Simulation of airbag sensing signals using finite element method

Dr. Thomas Kiefer
thomas.dr.kiefer@de.opel.com

Dr. Peter Erb
peter.erb@de.opel.com

Bernd Gosolits
bernd.gosolits@de.opel.com

Radu Visinescu
radu.visinescu@de.opel.com

Adam Opel AG
Rüsselsheim, Germany

Abstract:

Using FE simulation to aid in development of the body structure for vehicle crashworthiness is a common practice in automotive industry today. However, development of airbag sensing calibration is still heavily depended on the physical tests. The airbag sensing algorithm is typically developed using a suite of signals from real crashes and immunity tests.

The use of FE method to calculate the airbag sensing signals is an emerging technology with many potential advantages. Some recommendations are proposed in this study to reproduce the laboratory crash signals using FE simulations for obtaining usable FE data. In addition to the recommendations to the simulation, some recommendations to the airbag algorithm are proposed as well in order to have a FEM-compatible airbag sensing algorithm.

For acceleration-based airbag sensing systems, the corresponding sensor accelerations are calculated using LS-DYNA. Two upcoming issues need to be resolved:
- high frequency content of acceleration data (frequency range and accuracy)
- aliasing problem when not exporting results to nodout file at every calculated time step.

When the airbag algorithm is mainly based on low frequency accelerations or integral of the acceleration (Δ velocity), differences in the high frequency content between the simulations and the tests will not be a concern. The proposed method does use the global nodal information (th-node) from nodout file, instead of the usually used element “seatbelt_accelerometer” in LS-DYNA which outputs nodal information in a specified local coordinate system. In the proposed method the accelerometer information corresponding to its local coordinate system is obtained by post-processing the simulation results. A local default rotation of the sensor relative to the global coordinate system can also be calculated in the post-processing. With other post-processing algorithms, an optimized sensor orientation can also be determined without crashing several vehicles or running different models.

Keywords:

airbag sensing, aliasing, accelerometer, sensor location, sensor orientation, signal prediction

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Adam Opel AG, Rüsselsheim

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Overview

Introduction
- airbag sensing system
- airbag sensing development

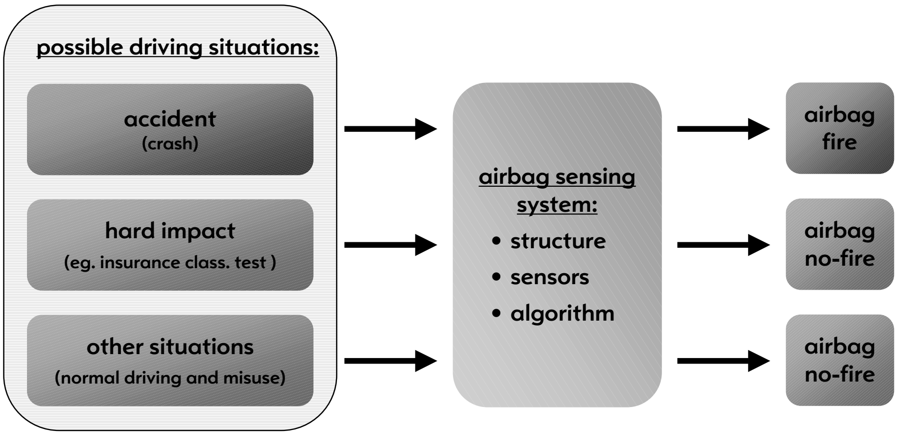
FEM acceleration data for airbag sensing
- modelling
- general problems and solutions

New method
- requirements
- description
- validation results

Summary

Introduction

Airbag sensing system

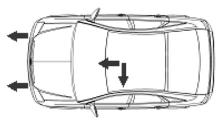


Introduction

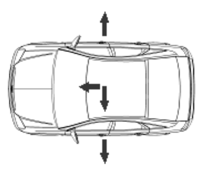
Airbag sensing system

Example: acceleration based airbag sensing system

front airbag system:
- 2 acc. sensors in front (x-dir.)
- 2 acc. sensor in ECU (x- and y-dir.)

