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Reconfiguration of smart products during their use phase based on virtual product twins

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ABSTRACT

Recent ICT innovations have begun to dramatically change traditional products towards intelligent, connected Smart Products. These product-related changes inevitably imply the need for radically new engineering processes. Product development will no longer solely concentrate on the early phase of product lifecycles but also on the product use phase. Here, especially the reconfiguration of products during their use phase across different engineering domains will be a core challenge. This paper introduces a conceptual approach for the reconfiguration of Smart Products, which considers dynamical, virtual models of each real product instance using the concept of virtual product twins and an Internet of Things platform. The conceptual approach is prototypically demonstrated by considering a model environment for smart cars, which are temporarily reconfigured during their use phase.

1. Introduction

Recent innovations in the field of information and communication technologies (ICT) have begun to dramatically change traditional products towards Smart Products (SP). Smart Products are defined as intelligent multidisciplinary products capable to communicate and interact with their environment and other Smart Products by using Internet-based services [1]. One of the best known example for a Smart Product in the consumer sector is the smart phone. Likewise, Smart Products arise more and more in all industrial areas, such as manufacturing (i.e., smart machines, smart robots, smart factories), mobility (i.e. smart car, self-driving vehicles), logistics (i.e. smart packagers, smart containers), healthcare (i.e. smart clothes, smart hospitals) and energy (i.e. smart energy grid).

Besides their Internet connectivity, main characteristics of Smart Products are a high degree of personalization and autonomy, a large number of multidisciplinary components, their ability to react in real-time and their dynamic reconfiguration during the whole lifetime [4,5]. These characteristics of Smart Products simultaneously determine a dramatic necessity for changes of traditional engineering lifecycle processes. Offering Smart Products requires the development and management of new business models, which lead to increasing responsibilities for the product manufacturing companies across the entire product lifecycle (e.g. product as a service or multi-sectorial business models) [10,12]. The Internet-based connectivity enables Smart Products to interact with cloud platforms and other Smart Products permanently. It also enables manufacturers to technically access a huge amount of usage data generated by every physical Smart Product instance. In this context, fundamental new potentials for IT-based product reconfiguration are emerging. In particular, the high amount of functionalities, which are realized by software components and Internet-based services in combination with the connectivity capabilities of Smart Products, provides enormous potentials for multiple reconfigurations of Smart Products during their use phase. For example, functionalities of a smart car can be enhanced by adding Internet-based parking services during the product operation.

In a previous contribution in the CIRP Annals 2016 we already presented a semantic data management approach for continuous product development and reconfiguration considering heterogeneous lifecycle data of a smart, self-driving car like for example a Tesla Model S [2]. This paper bases on follow-up research activities in the field of Smart Product reconfiguration.

2. Product configuration vs. smart product reconfiguration

Reconfiguration in general is described as a modification of an already existing product instance to meet new requirements [11]. In the context of Smart Products, reconfiguration processes during the product use phase primarily pursue the following types of goals:

- general technical improvements for product classes (e.g. new software releases for a smart car generation)
- individual runtime upgrades providing additional functionalities (e.g. IT-based parking assistant system for a smart car) or IT-services (e.g. cloud services for individually optimized energy management for a smart car)

In order to enable methodical Smart Product reconfigurations existing product configuration approaches aiming at the generation of initial customer specific virtual product models

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can serve as conceptual basis. The normative standard ISO 10007 defines configuration units, which in turn are entities within a configuration that provide specific end use function. This configuration units are subject to a configuration management model that also contains a change control module for reconfiguring a specific configuration [9]. However, a configuration management covering the entire product lifecycle is only possible as long as product instances can be managed. This applies as well for product configurators that aim at the mass customization of products. They define a rule-based system for compatibilities between configuration units that needs to be maintained and extended continuously [16]. The standard IEC 61499 defines function blocks that describe control unit configurations with a focus on (agile) manufacturing systems [7]. This methodical approach has been enhanced in several research works by addressing electronic or software centred product reconfiguration issues [9,14].

Since smart cars can serve as a representative example for a very complex, already commercialized Smart Product which is also part of cross sectoral smart systems (like smart energy systems), reconfiguration processes of smart cars have been analyzed in detail to identify important requirements on a Smart Product reconfiguration approach. In contrast to the above-mentioned approaches for an initial, customer specific configuration of virtual product model variants based on modular product structures a Smart Product configuration additionally requires

- a continuous development and enhancement of product models including their compatibility to previous product model versions which are already in their operation phase.
- a permanent individual management of each product instance across all engineering domains involved including its specific history.
- a synchronization of initial virtual product configuration models (initial customer orders) and multiple reconfigured variants of product instances.
- a continuous development and update of ex post configuration knowledge (e.g. rules and constraints) for all physically existing product instances.
- an integration of external service providers involved during the use phase of Smart Products.

