

Contents

1	Introduction	1
1.1	Motivation	2
1.2	Framework of this Thesis	4
1.3	Structure of this Thesis	8
2	Basic Principles	9
2.1	Technologies for studying Behavior	10
2.2	Plants	11
2.3	Controllers	12
2.3.1	IEC 61131-3	12
2.3.2	IEC 61499-1	14
2.4	System Models	14
2.4.1	Syntax	15
2.4.2	Semantics	20
2.5	Basics of Specifications	23
2.5.1	Computation Tree Logic	23
2.5.1.1	Syntax	24
2.5.1.2	Semantics	25
2.5.1.3	Equivalences	26
2.5.1.4	Rules Of Precedence	26
2.5.2	Extended Computation Tree Logic	27
2.5.2.1	Syntax	27
2.5.2.2	Semantics	28
2.5.3	Timed Computation Tree Logic	29
2.5.3.1	Syntax	29
2.5.3.2	Semantics	30
2.5.4	Symbolic Timing Diagrams	30
2.6	Closed-Loop Composition	32
2.7	Model Checking	35
2.7.1	General Remarks	35
2.7.2	Model Checking Algorithm	36
2.8	Summary	38

3	Formal Modeling of Plant, Controller, and the Closed Loop	39
3.1	Demonstration Example	40
3.2	Formal Plant Modeling	42
3.2.1	Modeling of Components	43
3.2.2	Semi-Automatic Model Generation	49
3.3	Formal Controller Modeling	54
3.3.1	Controller Modeling	55
3.3.2	Model Generation	60
3.4	Formal Closed-Loop Modeling	63
3.5	Summary	64
4	Specification	65
4.1	Safety-Oriented Technical Language	66
4.1.1	Syntax	67
4.1.2	Semantics	68
4.1.3	Compiler for SOTL	69
4.2	Symbolic Timing Diagrams	71
4.2.1	Modifications	72
4.2.2	Translation	73
4.2.3	STD Editor	74
4.3	Summary	78
5	Analysis of the Closed-Loop Behavior	79
5.1	Simulation in Closed Loop	79
5.1.1	Hardware-In-The-Loop Simulation	80
5.1.2	Software-In-The-Loop Simulation	86
5.2	Verification in Closed Loop	86
5.2.1	Hardware-In-The-Loop Verification	87
5.2.1.1	General Remarks	87
5.2.1.2	Case Study	90
5.2.2	Software-In-The-Loop Verification	97
5.2.2.1	General Remarks	97
5.2.2.2	Case Study	99
5.2.3	Limits of Verification	102
5.3	Summary	103
6	Conclusion and Outlook	105
6.1	Conclusion	105
6.2	Outlook	107
A	Temporal Logics	109

B SOTL Grammar	111
C Algorithms	113
D Example for Model Checking	117
Bibliography	121
Index	127
Curriculum Vitae	129