Model Behaviour Generation for Multiple Simulators

Faculty of Engineering / Research Group CEA

Thorsten Pawletta Hendrik Folkerts

E-Mail: thorsten.pawletta@hs-wismar.de hendrik.folkerts@hs-wismar.de

Web: www.hs-wismar.de / www.cea-wismar.de





Prerequisite

A prerequisite for this supplementary material is the knowledge of Chapter 1.5, where basic concepts of the System Entity Structure (SES) are described.

Outline

- 1. Case study
- 2. Implementation of the SES and an MB
- 3. Model selection and model generation
- 4. Organization of a simulator-independent MB
- 5. Full automation of simulation experiments
- 6. Summary

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1. Case study

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• Feedback control system





- Feedback control system
- Described by transfer functions

 $G_{Su}(s) = \frac{1}{20 \cdot s + 1}$



- Feedback control system
- Described by transfer functions
- Influenced by disturbances

 $G_{Su}(s) = \frac{1}{20 \cdot s + 1}$ $G_{Sz}(s) = \frac{1}{10 \cdot s + 1}$





Case Study (2)

• Two system structure variants

- Without feedforward control: feedforward=0
- With feedforward control: feedforward=1



Case Study (2)

Two system structure variants

Without feedforward control: feedforward=0

- With feedforward control: feedforward=1
- For every structure variant
 - \rightarrow Different parameter configurations of PID controller

(we consider two)



Case Study (2)

Design objective: Find best control configuration.

• Two system structure variants

- Without feedforward control: feedforward=0
- With feedforward control: feedforward=1
- For every structure variant
 - \rightarrow Different parameter configurations of PID controller

(we consider two)



Outline

1. Case study

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SES/MB-based Modeling



- **SES** describes permissible structure & parameter variants (simulator-independent)
- **MB** defines basic dynamic models (usually simulator dependent)



































Python Toolset

• Available:

https://github.com/cea-wismar/SESMB_Inf_Python/

- Tools
 - > SESToPy \rightarrow SES editor and IDE
 - SESViewEl → SES tree viewer
 - SESMoPy
 SESEuPy
 SESEcPy

Demonstration of SESToPy with SESViewEl (case study) \rightarrow Screenshots on Next Slides

- Connect SESToPy with SESViewEl (show SESToPy and SESViewEl next to each other)
- Add sub node, add sibling node, change type of node, rename node, delete node, inflate tree, deflate tree
- Edit entity node, descriptive node (aspect, specialization)
- Empty current model
- Save/Load model (JSON) \rightarrow load Feedback.jsonsestree example
- Export/Import model (XML)
- Maximize SESToPy
- Use the feedback example to show:
 - > SES Variables, Semantic Conditions
 - > Selection rules \rightarrow here: specrule
 - NONE node
 - > Attributes, mb-attribute (decouple name of node and name of basic model)
 - Coupling list (composition of basic models)
 - > SES function to set couplings (dynamic coupling) \rightarrow procedural knowledge
- Merging

Connection of SESToPy and SESViewEl

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Create SES Tree with SESToPy

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Edit Entity Node with SESToPy

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SESToPy XML Export / Import

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SESToPy SES Variables



SESToPy Semantic Conditions



SESToPy Selection Rules (here Specrule)



SESToPy Attributes

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SESToPy Coupling List

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SESToPy SES Function / Coupling Function



SESToPy Merging

SESToPy	- SES Tools in Pyt	thon3 / PyQt5											_	
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		#children[2] is feedbackSys	he a	addFeedforward	Entity	'MB/Add'	х							
		#children[3] is ctrlPIDSys			Entity	'MB/Constant'	×							
		#children[4] is procUnitSys #children[5] is sourceDist	F	E feedbackSvs	Entity	'MB/Feedback'	x							
		#children[6] is tfDist	F	e ctrIPIDSys	Entity	'MB/PID'	x							
		#children[7] is addDist		procUnitSys	Entity	'MB/TransferFunction'	x							
		cola = []		sourceDist	Entity	'MB/Step'	x							
				E tfDist	Entity	'MB/TransferFunction'	х							
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		cplg.append([children[7],")												
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SESToPy Documentation

SESToPy - SES Tools in Python3 / PyQt5			- 🗆 X
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SES Functions			Specrule

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• See the documentation for more information

OpenModelica MB

- MB built of Modelica basic models in a Package
- Save package as MB.mo file



Outline

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Model Selection and Generation



Model Selection and Generation of Variant #1



Model Selection and Generation of Variant #1



Model Selection and Generation of Variant #1 (2)



Model Selection and Generation of Variant #1 (3)



Model Selection and Generation of Variant #1 (4)



Model Selection and Generation of Variant #2



Model Selection and Generation of Variant #2





Model Selection and Generation of Variant #2 (2)