3. Smart Product reconfiguration approach

In order to meet these requirements, the Smart Product reconfiguration approach introduced in this section has been developed by considering a concrete model environment for the reconfiguration of smart cars. This approach bases on an engineering lifecycle model, which has been adapted according to the identified engineering changes determined by the transformation of products towards Smart Products mentioned in Section 1 (cf. Fig. 1).

Mainly these adaptions refer to an extended product development phase that no longer solely concentrates on the initial phase of the product lifecycle. Since the provider of Smart Products is involved in all lifecycle phases, product development and improvement becomes a continuous task covering the whole product lifecycle. Early stages of the Smart Product development lead to modular virtual product models and structures, which can serve as basis for the configuration of initial, customer specific product variants (as ordered). By finishing the manufacturing and delivery phase a cyclic process including the phases of Smart Product use, reconfiguration and remanufacturing begins.

3.1. Virtual product twin concept

In every stage of the Smart Product engineering lifecycle new versions of product models, based on previous product models versions of the concrete product instance are generated. In case of the configuration and the manufacturing stage especially product structure models (e.g. bills of materials) including references to a multitude of linked product models (e.g. product component meta

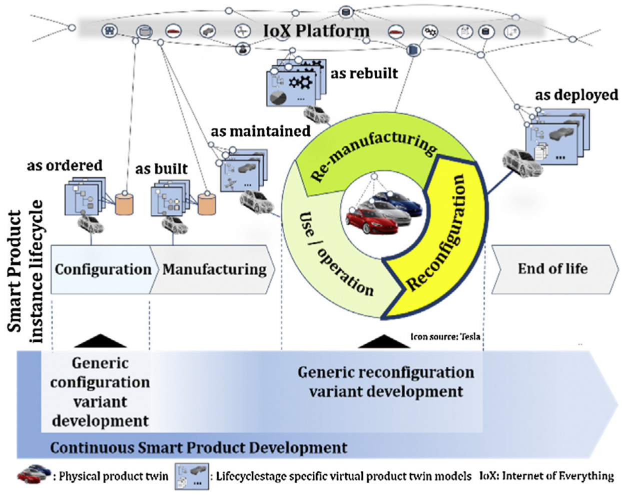

Fig. 1. Overview of the Smart Product reconfiguration approach.

data and CAD models) are generated. The cyclic downstream phases of the Smart Product instance lifecycle (use, reconfiguration and remanufacturing) rather focus on improvements of existing and extensions of new product components that are relevant for product reconfiguration and on extensions of specific product use data from physical product instances. Thus, new versions of the instance specific virtual product models are generated.

As a conceptual approach for the management of the above-mentioned product models and data of all virtual and physical product instances along the entire product lifecycle, the virtual product twin concept has been adapted and specified according to the requirements of Smart Product reconfiguration processes.

The term “virtual twin” was initially introduced in NASA’s technology roadmap “Modelling, Simulation, Information Technology & Processing” [13]. In the context of a Smart Product, the virtual twin can be considered as the notion where the data of each stage of the product lifecycle is transformed into information and is made seamlessly available to subsequent stages [15]. As every virtual twin along the entire product’s lifecycle has a physical twin, a separation between a virtual and a physical product lifecycle is necessary to differentiate what lifecycle data can be retrieved for the definition of the virtual product twin. In our approach, all data generated during the virtual product lifecycle and the physical product lifecycle are gathered in a virtual twin data space. It combines interdisciplinary (mechanics, electronics and informatics) models that have to be synchronized situationally with their respective physical twin. This integration allows context-specific decisions, for example reconfigurations like temporarily enabling an IT-service for the customer based on the product’s BOM, CAD data and software version [3].

3.2. Architectural approach of a reconfiguration platform

In order to enable reconfigurations of Smart Products during their use phase based on virtual product twins, an environment has been developed that allows the integration of all necessary product instance data with the reconfiguration options and the related reconfiguration rules. Fig. 2 shows the proposed approach for a cloud-based reconfiguration environment.

The reconfiguration platform comprises two main sections: Reconfiguration function modules that combine all operational units needed for the reconfiguration process and databases that provide the necessary data for the reconfiguration process.

Core of the database-section is the virtual product twin database. It allows the assignment of virtual product models and product condition data to one physical product instance via wireless connection with e.g. services as part of an Internet of Things (IoT) platform. Primary sources for the virtual product models are product lifecycle management (PLM) as well as enterprise resource planning (ERP) systems of the companies