Scalable Compact Models for Complex High-Speed Systems

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WMC: Advanced techniques for electromagnetic-based model generation
Introduction

Scalable Macromodels

Numerical examples
- Data-driven PMOR
- Model-driven PMOR

Conclusions
Introduction

Scalable Macromodels

Numerical examples
  • Data-driven PMOR
  • Model-driven PMOR

Conclusions
Introduction

input \rightarrow \text{out} = f(\text{in}) \rightarrow \text{output}

- electronics
- telecom
- fluid dynamics
- chemistry
- biomodeling
- geology
- automotive
Introduction

Design variables
width, temperature, angle, frequency, ...

Response variables
lift, S-parameters, pressure, stress, ...

Costly

Adaptive Modeling

Surrogate Model / Metamodel
Neural network, Kriging, SVM, rational function, spline, ...

Cheap

CAD/CAM/CAE Environment

Prototyping
Optimization
Sensitivity Analysis

WMC: Advanced techniques for electromagnetic-based model generation

IMS2012, Montreal, June 17-22, 2012
Introduction

Simulation Model

Design variables
width, temperature, angle, frequency, ...

Response variables
lift, S-parameters, pressure, stress, ...

Costly

Surrogate Model / Metamodel

Design variables

Response variables

Cheap

Adaptive Modeling

Distributed Computing

WMC: Advanced techniques for electromagnetic-based model generation
Introduction
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Introduction
Design process

- several decisions
  - materials
  - geometrical dimensions
  - shape
  - constraints
    - space
    - cost
    - performance
Design process

Simulators
- implementation of models
- describe systems behavior
- help designers

Measurements
- post tuning
- verification
- help designers
OUTLINE

Introduction

Scalable Macromodels

Numerical examples
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- Model-driven PMOR

Conclusions
A typical design process requires

- Multiple simulations (measurements)
  - different design parameters values (e.g. layout features)
  - design space optimization
  - design space exploration
  - sensitivity analysis
Scalable macromodels

A typical design process requires

- Multiple simulations (measurements)
  - computationally expensive (time and memory)

- Can we do better?

- Yes
  - By scalable macromodels
Scalable macromodels

Model-driven PMOR

\[ sX = AX + BU \]
\[ Y = CX + DU \]

scalable macromodel
Scalable macromodels

modeling

discretisation by simulators

real world

PDE

U(s,g)

sX = AX + BU
Y = CX + DU

Y(s,g)

Model-driven PMOR

Data-driven PMOR

scalable macromodel

WMC: Advanced techniques for electromagnetic-based model generation
Scalable macromodels

modeling

discretisation by simulators

real world

measurements

data

Model-driven PMOR

Data-driven PMOR

scalable macromodel

U(s,g)  sX = AX + BU  Y(s,g)

Y(s,g)  Y(s,g)  H(s,g)

U(s,g)
Scalable macromodels

PMOR concepts
Two design space grids are used in the modeling process
- estimation grid
- validation grid

Design space

\[ g = (g^{(n)})_{n=1}^N \]
Scalable macromodels

Model-driven PMOR

\[ \begin{align*}
    sX &= AX + BU \\
    Y &= CX + DU
\end{align*} \]

scalable macromodel

\[ \begin{align*}
    U(s,g) \\
    Y(s,g)
\end{align*} \]
Model-driven PMOR

- PRIMA
- LAGUERRE SVD
- HYBRID TBR
- FAST TBR
- EIGENSPACE PROJECTION

Model Order Reduction

Interpolation
Least Square

SYSTEM MATRICES
TRANSFER FUNCTIONS
PROJECTION MATRICES

MOR

A
B
H
C
D
A_r
B_r
H_r
C_r
D_r
Model-driven PMOR

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SYSTEM MATRICES
TRANSFER FUNCTIONS
PROJECTION MATRICES

\[
\begin{bmatrix}
A & B \\
C & D \\
\end{bmatrix} \approx \begin{bmatrix}
A_r & B_r \\
C_r & D_r \\
\end{bmatrix}
\]

EIGENSPACE PROJECTION

SYSTEM MATRICES
Model-driven PMOR

Model Order Reduction

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Interpolation

- SYSTEM MATRICES
- TRANSFER FUNCTIONS
- PROJECTION MATRICES

model-driven PMOR

- accuracy
- efficiency
- stability guaranteed
- passivity guaranteed

H_r(s,g)
Data-driven PMOR

Model-driven PMOR

\[ UX = AX + BU \]
\[ Y = CX + DU \]

Real world

Data-driven PMOR

Data

Simulations

Measurements

Discretisation by simulators

Modeling

Scalable macromodel
Data-driven PMOR

Rational Fitting Methods
- VECTFIT
- MULTIPORT
- STABILITY
- PASSIVITY
- NOISY DATA