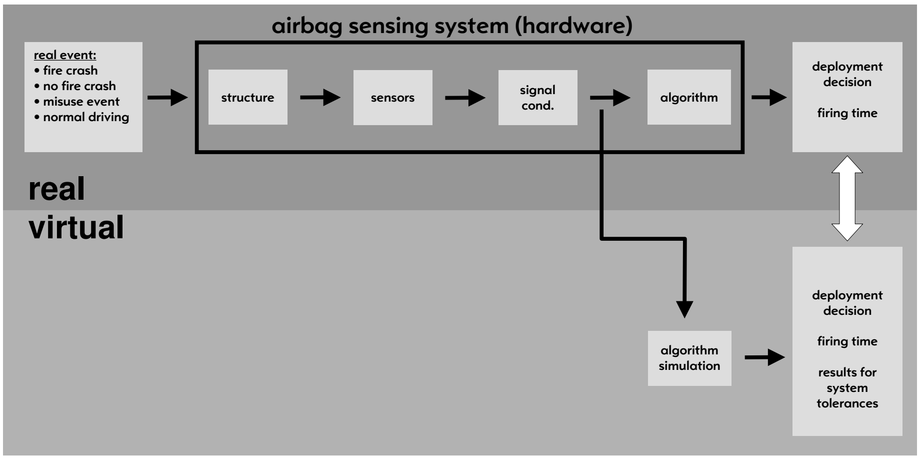


side airbag system:
- 2 acc. sensor in b-pillars (y-dir.)
- 2 acc. sensor in ECU (x- and y-dir.)



Introduction

Airbag sensing development



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Introduction

Airbag sensing development

Hardware based development:

- large amount of prototypes for crashtests
- airbag algorithm development always one step behind vehicle structure development
- changes of vehicle structure may cause changes of airbag sensing system performance which are not predictable
- costs for late changes /adaptions in airbag sensing system

⇒ simulation based airbag sensing system development !

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Introduction

Airbag sensing development

Advantages of simulation based development:

- reach basic decisions for system design based on structural analysis of actual project
- avoid late changes in sensing system (amount of sensors, locations, sensor-brackets)
- analyse effects on airbag algorithm performance in case of changes in vehicle structure
- compensate less hardware prototypes in actual projects

⇒ stretch target for the near future:

develop airbag algorithm without prototype hardware

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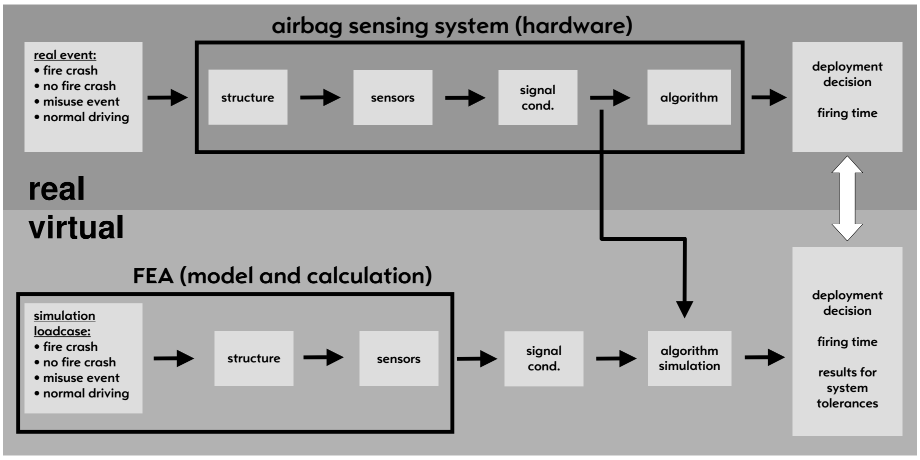
Introduction

