Experimental modeling of vertical dynamics of vehicles with controlled suspensions

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Outline

- Introduction
- Experimental setting
- SM Structured identification method
- Application to identification of vehicles vertical dynamics
- Validation results
- Conclusions

Introduction

- Identification of vertical dynamics of vehicles with controlled suspensions is considered.

Goal:

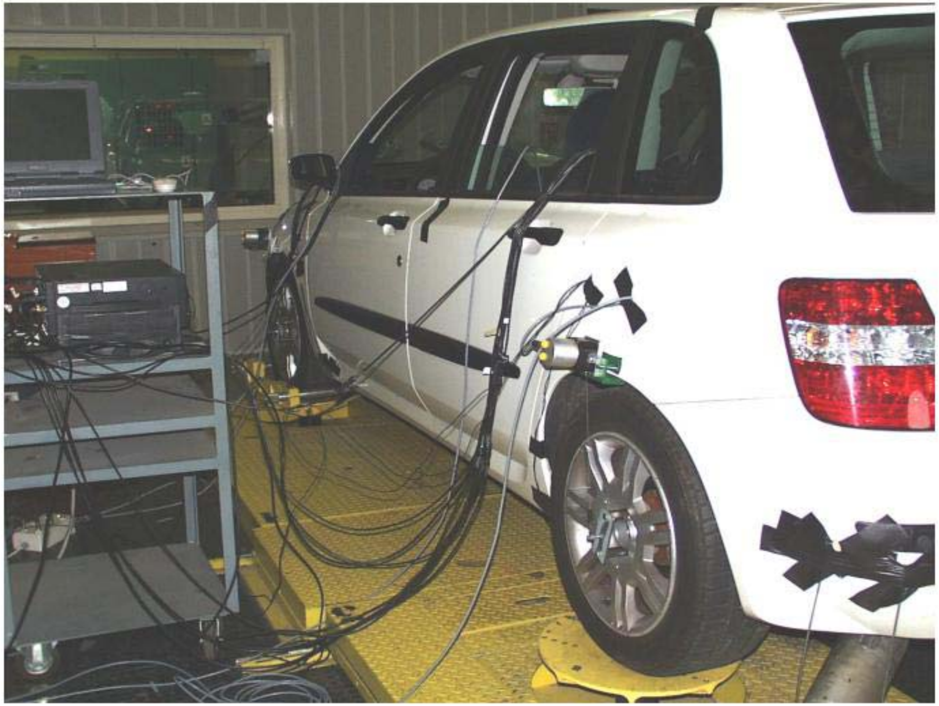
Derive a model with:

Inputs: road profile and control currents

Outputs: chassis and wheels accelerations

Experimental setting

- C-segment prototype vehicle with controlled dampers and a CDC-Skyhook (continuous damping control) system.
- Measurements are performed on a four-poster test bench of FIAT-Elasis Research Center.



Experimental setting

CDC-Skyhook control settings:

- Constant hard (CH): dampers currents on average zero, maximum dampening effect.
- Hard (H): dampers current modulated by the CDC-Skyhook, "sporting" calibration.
- Soft (S): dampers current modulated by the CDC-Skyhook, "comfort" calibration.
- Constant soft (CS): dampers currents on average maximum, minimum dampening effect.

Experimental setting

Road profiles:

- Random: random road.
- English Track: road with irregularly spaced holes and bumps.
- Short Back: impulse road.
- Motorway: level road.
- Pavé track: road with small amplitude irregularities.
- Drain well: negative impulse road.

Note: The road profiles are symmetric (left=right).