Model Selection and Generation of Variant #2 (3)



Model Selection and Generation of Variant #2 (4)



Model Selection and Generation of Variant #2 (4)



Python Toolset

• Available:

https://github.com/cea-wismar/SESMB Inf Python/

- Tools
 - > SESToPy \rightarrow SES editor and IDE
 - > SESViewEl \rightarrow SES tree viewer
 - \rightarrow SESMoPy \rightarrow Model builder \iff Dymola
- OpenModelica Simulink

SESEuPy >SESEcPy

Demonstration of SESMoPy (case study) → Screenshots on Next Slides

- Show provisional Experimental Frame from SESMoPy examples → Template_for_SESMoPy
- Show that different simulators can be set \rightarrow here <code>OpenModelica</code>
- Show that two interfaces can be set → here native
- Merge Feedback SES from SESToPy examples to simModel → rename simModel to ctrlSys for merging.
- Show that configurations can be set in expMethod
- Prune for feedforward=0 → dynamic couplings to static couplings
- Flatten for feedforward=0 and save the FPES as file \rightarrow explanation flattening: remove inner, coupled components \rightarrow root node and leaves stay in tree \rightarrow couplings recalculated
- (Prune for feedforward=1 to show)
- Show the OpenModelica MB MB.mo and copy it in the same directory to the FPES file
- Open SESMoPy GUI \rightarrow set FPES \rightarrow create model \rightarrow models for both configurations created
- Open one created model in OpenModelica and load MB file
- In OpenModelica open the model by double clicking \rightarrow model not displayed (no annotation set) \rightarrow click button Text View
- Execute simulation \rightarrow set simulation time to 50 seconds
 - \rightarrow Signals of interest (setpoint, disturbance, controlled variable):

```
sourceSys.y sourceDist.y addDist.y
```

- → If the signals do not show up in plot: Click Auto Scale and Fit in View in plot
- If design objectives are not met with this structure and parameterization \rightarrow later how to simulate automatically to find fitting structure and parameterization
SESMoPy's Provisional Experimental Frame Show in SESToPy



Different Simulators & Interfaces can be set



Merge Feedback SES to Provisional Experimental Frame

SESToPy - SES Tools in Python3 / PyQt5	- 0	×
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Merge Feedback SES to Provisional Experimental Frame (2)

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	E		Entity	IVIB/Add	x	
		e sourceSvs	Entity	'MB/Constant'	x	
		e feedbackSys	Entity	'MB/Feedback'	x	
		e ctrIPIDSys	Entity	'MB/PID'	x	
		procUnitSys	Entity	'MB/TransferFunction	'x	
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Different Parameters can be set



Prune & Flatten for feedforward=0

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Flattened PES for feedforward=0

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O incompletely pruned PES	Verexp Entit	t x	1 PARAMVARY1 "ctrlPIDSys.k=[1,5]" template:
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	e ctrlPIDSys Entit	'MB/PID' x	
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	sourceDist Entit	'MB/Step' x	
	tfDist Entit	'MB/TransferFunction' x	
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Selection Constraints			Coupling
SES Functions	<	>	Specrule

Save Flattened PES for feedforward=0



Open Flattened PES in SESMoPy

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Add MB in Modelfolder & Build Model

🗭 SESMoPy - SES Model B	uilder in Python3 / Py	Qt5	_	- 🗆 X		
SESMoPy - SES Model Builder for Python						
Select an FPES JSON / XML File	Select an FPES JSON / XML File Open FPES File C:/Users/Win10/Desktop/modeltest/Feedback_FPES.jsonsestree					
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Created Models



Load MB

Open Created Models in OpenModelica &



Model & Setup Simulation in OpenModelica

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Restart After Event			
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Maximum Step Size:	v		
Save experiment annotation inside model SaveOpenModelica_simulationFlags annotation inside model Simulieren O	Abbrechen		

OpenModelica Simulation Results





SESMoPy Documentation

SESMoPy - SES Model Builder in Python3 / PyQt5	—		×
SESMoPy - SES Model Builder for Python			
Select an FPES JSON / XML File 🔄 Open FPES File			
illo Build Model	1	Documer	ntation
Status:			

• See the documentation for more information

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 - Simulators are domain specific
 - Verify simulator correctness

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- Native model building using a simulator dependent MB
 - > Needs **one** MB for **each** simulator (error prone and costly to maintain)
 - Needs specific model builders, because simulators are different (syntax and semantics such as port names, block parameters, ...)
- Goal: One (simple) MB and model builder for all simulators



¹Blochwitz et al. (2011) "The Functional Mockup Interface for Tool independent Exchange of Simulation Models". Proc. of the 8th Modelica Conference, Dresden.