Airbag sensing development



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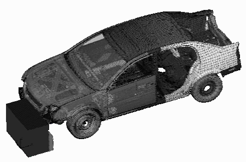
Introduction

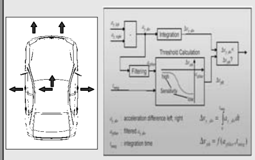
Integrated safety simulation

Structure Simulation



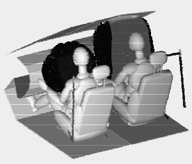
- Deformations
- Intrusions
- Collapse modes
- Pulses

Algorithm & Sensor Integration



- Sensors
- Signals
- Algorithms
- Fire decisions

Occupants & Restraints



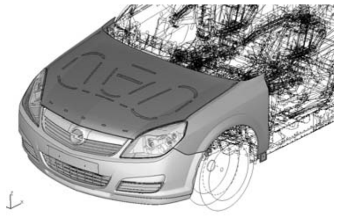
- Dummy Response
- Dummy Injury Severities

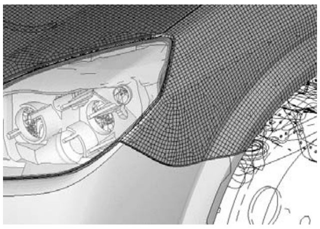
FEM acceleration data

Vehicle modelling for airbag sensor simulations

- element size: 4-7 mm
- total number of elements: ≈1.700.000
- required additional parts: bumper fascia, grill, headlamps (material models for polymer components required)

⇒ Similar model content as for pedestrian protection simulations





FEM acceleration data

Acceleration sensor modelling

Influences on sensor signal:

- global rotations of vehicle
- local rotations of sensor caused by deformations
- sensor mass

⇒ use of element "seat-belt-accelerometer" with additional mass

⇒ alternative method without using "seat-belt-accelerometer" will be presented in this paper

FEM acceleration data, general problems and solutions

„High" frequency content

problem: „high" frequency content (> 150 Hz) not accurate enough for airbag sensing signal prediction

solution:

- use a frontal algorithm with fire decisions strictly based on low frequency or integral criteria
- use additional upfront sensors
- avoid low frequency Eigen modes of sensor brackets and surrounding structure
- realize a robust/predictable behaviour of structure in crash

FEM acceleration data, general problems and solutions
„Aliasing“ problem, description

problem: „Aliasing“ occurs if

- analog signals are digitized with a sample frequency which is lower than twice the highest frequency content of the analog signal (Nyquist-criterion $f_n = 0.5 * f_{sample}$)
- digital signals are down sampled by steady skipping of samples and the signal contains frequency which is higher than half of the (new) sample rate

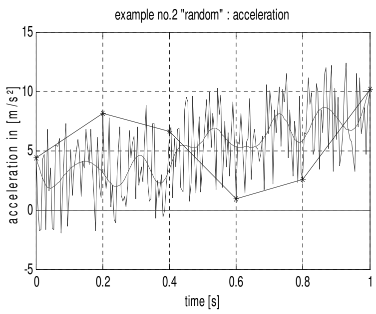
solution:

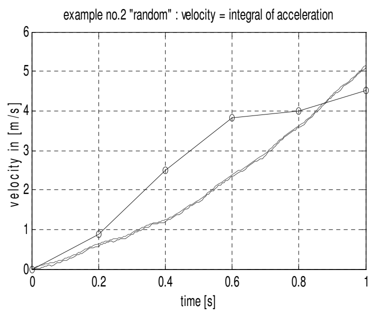
- remove high frequency content with an low pass filter (so called „anti aliasing-filter“, standard in digital measurement)
- integration of acceleration data before resampling has also an „anti aliasing filter effect“, because the major part of the high frequency content is removed (depending on signal characteristic)