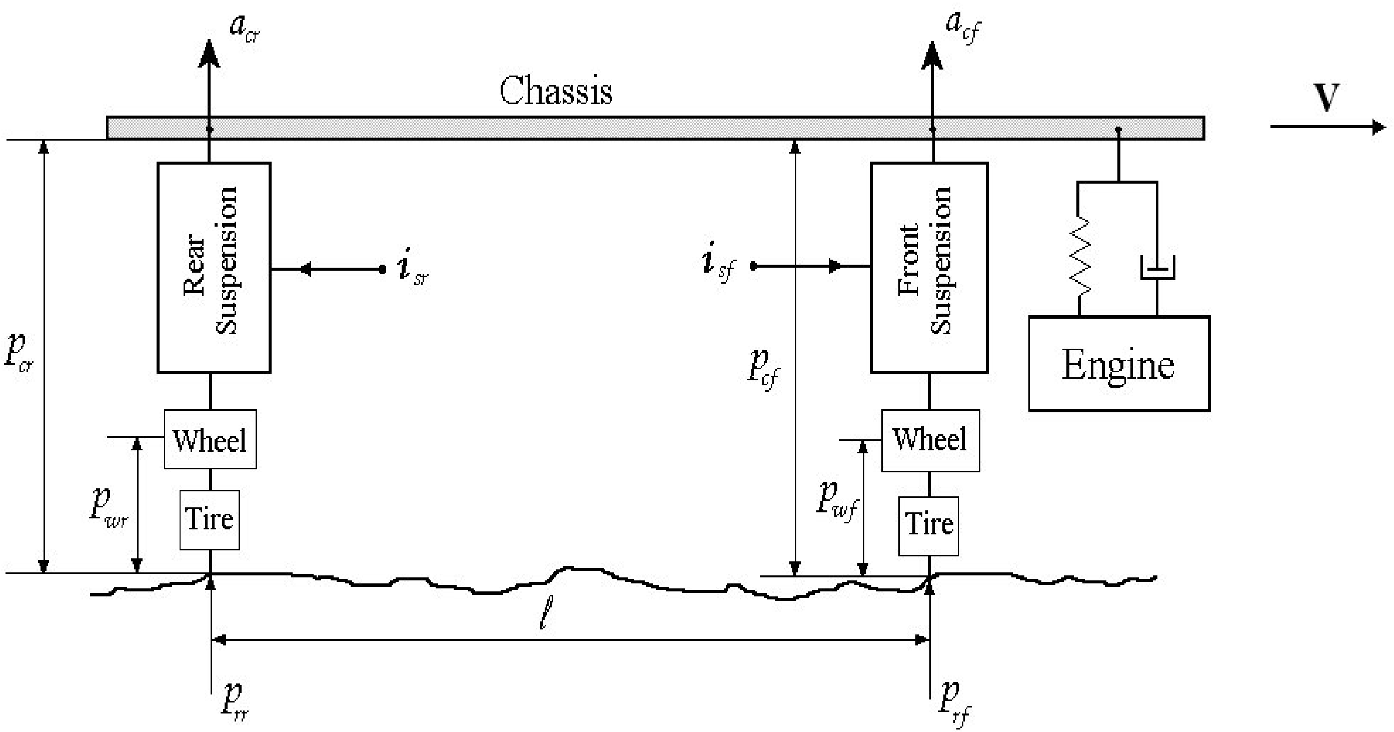
Experimental setting

Data set: 93184 data, collected with a sampling frequency of 512 Hz, partitioned as follows:

- Identification set: first 7 seconds of each acquisition. Used for model identification.
- Testing set: seconds from 7 to 14 of each acquisition. Used for model testing.

Structured Identification of vehicles vertical dynamics

Since the road profiles are symmetric, a Half-car model has been considered:



Structured Identification of vehicles vertical dynamics

- Usual identification approaches use physical laws to derive the structure of the model.
- Parameters of the model are tuned using experimental data.
- Accuracy of models obtained by such an approach resulted to be not quite satisfactory, mainly due to the complexity of physical laws.

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Input-output (black-box) models

Structured Identification of vehicles vertical dynamics

- Still not sufficiently accurate modeling is obtained, mainly due to the large dimension of required regressor space.

