

Contents

1	Introduction	1
1.1	The RailCab System	2
1.2	Problem Statement	3
1.3	Contribution	7
1.4	Overview	9
2	Foundations	11
2.1	Self-Adaptive Mechatronic Systems	11
2.1.1	Structuring	11
2.1.2	Operator-Controller-Module	12
2.1.3	Models@Runtime	14
2.2	Timed Model Checking	14
2.2.1	Timed Automata	15
2.2.2	Timed Computation Tree Logic	18
2.2.3	Model Checking Procedure	19
2.3	Graph-Based Specifications	19
2.3.1	Typed Attributed Graph Transformations Systems	20
2.3.2	Story Driven Modeling	22
2.4	MechatronicUML	26
2.4.1	Real-Time Coordination Protocols	26
2.4.2	Real-Time Statecharts	27
2.4.3	Assumptions on Quality-of-Service Characteristics	31
3	MechatronicUML Component Model	33
3.1	Modeling Components	34
3.1.1	Ports	35
3.1.2	Atomic Components	38
3.1.3	Structured Components	41
3.1.4	Connectors	45
3.1.5	Component Properties	46
3.2	Component Instances	46
3.3	Modeling Reconfiguration	49
3.3.1	Component Story Diagrams	50
3.3.2	Controller Exchange Nodes	51
3.3.3	Constraints for Multi Port Variables	52
3.3.4	Reconfiguration of Atomic Components	55
3.4	Instantiating Real-Time Coordination Protocols on System Level	56
3.4.1	Instantiating the RTCP ProtocolInstantiation	57

3.4.2	The RTCP ProtocolInstantiation	58
3.5	Modeling Component Properties by Architectural Constraints	61
3.6	Implementation	65
3.7	Related Work	66
3.7.1	Software Component Models	66
3.7.2	ADLs for Self-Adaptive Systems	68
3.7.3	Constraint Languages	68
3.8	Summary	70
4	Transactional Execution of Hierarchical Reconfigurations	71
4.1	MechatronicUML Reconfiguration Controller	73
4.2	Executing Reconfigurations	75
4.2.1	Single-Phase Execution	76
4.2.2	Three-Phase Execution	77
4.2.3	Quiescence	81
4.3	Declarative, Table-based Specification of the Reconfiguration Controller	84
4.3.1	Interface Specification of RM Ports	85
4.3.2	Manager Specification	85
4.3.3	Executor Specification	87
4.3.4	Interface Specification of RE Ports	88
4.4	Generating Operational Behavior Specifications	89
4.4.1	Manager Specification	89
4.4.2	Executor Specification	93
4.5	Verifying the Reconfiguration Specification	99
4.5.1	Consistency	101
4.5.2	Timing	102
4.6	Implementation	106
4.7	Assumptions and Limitations	107
4.8	Related Work	107
4.8.1	Approaches Supporting Reconfiguration of Hierarchical Components	107
4.8.2	Quiescence of Components	109
4.9	Summary	110
5	Verifying Refinements based on Test Automata	111
5.1	Refining Real-Time Coordination Protocols to Port Implementations	114
5.1.1	Real-Time Coordination Protocol EnterSection	114
5.1.2	Refined Port Real-Time Statecharts	115
5.2	Considered Refinement Definitions	118
5.3	Test automata-based Refinement Checking	123
5.3.1	Refinement Selection	124
5.3.2	Construction of the Test Automaton	125
5.3.3	Adjusting the Port Real-Time Statechart	131
5.3.4	Parallel Composition and Reachability Analysis	132
5.4	Implementation	132
5.5	Assumptions and Limitations	134