FEM acceleration data, general problems and solutions
„Aliasing“ problem , description

Theoretical example for „Aliasing“:

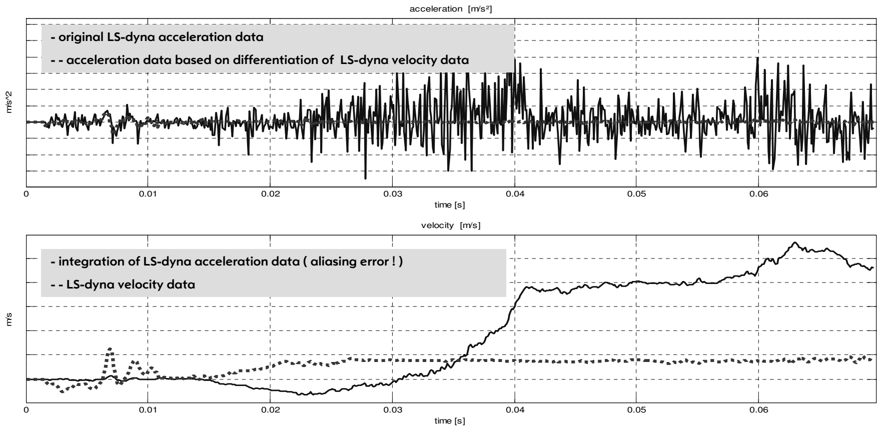
acceleration → velocity (integral)





FEM acceleration data, general problems and solutions
„Aliasing“ problem , description

LS-Dyna example for „Aliasing“:



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FEM acceleration data, general problems and solutions
„Aliasing“ problem , solutions

Overview: several known solutions for „Aliasing“ problem in LS-DYNA:

1. internal low pass filtering
2. exporting every calculation time step
3. acceleration average filter („IACCOP“)
4. LS-DYNA version 970 with option „INTOPT=1“

new method will be presented in this paper:

5. using „global TH-nodes“ instead of „seat-belt-accelerometer“

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FEM acceleration data, general problems and solutions
„Aliasing“ problem , solutions

1. Internal low pass filtering:

description:
- using LS-DYNA „seat-belt-accelerometer“
- internal interpolation (to get constant time steps)
- internal low pass filtering (eg. SAE 1000)
- exporting nodal data with „low“ sampling rate (eg. 10 kHz)

pros:
- no aliasing errors
- small nodout-files

cons:
- not available, but should be a standard option

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FEM acceleration data, general problems and solutions
„Aliasing“ problem , solutions

2. Exporting every calculation time step:

description:
- using LS-DYNA „seat-belt-accelerometer“
- exporting every calculation time step
- post-processing interpolation to get constant time steps
- post-processing low pass filtering (eg. SAE 1000)
- post-processing resampling (eg. 10 kHz)

pros:
- no aliasing errors

cons:
- large nodout-files

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FEM acceleration data, general problems and solutions
„Aliasing“ problem , solutions

3. Acceleration average filter („IACCOP“) :

description:
- using LS-DYNA „seat-belt-accelerometer“
- using LS-DYNA acceleration average filter
- add lumped mass at „measured“ node (if necessary)
- exporting nodal data with „low“ sampling rate (eg. 10 kHz)
- post-processing low pass filtering (eg. SAE 1000)

pros:
- small nodout-files

cons:
- still some (small) aliasing errors
- artificial masses in model

FEM acceleration data, general problems and solutions
„Aliasing“ problem , solutions

4. Dyna-Version 970 with option „INTOPT=1“

description:
- using LS-DYNA „seat-belt-accelerometer“
- using LS-DYNA option „INTOPT=1“
- exporting nodal data with „low“ sampling rate (eg. 10 kHz)
- „not-aliased“sensor acceleration is calcualted in post-processing as derivative of the accelerometer-velocity
- post-processing low pass filtering (eg. SAE 1000)

pros:
- small nodout-files

cons:
- still some (small) aliasing errors equivalent to solution 3
- physical not reasonable data in nodout-file