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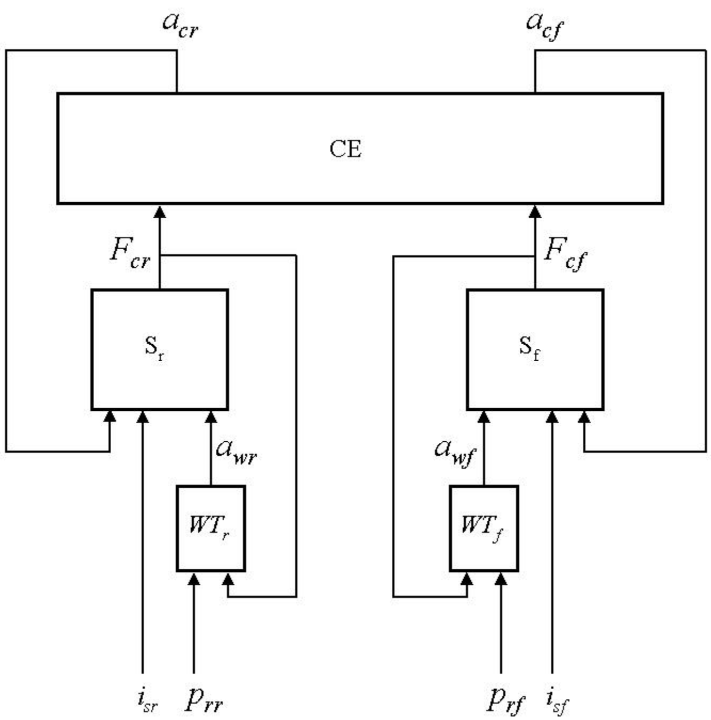
Structured identification

- The high-dimensional problem is reduced to the identification of lower dimensional subsystems and to the estimation of their interactions

Structured Identification of vehicles vertical dynamics

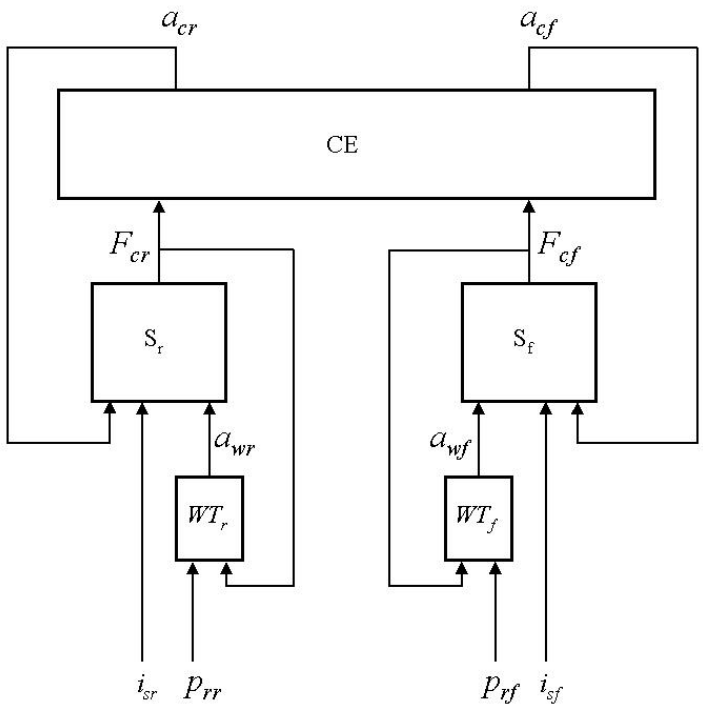
Structure decomposition:



- CE: chassis + engine
- S: suspension
- WT: wheel + tire

Structured Identification of vehicles vertical dynamics

Structure decomposition:

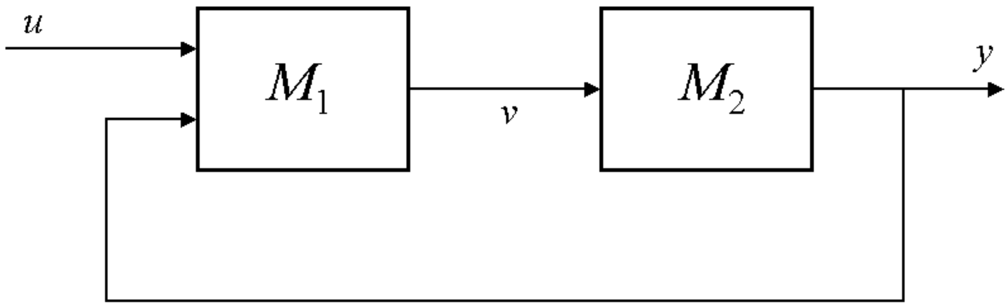


Measured variables:

