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ScienceDirect

Procedia Technology 15 (2014) 46 – 53

Procedia Technology

2nd International Conference on System-Integrated Intelligence: Challenges for Product and Production Engineering

Method to identify dependability objectives for use in multiobjective optimization problem

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Abstract

Intelligent mechatronic systems, such as self-optimizing systems, allow an adaptation of the system behavior at runtime based on the current situation. To do so, they generally select among several pre-defined working points. A common method to determine working points for a mechatronic system is to use model-based multiobjective optimization. It allows finding compromises among conflicting objectives, called objective functions, by adapting parameters. To evaluate the system behavior for different parameter sets, a model of the system behavior is included in the objective functions and is evaluated during each function call. Intelligent mechatronic systems also have the ability to adapt their behavior based on their current reliability, thus increasing their availability, or on changed safety requirements; all of which are summed up by the common term dependability. To allow this adaptation, dependability can be considered in multiobjective optimization by including dependability-related objective functions. However, whereas performance-related objective functions are easily found, formulation of dependability-related objective functions is highly system-specific and not intuitive, making it complex and error-prone. Since each mechatronic system is different, individual failure modes have to be taken into account, which need to be found using common methods such as Failure-Modes and Effects Analysis or Fault Tree Analysis. Using component degradation models, which again are specific to the system at hand, the main loading factors can be determined. By including these in the model of the system behavior, the relation between working point and dependability can be formulated as an objective function. In our work, this approach is presented in more detail. It is exemplified using an actively actuated single plate dry clutch system. Results show that this approach is suitable for formulating dependability-related objective functions and that these can be used to extend system lifetime by adapting system behavior.

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Peer-review under responsibility of the Organizing Committee of SysInt 2014.

Keywords: Self-optimization, multiobjective optimization, objective function, dependability, intelligent system, behavior adaptation

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Peer-review under responsibility of the Organizing Committee of SysInt 2014.
doi:10.1016/j.protcy.2014.09.033

1. Introduction

Self-optimizing mechatronic systems are able to autonomously adapt their behavior if the user requirements or operating conditions change [1]. To this end, the current situation is monitored and the objectives of the system are determined. Using model-based multiobjective optimization, for which a model of the behavior of the system is used, optimal system configurations are calculated before operation of the system. To adapt the system behavior during operation, the self-optimizing system sets its working point by selecting or interpolating the working point from these pre-calculated optimal system configurations. These concepts and structures were successfully employed e.g. for mechatronic systems such as a hybrid energy storage system [2] or for manufacturing systems [3].

While the adaptation process opens up new ways of system usage, e.g. by changing the responsiveness according to individual user demands, it also comes at the expense of additional complexity. This complexity increases the risk of failures and can degrade system dependability [4]. At the same time, the adaptation capabilities can be used advantageously by actively increasing system dependability if it is critical. According to [5], dependability comprises several attributes: Reliability and in turn availability, which is also influenced by maintainability, but also integrity and safety. For mechatronic systems, those attributes that are influenced most effectively are reliability and safety. By improving reliability, maintenance planning is greatly simplified, thus availability is increased by avoiding unscheduled maintenance actions.

To adapt the system behavior advantageously with regard to system dependability, it has to be possible to lower loading factors on critical components such as work load or wear by selecting appropriate optimal system configurations. Thus it is also necessary to include system degradation in the objective functions used for the multiobjective optimization. However, the identification of necessary objective functions is currently the responsibility of the developing engineers. At present, there is no clearly defined procedure or method to guide them. The proposed method can be used to structure this process of identifying dependability-related objective functions.

The remainder of the paper is structured as follows: It begins with a more concise introduction to the behavior adaptation process, the adaptation based on dependability using the Multi-Level Dependability Concept and the required multiobjective optimization. Section 2 introduces the proposed method and the five steps required for conducting it before section 3 resumes with a practical example. The application of the proposed method to an actively actuated single plate dry clutch is shown. The paper ends with a short discussion of the results and a conclusion.

1.1. Self-optimizing systems and Multi-Level Dependability Concept

A self-optimizing system is capable of adapting its behavior to changed environmental conditions or changes in system requirements. To do so, it continuously cycles through three actions: 1. Analyze current situation, 2. Determine system objectives, 3. Adapt system behavior [1].

In the first action, the current state of the system is taken into account. In order to use self-optimization to increase system dependability, methods such as condition monitoring are required. This action serves to identify the current compliance to the given objectives. In the second action, the system objectives are selected, generated or adapted. These objectives are quantified, i.e. not only whether they should be pursued is known but also to what extent or whether some of them are more important than other ones. The third action is to adapt the system behavior. During this action, the objectives from action 2 are taken into account and system parameters are selected. Then they are set on machine control level and the cycle starts again.

When using self-optimization to increase the dependability of intelligent mechatronic systems, the three actions need to take dependability into account. For this, the Multi-Level Dependability Concept was developed [6]. It classifies the current system state into four discrete levels, of which the first two represent a (partially) usable system whereas level 3 already engages emergency mechanisms to keep the system safe and running and level 4 equates to a fail-safe state, e.g. an emergency shutdown. In levels 1 and 2, system behavior adaptation to increase dependability is possible. For this, the Multi-Level Dependability Concept relies on the system being able to adapt its behavior to allow for more dependable system behavior. To enable the system to do so, dependability as objective of the system needs to be taken into account during early product development phases.

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