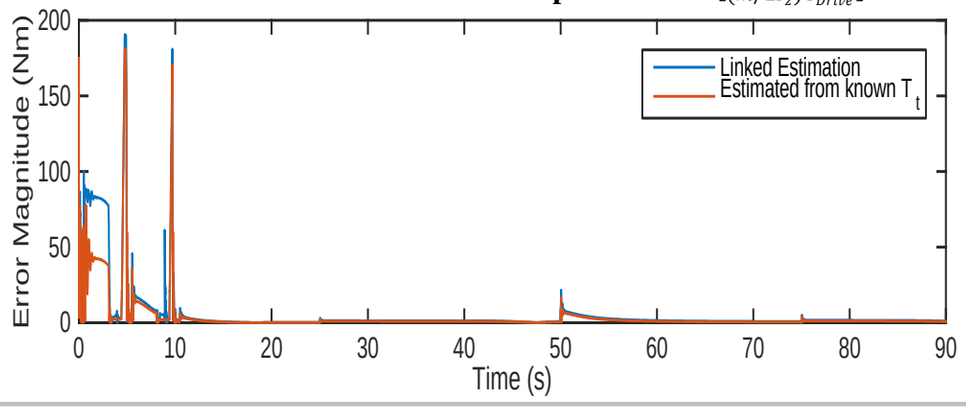
Estimation

Multiple input and parameter observers were designed and implemented to estimate torque:

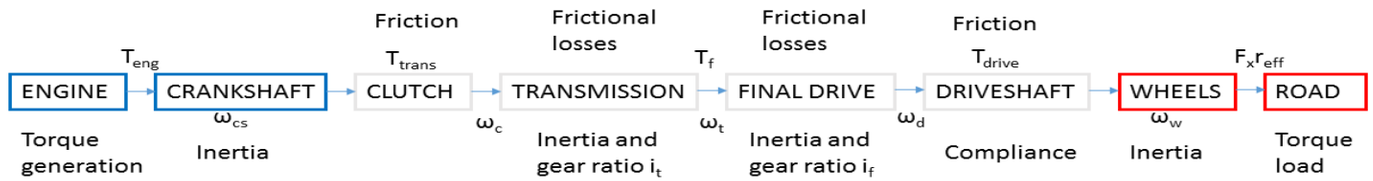
- a filter-based observer: $\hat{u} = \frac{x - x_f}{k} - y_f$ where $(\bullet)_f = [\bullet]/(ks+1)$
- a sliding-mode observer: $\hat{u} = \frac{1}{ks+1}[\lambda \operatorname{sgn}(v_x)]$ where $v_x = x - \hat{x}$
- a high-gain observer: $\hat{u} = \gamma x - \varepsilon$ where $\dot{\varepsilon} = -\gamma\varepsilon + \gamma y + \gamma^2 x$
- an adaptive parameter observer:

$$\dot{\hat{x}} = (2F_z/m)\begin{bmatrix}\tanh(a_2 s_x) & -\tanh(a_3 s_x) & \tanh(a_5 s_x) & s_x & -1/\mathrm{m} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1/2J_w\end{bmatrix}\begin{bmatrix} a_1 \\ a_7 \\ a_4 \\ a_6 \\ (m/2F_z)F_{Drag} \\ (m/2F_z)T_{Drive}\end{bmatrix} + \begin{bmatrix}0 \\ -r_e/J_w\end{bmatrix}\hat{F}_x.$$

Estimator Output

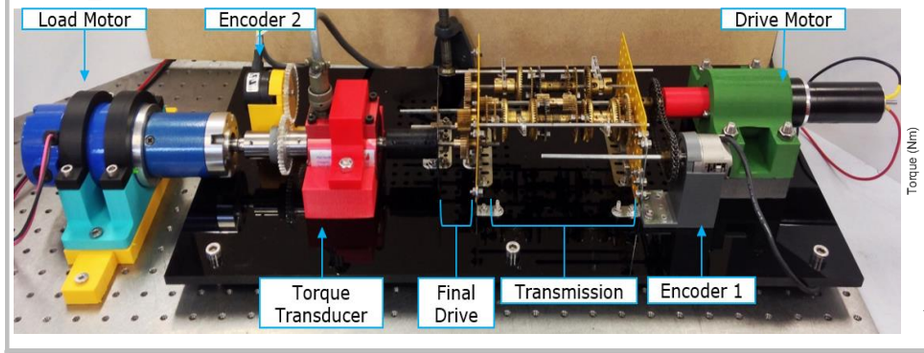


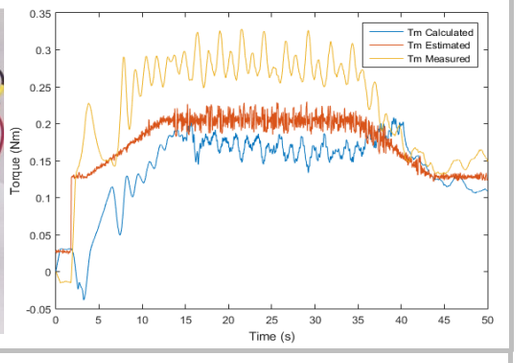
Model



The above diagram shows the power flows between the powertrain subsystems. The engine predicts the mean value of engine states (intake manifold pressure, temperature and crankshaft velocity) as well as internal variables such as volumetric and thermal efficiencies. The drivetrain model incorporates a friction clutch and gearbox controlled automatically by shift logic. Additional flexibilities in the drivetrain and gear and bearing friction provide a realistic model of an Automated Manual Transmission drivetrain. The tyre model is based on slip dynamics, relating these to frictional force via Pacejka's Magic Tyre Formula. This interfaces powertrain rotational dynamics with longitudinal vehicle dynamics.

Experiment





Conclusions

A novel method of powertrain torque estimation has been shown to be stable and effective in simulation, demonstrating commercial potential. A holistic powertrain model has been derived from physical principles and offers realistic results in simulation. The experimental rig demonstrates the real-world applicability of our estimation techniques.