- p_{rf} and p_{rr}: front and rear road profiles.
- i_{sf} and i_{sr}: control currents of front and rear suspensions.
- a_{cf} and a_{cr}: front and rear chassis vertical accelerations.
- a_{wf} and a_{wr}: front and rear wheels vertical accelerations.

Note: F_{cf} and F_{cr} are not measured.

Structured identification



Note: F_{c*} are not known.

First level:

M_2 is CE

M_1 composed of:

S_f S_r WT_f WT_r

$u=[p_{rf}\, p_{rr}\; i_{sf}\, i_{sr}]$

$y=[a_{cf}\, a_{cr}]$

$v=[F_{cr}\; F_{cf}]$

Second level:

M_2 is S_*

M_1 is WT_*

$u=[p_{r*}\;\; i_{s*}\, a_{c*}]$

$y=[F_{c*}]$

$v=[a_{w*}]$

$*$ stands for r or f.

Structured identification

- The identification problem is solved by means of the iterative algorithm proposed in: M. Milanese and C. Novara, "Structured experimental modeling of complex nonlinear systems", IEEE CDC 2003, Maui, USA.

Iterative identification algorithm:

- Initialisation: get an initial guess $M_2^{(0)}$ of M_2
- Step k:

1) Compute $v^{(k)}$ such that $M_2^{(k-1)}[v^{(k)}]=y$
2) Identify $M_1^{(k)}$ using u and y as inputs, $v^{(k)}$ as output
3) Identify $M_2^{(k)}$ using $v^{(k)} = M_1^{(k)}[u,y]$ as input, y as output and return to step 1)

Key feature: The identification error is decreasing for increasing iteration.

Nonlinear SM identification

- Identification of the nonlinear system M_1 is performed using the Nonlinear Set Membership method.

Key features:

- No assumptions on the functional form of the regression model are required. Regularity assumptions are used.
- No statistical assumptions on noise are made. Noise is only supposed to be bounded.
- The complexity/accuracy problems posed by the choice of the parametrization of the nonlinear regression are circumvented.

Reference: M. Milanese and C. Novara, "Optimality in SM Identification of Nonlinear Systems", IFAC SYSID 2003, Rotterdam, the Netherlands.

Simulation results on testing set

NSM$^{(k)}$: model identified at iteration k.
RMSE: Root Mean Square Acceleration Error on the testing set.

Model	RMSE (front chassis)	RMSE (rear chassis)
NSM$^{(1)}$	2.85	3.53
NSM$^{(2)}$	0.72	1.19

Note: A third iteration has been also performed, but no significant decrease of errors has been observed.