• FMI defines a standardized interface of components (models, blocks)

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- FMI defines a standardized interface of components (models, blocks)
 - Reuse of components
 - (i) For model exchange
 - ≻ (ii) For co-simulation

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 - (ii) For co-simulation
 - Based on C code or binaries
 - Many simulators support FMI
 - Still problems for discrete event models

- ¹Blochwitz et al. (2011) "The Functional Mockup Interface for Tool independent Exchange of Simulation Models". Proc. of the 8th Modelica Conference, Dresden.
- ²Blochwitz et al. (2012) "Functional Mockup Interface 2.0: The Standard for Tool independent Exchange of Simulation Models". Proc. of the 9th Modelica Conference, Munich.





Component implementing FMI = Functional Mock-up Unit (FMU) a zipped file with fileextension .fmu

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Model Exchange



Figure taken from the FMI presentation on the website www.fmi-standard.org.



• Idea: Using FMI for model exchange

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 - > Export basic models as FMUs from any simulator to create simulator-independent MB

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Model Building – Support Different Simulators Using FMI

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 - > Export basic models as FMUs from any simulator to create simulator-independent MB
 - Model generation (build):
 - Import and configure FMUs from MB and create couplings in OpenModelica
 - Export the configured model as one FMU
 - Import model FMU in the target simulator



















• Create simulator specific instructions on how to execute the model FMU



- Create simulator specific instructions on how to execute the model FMU
- Simulink models can be created and manipulated with a Matlab script → "Simulation Model Representation" (SMR)



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Case Study with FMI



- FMI-based approach implemented in SESMoPy
- Flattened PES for the FMI-based case study in the examples/Example03_FeedbackControl_FMI directory of SESMoPy: Feedback_FPES.jsonsestree
- Usage of SESMoPy as presented before

Matlab

. . .









Generated Model in OpenModelica



Case Study: Model FMU Imported in MATLAB/Simulink





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Source: Pawletta, T. and Folkerts, H. (2023). Model Behavior Generation for Multiple Simulators (Section 18.6). InBook: SCS MSBoK Guide - Body of Knowledge of Modeling and Simulation Guide. T. Ören, B.P. Zeigler, A. Tolk (Eds.).



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Automation of Case Study: Control Goals





Code in Experiment Control

- Code in Experiment Control
 - > Try without a feedforward control:
 - feedforward=0 simulate with PID: k=1, Ti=1, Td=0
 - feedforward=0 simulate with PID: k=5, Ti=0.5, Td=0

- Code in Experiment Control
 - > Try without a feedforward control:
 - feedforward=0 simulate with PID: k=1, Ti=1, Td=0
 - feedforward=0 simulate with PID: k=5, Ti=0.5, Td=0
 - If the goals are reached with one of these configurations:
 - Return PID configuration as overall result

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 - > Try without a feedforward control:
 - feedforward=0 simulate with PID: k=1, Ti=1, Td=0
 - feedforward=0 simulate with PID: k=5, Ti=0.5, Td=0
 - If the goals are reached with one of these configurations:
 - Return PID configuration as overall result
 - Else try with a feedforward control:
 - feedforward=1 simulate with both PID configurations

- Code in Experiment Control
 - > Try without a feedforward control:
 - feedforward=0 simulate with PID: k=1, Ti=1, Td=0
 - feedforward=0 simulate with PID: k=5, Ti=0.5, Td=0
 - If the goals are reached with one of these configurations:
 - Return PID configuration as overall result
 - Else try with a feedforward control:
 - feedforward=1 simulate with both PID configurations
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 - > Try without a feedforward control:
 - feedforward=0 simulate with PID: k=1, Ti=1, Td=0
 - feedforward=0 simulate with PID: k=5, Ti=0.5, Td=0
 - If the goals are reached with one of these configurations:
 - Return PID configuration as overall result
 - Else try with a feedforward control:
 - feedforward=1 simulate with both PID configurations
 - If the goals are reached with one of these configurations:
 - Return PID configuration as overall result
 - ≻ Else:
 - Return goals cannot be reached with these configurations / parameters

- Code in Experiment Control
 - > Try without a feedforward control:
 - feedforward=0 simulate with PID: k=1, Ti=1, Td=0
 - feedforward=0 simulate with PID: k=5, Ti=0.5, Td=0
 - If the goals are reached with one of these configurations:
 - Return PID configuration as overall result
 - Else try with a feedforward control:
 - feedforward=1 simulate with both PID configurations
 - If the goals are reached with one of these configurations:
 - Return PID configuration as overall result
 - Else:
 - Return goals cannot be reached with these configurations / parameters

Starting over with another simulator possible (model by model validation)

Case Study: Simulation Results



Case Study: Simulation Results



Outline

- 1. Case study
- 2. Implementation of the SES and an MB
- 3. Model selection and model generation
- 4. Organization of a simulator-independent MB
- 5. Full automation of simulation experiments
- 6. Summary



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