Systematic Design and Verification of Timing Constraints

J. Neumüller, 30.09.2010
Agenda

- Project overview
- Design process of timing constraints
- Verification of timing constraints
Project overview

Functionality: Vehicle dynamics control

- Reduce pitching
- Prevent over and under steering

Used design languages

- EAST-ADL 2.0
- TIMMO TADL
- AUTOSAR 3.1
**Technical solution**

- Stabilization of vehicle movement by regulating the engine torque

**Physical setup consisting of**

- ECU with control application
- Modified engine management ECU
- Vehicle
Agenda

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Methodology based on TIMMO

Vehicle Feature Model

Realize

Satisfy

Quality Requirements

Realize

Satisfy

Design Constraints

Functional Analysis

TADL Event Chain

Derive

Functional Design

TADL Event Chain

Derive

Design Constraints

Implementation
Vehicle level

Quality requirements

- are textual requirements from the user point of view
- may contain requirements on timing

Example:

- Accelerate on user request
  ‘When the user requests the vehicle to accelerate, the user shall have the impression that the vehicle reacts instantaneously to his request.’

- Prevent pitching
  ‘The pitching shall be at least as low as in typical premium segment vehicles (EU 2009)’
**Analysis level**

**Design constraints**

- are textual requirements on the Functional Analysis Architecture or on the Functional Design
- may contain requirements on timing

**Example: Constraint 'Pitching Stabilization'**

'The vehicle pitching shall be stabilized by regulating the driver torque request'

![Diagram showing the relationship between driver torque request, motion estimator based on vehicle model, and modified drive torque request.](Diagram-1)

- Driver Torque request
- Motion estimator based on vehicle model
- Modified Drive torque request
- State value estimation: pitch angle, pitch rate
- Pitch control

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Derived, technically imposed Constraint 'Pitch Regulation Phase'

‘To be effective, the pitch regulation has to be added to the torque request with correct phase’

Motivation for constraint 'Pitch Regulation Phase':

- Phase shift has to be small enough so that the vehicle oscillations are stabilized
Analysis level

What does 'small enough' mean?

- The concrete constraint value depends on the oscillation frequency
- Different physical vehicle parts oscillate with different frequencies

→ Different synchronization constraint values for different physical vehicle parts
Timing requirements for the vehicle stabilization control

- Synchronization constraints satisfying Design constraints

The age of the driver torque request and the age of the calculated regulation may differ by max $\pi/5$ phase shift.
Timing constraints

Identify the most critical timing path

- Different synchronization constraints for different vehicle parts
- Assumed highest oscillation frequency of modeled components: Engine Roll or Engine Bounce

Diagram:

- DriverTrqRequest Calculation
- Motion estimator based on vehicle model
- Engine bounce control
- Engine roll control
- Body pitch control
- Synchronization Point
Methodology based on TIMMO

Vehicle Feature Model

Functional Analysis

Design Entities

Functional Design

Quality Requirements

TADL Event Chain

Derive

Satisfy

Realize

Design Constraints

Requirements

Realize

Derive

Satisfy

Functional Analysis

Functional Design

Implementation
Timing constraint refinement:

- Highest oscillation frequency of modeled components:
  Engine Bounce with 9 Hz
  → Synchronization between engine bounce control and driver torque request is the most critical constraint!
What is a reasonable constraint value?

- Engine bounce oscillates with 9 Hz
- For a phase shift of max $\frac{\pi}{5}$, the maximum data age difference has to be less than 11 ms

Synchronization Constraint:

Engine bounce control shall be max 11 ms older than Driver Torque Request at synchronization point
Component Engine ECU

- Driver Torque Request calculated every 8 ms
- Request transmitted on CAN with 8 ms period
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Tool chain

- Project: Vehicle Dynamics
- Dev-Env: EB tresos Studio
- Debugger: Multi Debugger
- Tracing: Gliwa T1
- Timing Analysis: SymTA/S

EB Autosar OS and stack

Gliwa GmbH debugGURU

*.h
libs

integration

Target (V850) with AUTOSAR OS 3.0

Executable

Link, build

run

Gliwa T1

read
(CAN bus)

export
(XML)

SymTA/S

- tracing
- trace visualization
- runtime analysis

- scheduling analyses
- worst/best case visualization
- optimization

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Verification Process

Steps to verify the timing constraints

1. Trace ECU timing behavior
2. Set up analysis model of the system
3. Analyze model for worst case reaction time
Verification steps

Step 1: Tracing of ECU timing behavior

- Instrumentation of debugGURU with EB Autosar OS
- Result: task and interrupt activations and execution time
Step 2: Set up system model in SymTA/S

- Import debugGURU trace data into SymTA/S
- Import CAN network information (dbc)
- Model relevant data paths
Simple scheduling approach:
Torque regulation scheduled cyclically with 8ms period

8ms Task calculates torque regulation

Max age: 15.62ms

long delay caused by register communication
Veriﬁcation steps

- Constraint is violated if torque regulation algorithm is scheduled cyclically!

- Redesign necessary
  - Event driven calculation of torque regulation
  - Triggered by reception of driver torque request
Verification steps

Redesigned system and data path for torque regulation

Event driven activation
Verification steps

Simulation analysis of max data age of redesigned system

Max reaction time: 5514us
Conclusion

- Timing aspects were considered on all levels of abstraction

- Traceability of constraints through all levels of abstraction was achieved

→ Our process enabled systematic consideration and refinement of timing constraints

→ Simulation of timing behavior enabled easy verification of implementation alternatives