Simulation results on testing set

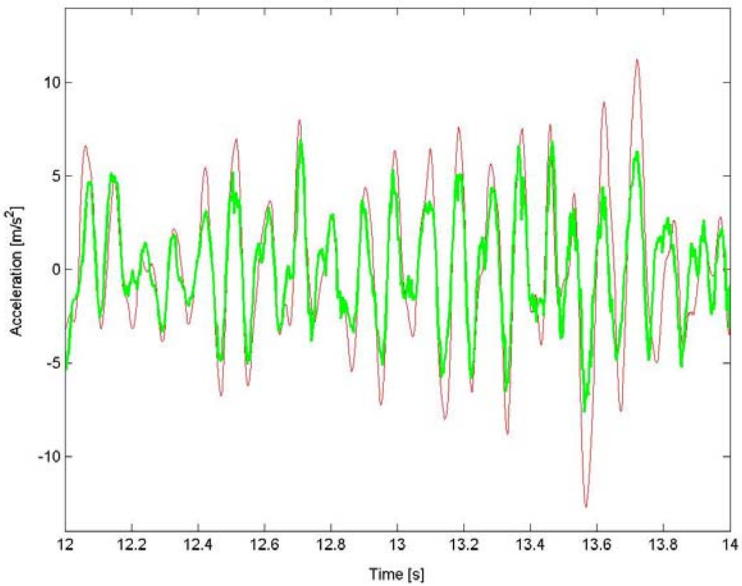
Road profile	Sky-hook setting	RMSE (front chassis) NSM(2)	RMSE (rear chassis) NSM(2)
Random	CH	1.02	1.75
Random	H	0.46	0.73
Random	S	0.44	0.70
Random	CS	0.57	0.77
En. track	CH	1.35	1.91
En. track	H	0.87	1.34
En. track	S	0.88	1.36
En. track	CS	0.83	1.46
Short back	S	0.43	1.04
Motorway	CH	0.27	0.52
Motorway	CS	0.32	0.41
Pavé	CH	0.70	1.31
Drain well	S	0.33	0.94

Simulation results on testing set

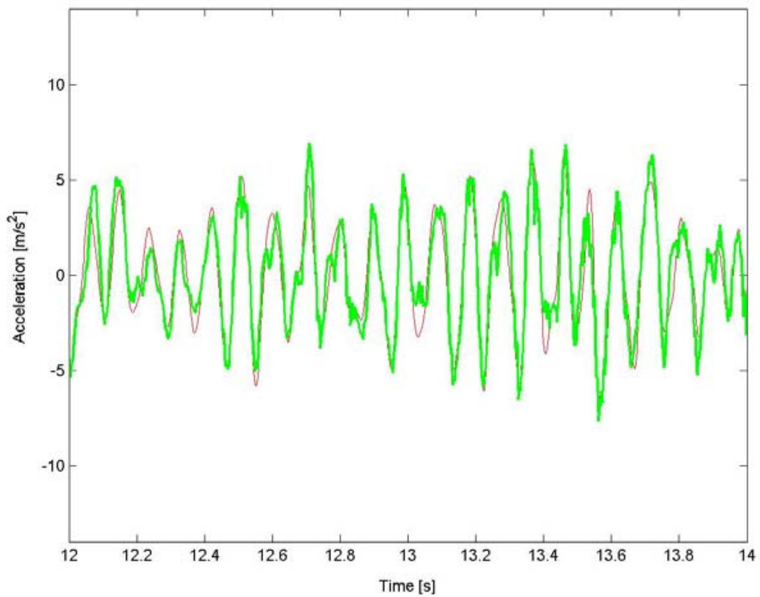
Road profile	Sky-hook setting	RMSE (front wheel) NSM(2)	RMSE (rear wheel) NSM(2)
Random	CH	3.18	5.14
Random	H	1.90	4.66
Random	S	1.79	3.90
Random	CS	2.90	4.46
En. track	CH	3.90	8.12
En. track	H	3.67	9.79
En. track	S	3.81	9.83
En. track	CS	5.69	12.71
Short back	S	4.57	6.57
Motorway	CH	1.08	1.47
Motorway	CS	1.64	2.09
Pavé	CH	1.76	3.80
Drain well	S	3.09	4.65

Simulation results on testing set

Chassis front accelerations on the random road profile with CH sky-hook configuration: measurements (green line), model (red line)



First iteration (NSM$^{(1)}$)



Second iteration (NSM$^{(2)}$)