Interpolation Least Squares
- SYSTEM MATRICES
- TRANSFER FUNCTIONS
- POLES/RESIDUES

data-driven PMOR
- accuracy
- efficiency
- stability guaranteed
- passivity guaranteed

scattered data

H_r(s,g)
Data-driven PMOR

\[ H_r(s, g) = \sum_{p=1}^{P} \frac{Q(g)}{s-a_p(g)} \]

\[ H_r(s, g) = C(g)(sI - A(g))^{-1}B(g) + D(g) \]

scattered data
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scattered data

Rational Fitting Methods

Interpolation
Least Squares

SYSTEM MATRICES
TRANSFER FUNCTIONS
POLES/RESIDUES

VECTFIT
MULTIPORT
STABILITY
PASSIVITY
NOISY DATA
3D example: Interconnection structure
- Mobile phone application
- 10 lines (20 ports)
- etched ground plane

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency ($freq$)</td>
<td>0 Hz</td>
<td>20 GHz</td>
</tr>
<tr>
<td>Spacing ($S$)</td>
<td>25 $\mu$m</td>
<td>65 $\mu$m</td>
</tr>
<tr>
<td>Angle ($\alpha$)</td>
<td>45°</td>
<td>65°</td>
</tr>
</tbody>
</table>
Data-driven PMOR example

- CPU time model estimation
- CPU time model validation

<table>
<thead>
<tr>
<th>Step</th>
<th>CPU time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimation</td>
<td>10 h</td>
</tr>
<tr>
<td>Validation</td>
<td>6 h</td>
</tr>
</tbody>
</table>

Design space
Data-driven PMOR example

Poles

![Pole Diagram]

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IMS2012, Montreal, June 17-22, 2012
Data-driven PMOR example

Output

| \(|S_{13}|\) |
|---|---|---|---|
| 0.2 |
| 0.15 |
| 0.1 |
| 0.05 |
| 0 |

| Angle [°] | Frequency [GHz] |
|---|---|---|---|
| 70 |
| 60 |
| 50 |
| 40 |
| 30 |
| 20 |
| 10 |
| 0 |

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Data-driven PMOR example

Output

Output

WMC: Advanced techniques for electromagnetic-based model generation
Data-driven PMOR example

- Design optimization
- minimum $S$, minimum $\alpha$
- $|S_{13}(s, S, \alpha)| \leq -22$ dB over [0 - 20] GHz

![Graph showing the constraint $|S_{13}|$ dB vs frequency]
- Design optimization
- minimum $S$, minimum $\alpha$
- $|S_{13}(s,S,\alpha)| \leq -22$ dB over [0 - 20] GHz
- initial values
Data-driven PMOR example

- Design optimization
  - minimum $S$, minimum $\alpha$
  - $|S_{13}(s,S,\alpha)| \leq -22$ dB over [0 - 20] GHz
- initial values
- optimal values
Data-driven PMOR example

- Design optimization
- minimum $S$, minimum $\alpha$
- $|S_{13}(s, S, \alpha)| \leq -22$ dB over [0 - 20] GHz
- initial values
- optimal values

<table>
<thead>
<tr>
<th>Method</th>
<th>CPU time</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM solver</td>
<td>9 h</td>
</tr>
<tr>
<td>Parametric macromodel</td>
<td>37 s</td>
</tr>
</tbody>
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Model Order Reduction + Interpolation Least Squares

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model-driven PMOR: ★ accuracy, ★ efficiency, ★ stability guaranteed, ★ passivity guaranteed
Model-driven PMOR example

3D example: Spiral inductor

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<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency (freq)</td>
<td>10 kHz</td>
<td>30 GHz</td>
</tr>
<tr>
<td>Horizontal length (L_x)</td>
<td>0.46 mm</td>
<td>0.93 mm</td>
</tr>
<tr>
<td>Vertical length (L_y)</td>
<td>0.46 mm</td>
<td>0.93 mm</td>
</tr>
</tbody>
</table>

Original order = 801
Reduced order = 91
Model-driven PMOR example

3D example: Spiral inductor

Ly = 0.46 mm

Ly = 0.93 mm
3D example: Spiral inductor

Lx = 0.63 mm

Lx = 0.76 mm

Ly = 0.50 mm
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Design variables

Response variables

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Adaptive Modeling

Distributed Computing

Automotive  Chemistry  Aerodynamics  Electronics  Metallurgy

Design variables

Response variables

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Scalable macromodels

Multiple design variables

Compact models

Efficient design activities (excellent speed-ups)
- Multiple simulations (measurements)
  - Design space optimization, exploration, sensitivity analysis
Conclusions

Scalable macromodels

Time-domain simulations
- Non-linear drivers and receivers

Stochastic modeling
- Impact of manufacturing tolerances

Models from measurements
- Noise to handle

Applications in different domains
Questions