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Abstract

The engineering challenges in Systems of Systems(SoS) are in the focus of many research and innovation efforts as these systems are believed to have become the next generation of technical systems which will offer more efficient operation by making use of extensive information exchange between their constituent systems.

This thesis presents a Modelica-based simulation and validation framework (SVF) that supports the development of distributed control and optimization algorithms of systems of systems by providing a structured, plug-and-play approach for the validation of such algorithms on simulation models of SoS. The framework offers standardized interfaces to which simulation models and control and optimization algorithms that are implemented in different formalisms can be connected. A key element is that in the framework the validation models which represent the real system and models used in the algorithms can be different. The ready-to-use SoS simulation model, i.e. the set of validation models and controller components which are connected by standardized interfaces is generated automatically by a model generator module. To that end, an XML-based configuration file which includes detailed information about the information exchange structure between the validation models and the control and optimization algorithms provides the required information for the model generation step.

The SVF supports control and optimization algorithms written in C, Python and MATLAB. Besides validation models written in Modelica, models from modeling and simulation tools that are supported by the Functional Mock up Interface (FMI) can be integrated into the framework by co-simulation. The capabilities of the SVF are demonstrated on four use cases, two of which come from the process industries.

Kurzfassung

Die Herausforderungen des Engineerings von Systems of Systems (SoS) stehen im Mittelpunkt vieler Forschungs- und Innovationsbemühungen, da angenommen wird, dass solche Systems die nächste Generation technischer Systeme sind, die einen effizienteren Betrieb realisieren, indem sie einen umfassenden Informationsaustausch zwischen ihren den Komponenten des Systems nutzen.

Diese Arbeit stellt ein Modelica-basiertes Simulations- und Validierungs-Framework (SVF) vor, das die Entwicklung verteilter Steuerungs- und Optimierungsalgorithmen unterstützt, indem es einen strukturierten Plug-and-Play-Ansatz für die Validierung solcher Algorithmen auf Simulationsmodellen von SoS bereitstellt. Das Framework bietet standardisierte Schnittstellen, über die Simulationsmodelle und Steuerungs- und Optimierungsalgorithmen gebunden können. Ein wesentliches Element ist, dass die Validierungsmodelle, die das reale Verhalten der Komponenten repräsentieren und die in den Algorithmen genutzten Modelle unterschiedlich sind. Das vollständige SoS-Simulationsmodell (bestehend aus den Validierungsmodellen und den Algorithmen, die über standardisierte Schnittstellen verbunden sind) wird von einer Modellgeneratorsoftware erstellt. Zu diesem Zweck stellt eine XML-basierte Konfigurationsdatei, die detaillierte Informationen über die Struktur des Informationsaustauschs zwischen den Validierungsmodellen und den Algorithmen enthält, die erforderlichen Informationen für die automatische Modellgenerierung bereit.

Das SVF unterstützt Steuerungsalgorithmen, die in C, Python und MATLAB implimentiert sind. Neben in Modelica implementierten Modellen können Validierungsmodelle aus anderen Modellierungs- und Simulationswerkzeugen, die vom Functional Mock up Interface (FMI) von Modelica unterstützt werden, durch Co-Simulation in das Framework integriert werden. Die Leistungsfähigkeit des SVF wird anhand von vier Anwendungsbeispielen demonstriert, von denen zwei verfahrenstechnische SoS betreffen.

Publications

This dissertation is based on the following publications and technical reports. The occurrence of each publication or technical report in this dissertation is mentioned below.

Publications in Conference Proceedings

Nazari, S.; Sonntag, C.; Engell, S. A Modelica-based Modeling and Simulation Framework for Large-scale Cyber-physical Systems of Systems, IFAC-PapersOnLine 2015, 48 (1).

(The information in chapter 4 and the figure 4.1 are adapted from this paper.)

Kampert, D.; Nazari, S.; Sonntag, C.; Epple, U.; Engell, S. A Framework for Simulation, Optimization and Information Management of Physically-Coupled Systems of Systems, IFAC-PapersOnLine 2015, 48 (3), 1553-1558.

(The information in section 4.6 is adapted from this paper.)

Nazari, S.; Sonntag, C.; Stojanovski, G.; Engell, S. A Modelling, Simulation, and Validation Framework for the Distributed Management of Large-scale Processing Systems, Computer Aided Chemical Engineering (Proceedings of 12th International Symposium on Process Systems Engineering and 25th European Symposium on Computer Aided Process Engineering), 2015, Volume 37, 269-274.

(The case study in section 7.1 is used from this paper.)

Paulen, R.; Nazari, S.; Shahidi, S.A.; Sonntag, C.; Engell, S. Primal and Dual Decomposition for Distributed MPC - Theory, Implementation, and Comparison in a SoS Simulation Framework, 24th Mediterranean Conference on Control and Automation (MED), 2016, 286-291.

(The implementation of primal decomposition on a 4 tank benchmark in the SVF in section 7.4 is used from this paper.)

Nazari, S.; Wenzel, S.; Maxeiner, L.S.; Sonntag, C.; Engell, S. A Framework for the Simulation and Validation of Distributed Control Architectures for Technical Systems of Systems, IFAC-PapersOnLine 2017, 50 (1), 12458- 12461.

(The case studies in section 7.1 and section 7.2 are used from this paper.)

Trotha, C. v.; Nazari, S.; Sonntag, C.; Beisheim, B.; Krämer, S.; Engell, S.; Epple, U. Betrachtung eines chemischen Verbundstandorts als System of Systems zur dezentralen

Optimierung - Das notwendige Informationsmanagement, Automation 2017 , page 139 - 140

(The case study in section 7.1 and the figure 7.1 are adapted from this paper.)

Technical Reports

Kampert, D.; Nazari, S.; Sonntag, C.; Epple, U.; Engell, S. DYMASOS Engineering Concept Specification, Technical Report D4.1, DYMASOS, 2014.

(The information in chapter 4 is adapted from this report.)

Nazari, S.; Sonntag, C.; Engell, S. Report on Modelica Extensions for the Specification of Distributed Optimization Problems, Technical Report D4.2, DYMASOS, 2015.

(The information in chapter 6 (in particular figure 6.1), the configuration information in chapter 5 and the XML configuration file in appendix B are used from this report.)

Nazari, S.; Sonntag, C.; Engell, S. Integration of SoS methods including methods developed in WPs 1 to 3; prototype software framework, Technical Report D4.4, DYMASOS, 2016.

(The information in chapter 6, in particular figures 6.3 and 6.4, are used from this report.)

Trotha, C. v.; Elfahaam, H.; Nazari, S.; Sonntag, C.; Engell. Validation Report on the Engineering Tool Set, Technical Report D4.6, DYMASOS, 2016.

(The information in sections 7.1, 7.2, 7.3 and 7.4 are based on this report.)

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