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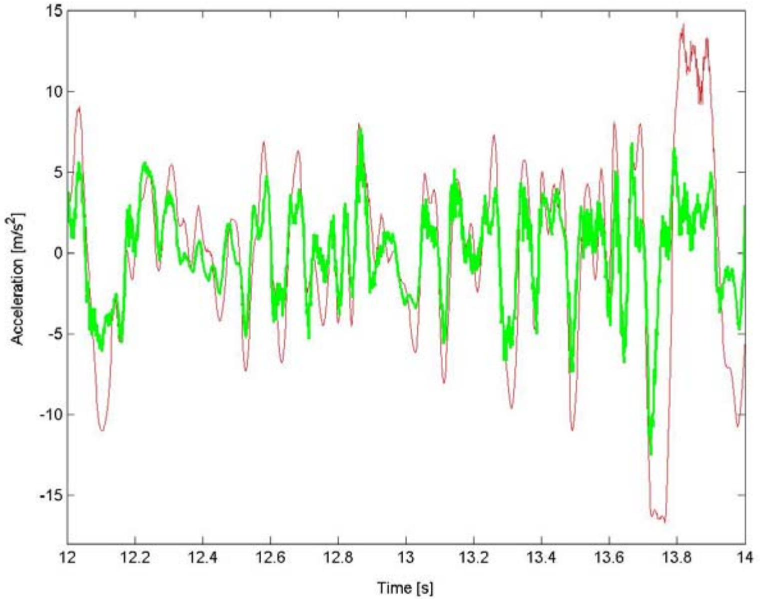
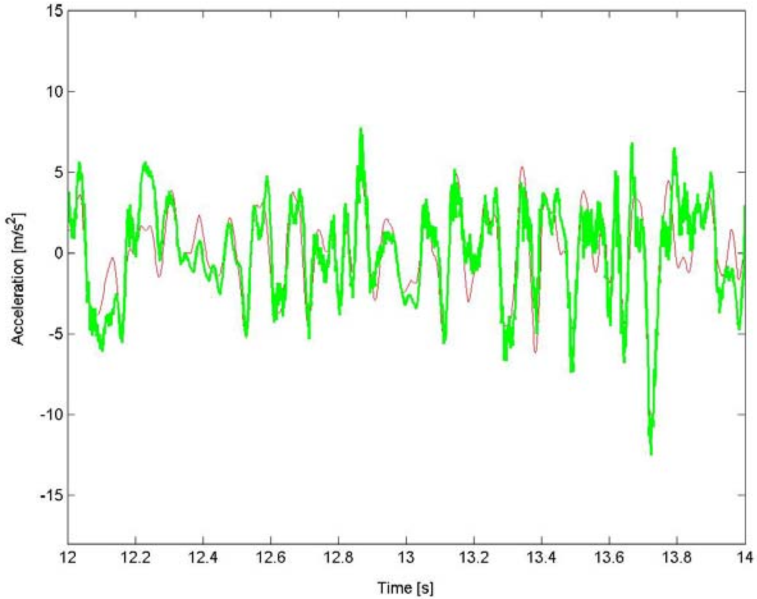
Simulation results on testing set

Chassis rear accelerations on the random road profile with CH sky-hook configuration: measurements (green line), model (red line).



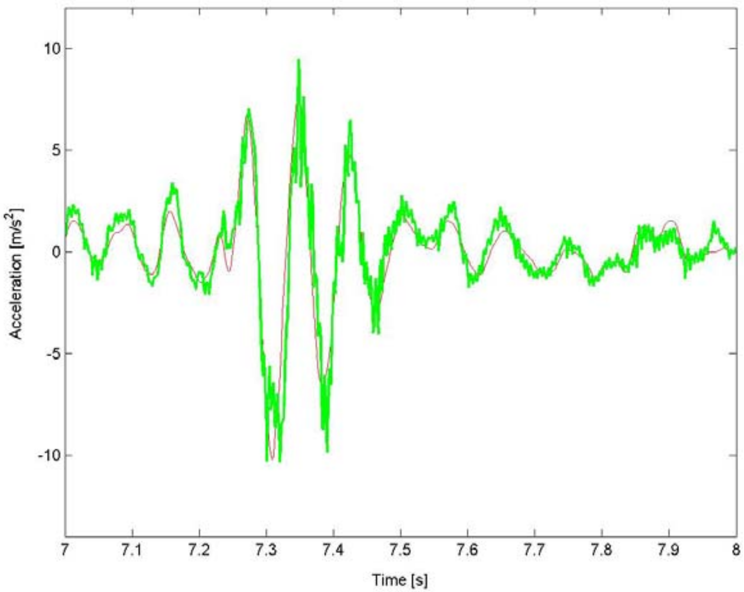
First iteration (NSM$^{(1)}$)