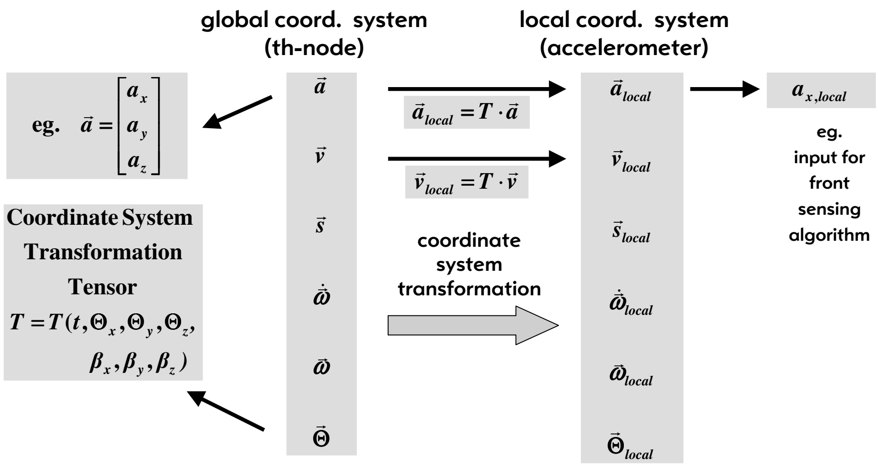
New method
Requirements

Requirements at start of project:

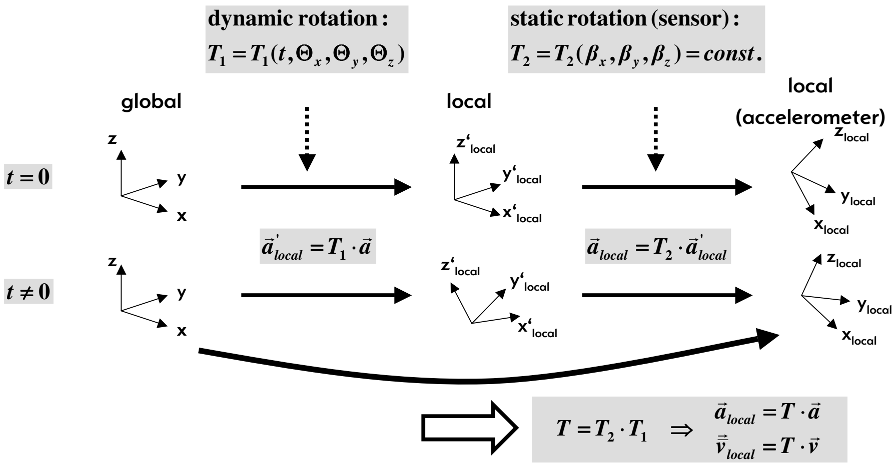
- non-“aliased“ accelerations in local coordinate system (reprensenting real sensor)
- possibility to optimize sensor orientation in post processing without new simulation runs (sensors may be slightly rotated for best sensing performance)
- influence on exisiting modelling guidelines should be as small as possible
- only small additional modelling effort
- use the same vehicle model as used in crash simulation for structure development
- no additional runs (resp. costs)
- small nodout files which may easyly be handled in post-processing

⇒ **new method had to be developed because none of the methods 1-4 fullfilled all requirements!**