5.6	Case Study	134
5.6.1	Case Study Context	134
5.6.2	Setting the Hypothesis	134
5.6.3	Preparing the Input Models	135
5.6.4	Validating the Hypothesis	135
5.6.5	Analyzing the Results	137
5.7	Related Work	138
5.7.1	Refinement Checking	138
5.7.2	Test automata-based Verification	138
5.8	Summary	139
6	Simulating Self-Adaptive Mechatronic Systems in MATLAB/Simulink	141
6.1	MATLAB/Simulink and Stateflow	143
6.1.1	Simulink	143
6.1.2	Stateflow	144
6.2	MIL Simulation of MechatronicUML Models in Simulink and Stateflow . . .	146
6.3	Translating Component Instance Configurations to Simulink Block Diagrams	149
6.3.1	Translating Atomic Component Instances	149
6.3.2	Translating Structured Component Instances	153
6.3.3	Using Message-Based Communication	157
6.3.4	Considering QoS Assumptions	159
6.4	Translating Real-Time Statecharts to Stateflow Charts	160
6.4.1	Basic Transformation Concepts	160
6.4.2	Message-Based Communication	162
6.4.3	Clock Concept	163
6.4.4	Urgency	165
6.4.5	Real-Time Statecharts of Multi Port Instances	165
6.4.6	Synchronizations	166
6.5	Translating Reconfiguration Specifications to Simulink and Stateflow	170
6.5.1	Step 1: Compute Possible Configurations	170
6.5.2	Step 2: Create Integrated CIC for Component	172
6.5.3	Step 3: Generate the MATLAB-specific Reconfiguration Controller	172
6.5.4	Step 4: Encode Configurations and Generate Control Signals	178
6.5.5	Step 5: Create Integrated System CIC	180
6.5.6	Integrate MATLAB-specific reconfiguration controller into the Si- mulink Block Diagram	180
6.5.7	Realizing Port Reconfiguration in Stateflow Charts	182
6.6	Implementation	183
6.7	Limitations	184
6.8	Case Study	185
6.8.1	Case Study Context	186
6.8.2	Setting the Hypothesis	187
6.8.3	Preparing the Input Models	187
6.8.4	Validating the Hypothesis	188
6.8.5	Analyzing the Results	188

6.9	Related Work	189
6.9.1	Reconfiguration in MATLAB/Simulink	189
6.9.2	Reconfiguration in other Simulation Environments	189
6.9.3	Reconfiguration in AUTOSAR 3.x	190
6.9.4	Hybrid Verification	190
6.10	Summary	191
7	Conclusions	193
7.1	Summary	193
7.2	Future Work	195

Appendix

A	Complete RailCab Example	199
A.1	RTCPs	199
A.1.1	ConvoyEntry	200
A.1.2	ConvoyCoordination	202
A.1.3	ProfileDistribution	203
A.1.4	SpeedTransmission	207
A.1.5	StartExecution	208
A.1.6	StrategyExchange	209
A.1.7	NextSectionFree	210
A.2	Instantiating Real-Time Coordination Protocols on System Level	211
A.2.1	A Simple Discovery Protocol and Environment Model	211
A.2.2	Instantiating the RTCP ProtocolInstantiation	215
A.2.3	The RTCP ProtocolInstantiation	217
A.3	Components	219
A.3.1	RailroadCrossing	219
A.4	Component Instances	220
A.4.1	RailCab Driving as a Coordinator	220
A.4.2	RailCab Driving as a Member	222
A.5	Component RTSCs	224
A.5.1	RTSCs of the RailCab Components	224
A.5.2	RTSCs of the Section Components	234
A.6	Reconfiguration Behavior Specification of Components	238
A.6.1	Declarative, Table-based Reconfiguration Specification	238
A.6.2	Reconfiguration Rules	242
A.6.3	Generated RTSCs for Manager and Executor of RailCabDriveControl	252
A.6.4	Specification of the Executor Operations	258
A.7	Component SDDs	266
A.7.1	RailCabDriveControl	266
A.7.2	ConvoyCoordination	267
A.7.3	VelocityController	267
A.7.4	OperationStrategy	272
A.7.5	RefGen	272

A.8	Excerpt of Generated MATLAB/Simulink Model	274
A.8.1	Simulink Model for Atomic Component Instance of Type RefGen	274
A.8.2	Simulink Model for Structured Component Instance of Type Con- voyCoordination	275
B	Formalization of the Real-time Statechart Semantics	283
C	A Framework for Reachability Analyses	289
C.1	Reachability Analysis Framework	290
C.1.1	Metamodel	290
C.1.2	Reachability Analysis Algorithm	291
C.2	Story Diagram Reachability Analysis	293
C.2.1	Metamodel Extension	293
C.2.2	Functions of the Reachability Analysis	294
C.3	RTSC Reachability Analysis	298
C.3.1	Metamodel Extension	298
C.3.2	Functions of the Reachability Analysis	299
C.4	UDBM Library	299
D	Metamodels	301
D.1	MechatronicUML Component Model	301
D.1.1	Core	301
D.1.2	Components	304
D.1.3	Component Instances	304
D.1.4	Runtime Model	307
D.2	MechatronicUML Reconfiguration	309
D.2.1	Reconfigurable Components	309
D.2.2	Component Story Patterns	311
D.2.3	Component Story Diagrams	314
D.2.4	Component Story Decision Diagrams	316
D.3	MATLAB/Simulink and Stateflow	317
D.3.1	Simulink	317
D.3.2	Stateflow	319
D.3.3	Message-Based Communication	321
D.3.4	Reconfiguration	322
	Own Publications	323
	Supervised Thesis	331
	Literature	333
	List of Abbreviations	373
	List of Figures	375