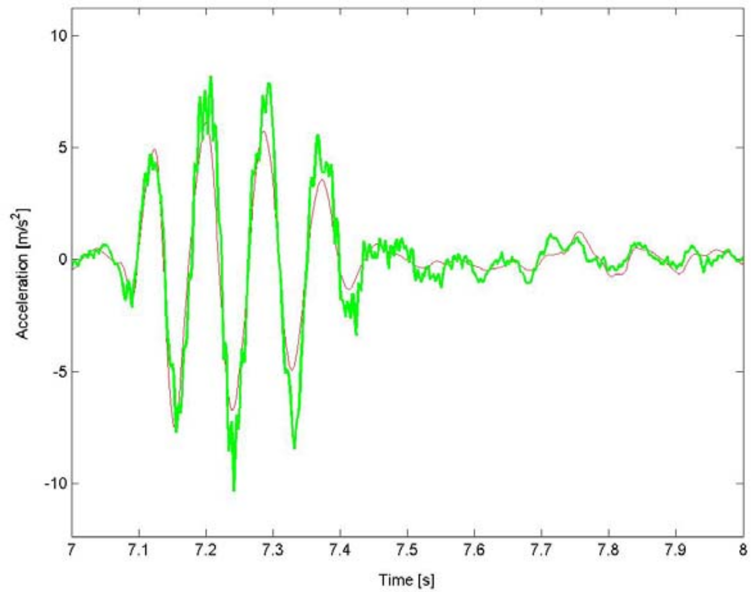
Second iteration (NSM$^{(2)}$)

Simulation results on testing set

Chassis accelerations on the english track road profile with H sky-hook configuration: measurements (geen line), model (red line).



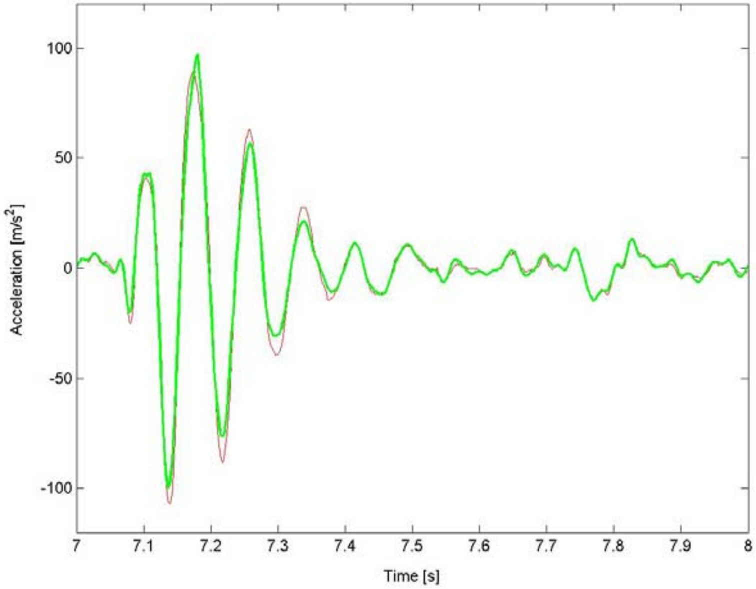
Second iteration ($NSM^{(2)}$), rear



Second iteration ($NSM^{(2)}$), front

Simulation results on testing set

Front wheel acceleration on the english track road profile with H sky-hook configuration: measurements (green line), model (red line).



Second iteration (NSM$^{(2)}$)

Conclusions

- Modeling of vertical dynamics of vehicles equipped with a CDC-Skyhook dampers control system has been considered.

- Identification has been performed by means of the Set Membership structured identification method which uses:
  - physical information on the structure of the system
  - nonlinear black-box identification techniques.

- The identified model, tested on a set of data not used for identification, provided quite satisfactory simulation accuracy for all the considered road profiles and Skyhook settings.