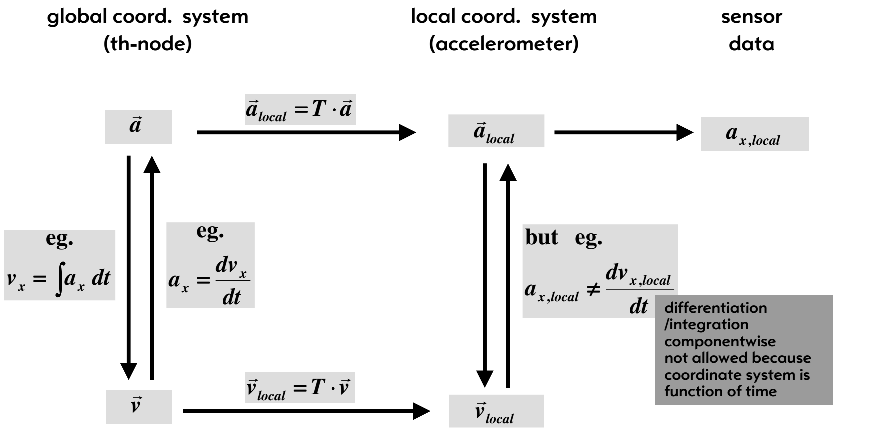
New method
LS-DYNA nodal data (nodout-file)



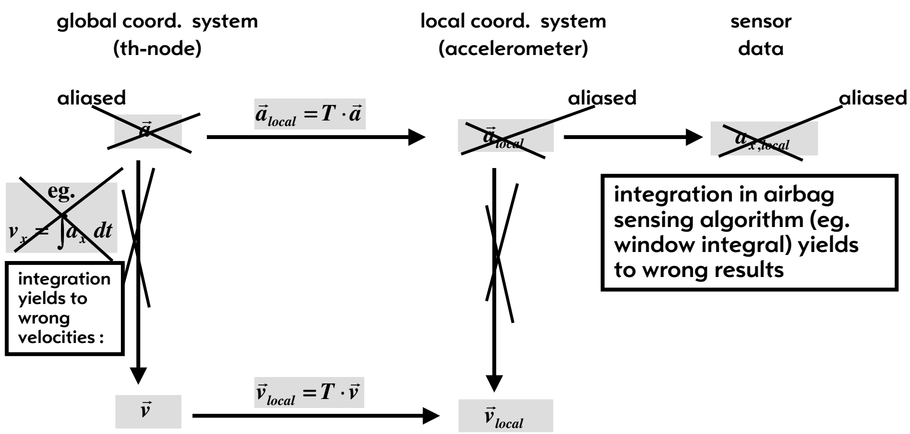
New method
coordinate system transformation



New method
integrals and derivatives



New method
problem: „aliased“ nodal data



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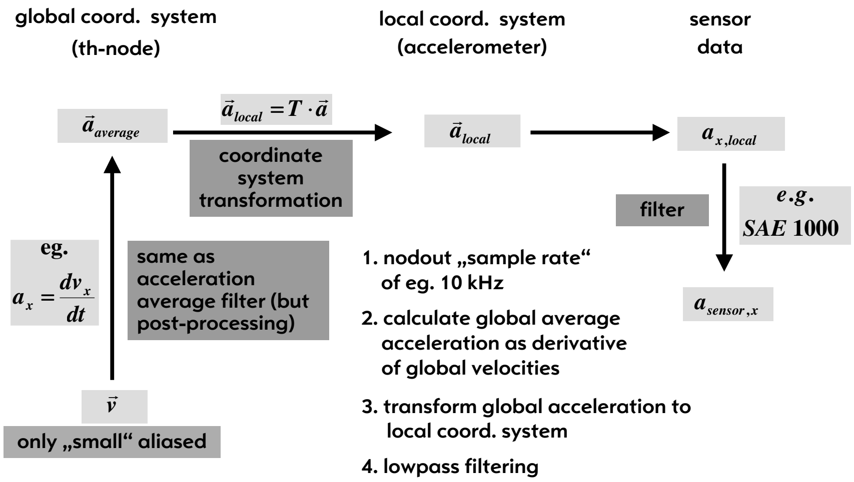
New method
solution: non-„aliased“ nodal data



