Implementation of a Control Concept for the Car-in-the-Loop Test Rig on the IPG Xpack4 Real-Time Target

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Introduction

- Numerous advancements in regards to safety and efficiency of a vehicle’s powertrain and suspension components
  - Many of these new developments incorporate mechatronic systems [1]

- The implementation of mechatronic systems is resulting in much higher complexity

- Hardware-in-the-Loop (HiL) systems allow automotive manufactures to test and validate the electrical, mechanical, and control concepts [3]
Car-in-the-Loop Test Rig

- Car-in-the-Loop (CiL) Test Rig built by the Institute for Mechatronic Systems (IMS) at the Technische Universität Darmstadt [4]
  - Quarter-car section of a Mini Countryman provided by BMW
  - Validate driving forces from test track data or computer simulations

- Advantages:
  - Elimination of safety concerns during prototype testing
  - Independence from weather conditions
  - Higher test repeatability
Xpack4 Real-Time Target

- The Xpack4 Real-Time Target provided by IPG
  - Test platform with multiple processor cores for increased performance
  - Compact PCI terminals for increased flexibility with interchangeable modules based on test requirements [7]
  - Embedded coder implementation
Controller Concepts

- Overall goal is the implementation of controller concepts which regulate the wheel speed and steering angle of the CiL in real-time
- Physical system must be modeled within a closed control loop
Wheel Speed Controller
Wheel Speed Controller (Continued)

\[
\begin{bmatrix}
\dot{\phi}_{RN} - \dot{\phi}_{BM} \\
\dot{\phi}_{RN} - \dot{\phi}_{BM}
\end{bmatrix} =
\begin{bmatrix}
\frac{-k_2}{\Theta_{RN}} & \frac{1}{\Theta_{RN}} & \frac{-1}{\Theta_{RN}} \\
\frac{k_2}{\Theta_{BM}} & \frac{d_2}{\Theta_{BM}} & \frac{(-d_2-d_v)}{\Theta_{BM}}
\end{bmatrix}
\begin{bmatrix}
\phi_{RN} - \phi_{BM} \\
\dot{\phi}_{RN} - \dot{\phi}_{BM}
\end{bmatrix} +
\begin{bmatrix}
0 & 0 & 0 \\
\frac{1}{\Theta_{RN}} & 0 & 0
\end{bmatrix}
[M_{AM}] +
\begin{bmatrix}
0 & 0 & 0 \\
\frac{k_2}{\Theta_{RN}} & \frac{-1}{\Theta_{RN}} & \frac{}{
\end{bmatrix}
[M_{BM}] +
\begin{bmatrix}
0 & 0 & 0 \\
\frac{k_2}{\Theta_{RN}} & \frac{-1}{\Theta_{RN}} & \frac{}{
\end{bmatrix}
[M_{C}]
\]

\[
\dot{x} = Ax + Bu \text{ (Linear)}
\]

\[
y = Cx
\]
Wheel Speed Controller (Continued)

- Pole locations on the Pole-Zero Map suggest border stability for the linear component of the state-space representation.
  - Controller must increase the stability margins of the poles to compensate for the non-linear influences, as well as disturbances from the AM.
Wheel Speed Controller (Continued)

- Non-collocated system suggests need for observer and pole placement controller [5]

- Matrices A, B, C, and E are direct substitutions from the state-space representation

- Matrices V, K, and L are left to be calculated based on the desired performance of the system
Steering Angle Controller
Steering Angle Controller (Continued)

\[
\tan(\varphi_L) = \frac{x_{BML}}{l_{LA}}
\]

\[
m\ddot{x} = F_{BML} - F_{Disturbances}
\]
Steering Angle Controller (Continued)

- P cascade controller is effective at combating instability caused by double poles at the origin [6]
- Simple system dynamics allow a linear assumption
Sensors

- Vehicle states are measured to provide valuable input information into the mechatronic systems

- Further measured states for analysis of controller implementation
  - Optical Encoder located at wheel hub
  - Torque Sensor located on side shaft
  - Load Cell in-line with tie-rod
  - Load Cell in-line with vertical adjustment
C-Code Generation and IPG CarMaker Implementation

- Implementation of the control concepts into the IPG CarMaker software is dependent on the generation of C-code from the developed Simulink control models.

- C-code generation is completed within the Simulink Model Configurator.
  - Important that the code generation parameters coincide with the implementation target, in this case the Xpack4.

- Interchangeable modules known as M-Modules for Xpack4 [7]
  - M401 (Encoder Signals)
  - M62 (Analog Outputs)
  - M36N (Analog Inputs)
C-Code Generation and IPG CarMaker Implementation (Continued)

- Within IPG CarMaker there are two user accessible modules of interest
  - User.c - Additional program functionality
  - IO.c - Communication with HiL components

- Individual code sections called at different times within the overall CarMaker simulation execution
  - Global Parameters at beginning of code
  - IO_Init() function for initialization of modules
  - IO_Out() function for HiL communication
Results (Video)
Results (Wheel Speed Controller)

- Goal of control is a deviation of no more than 5% from CarMaker setpoint
- Measured deviation is consistent around 5%
- Area of concern within the first 2 seconds of the simulation
  - Wheel Slip occurs during acceleration resulting in deviation peak
Results (Wheel Speed Controller Continued)

- Goal of control is a torque with scaled magnitude but follows CarMaker trend
  - After applying a re-scaling factor, the results almost perfectly overlay

- Further support wheel speed controller performance
Results (Wheel Speed Controller Continued)

- Goal of control is a torque with scaled magnitude but follows CarMaker trend
  - After applying a re-scaling factor, the results almost perfectly overlay
- Further support wheel speed controller performance
Results (Steering Angle Controller)

- Goal of control is a deviation of no more than 5% from CarMaker setpoint
- Measured deviation is consistent around 3%
- Wheel slip does not affect steering angle, therefore no peaks within deviation
Results (Steering Angle Controller Continued)

- Goal of control is a scaled force which follows CarMaker trend
  - Trending of the measured data does not correlate with CarMaker values
- Suggests further tuning is required for desired steering angle controller performance
Conclusion

- In conclusion, the wheel speed controller operates within the 5% deviation threshold

- Side shaft torque value, after re-scaling, replicates almost exactly the CarMaker calculated value

- Steering angle controller operates within the 5% deviation threshold at a more accurate 3% deviation

- Tie-rod force value suggests further tuning of AML performance from the steering angle controller in order to exhibit correctly trending data
Questions

Thank you for your attention.

Questions?
Sources


Sources (Continued)