1. nodout „sample rate“ of eg. 10 kHz
2. calculate global average acceleration as derivative of global velocities
3. transform global acceleration to local coord. system
4. lowpass filtering

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New method
Essential addition to modelling guidelines

problem: using single th-node for calculating sensing data failed, because rotational dof's were sensless for some special conditions
(nodal z-rotation for shell element is undetermined !)

solution: th-node should be part of a small „rigid body sensor element"

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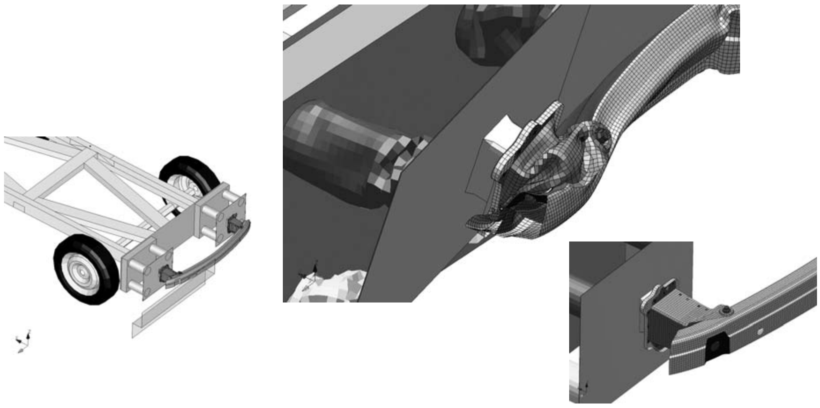
New method
Method validation

Component model for method validation:



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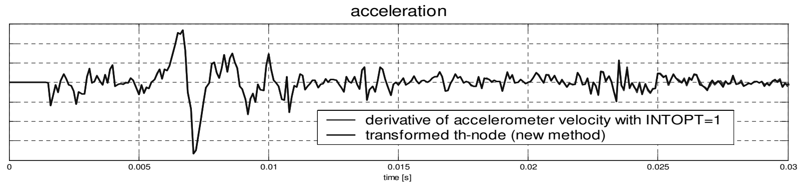
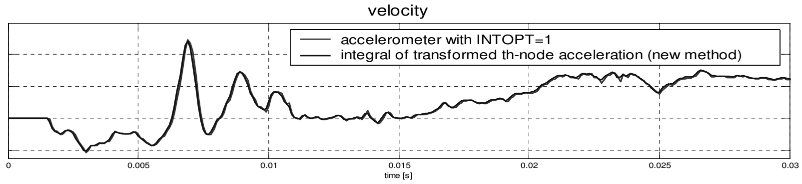
New method

Method validation, comparison of results

⇒ new method (#5) and method „INTOPT=1“ (#4) yield to almost identical sensor accelerations and velocities:





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Summary

Description of new method

New method using global TH-nodes instead of „seat-belt-accelerometer“:

description:
- using LS-DYNA global TH-node data of a „rigid body sensor element“
- exporting nodal data with „low“ sampling rate (eg. 10 kHz)
- post-processing „acceleration average filter“
- post-processing dynamic coordinate system transformation
- post-processing low pass filtering (eg. SAE 1000)

cons:
- still some (small) aliasing errors equivalent to solution #3 and #4

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Summary

Practical advantages of new method

New method using global TH-nodes instead of „seat-belt-accelerometer“:

practical advantages:

- no seat-belt-accelerometer modelling needed, modelling technique of sensor easier, this yields to less errors in daily work
- easy way to integrate airbag sensors in existing models
- small nodout-files because of 10 kHz „sample rate“ : reduction of needed data storage capacity of 90%
- „aliasing“ reduced by calculating averaged accelerations in post-processing
- local default rotations of sensor-direction resp. global xyz-direction are considered in post-processing ; post-processing optimization of local sensor direction possible