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Hybrid Simulators for Product Service-Systems - innovation potential demonstrated on urban bike mobility

Boris Beckmann-Dobrev[a,*], Simon Kind[a], Rainer Stark[a,b]

[a]*Technische Universität Berlin, Pascalstraße 8-9, 10587 Berlin, Germany*
[b]*Fraunhofer IPK, Pascalstraße 8-9, 10587 Berlin, Germany*

* Corresponding author. Tel.: +49 30 39006 109; fax: +49 30 3930 246. E-mail address: bdobrev@mail.tu-berlin.de

Abstract

One major goal of the Rethinking Prototyping project is to bring scientists from different domains like engineering and arts to explore collaboratively new approaches of development and testing of Product Service Systems (PSS). PSS combine products, services, and infrastructure to fulfil individual customer needs. Therefore, the development of PSS is an extension of traditional engineering design process, which mainly refers to purely tangible products or intangible services into an integrated development process of products and services.
The basis is a new technology called Smart Hybrid Prototyping (SHP), a joint development by Fraunhofer IPK and the TU Berlin. SHP is an innovative technology for a multimodal interdisciplinary evaluation of virtual prototypes in early development stages. It is based upon methods of Mixed Reality extended by modern industrial technologies to allow natural interaction with virtual prototypes of mechanical or mechatronic systems. It serves as a bridge between physical reality and digital virtuality.
The use cases in this paper are based on urban bike mobility. Therefore, three concepts have been worked out to specify main requirements for an urban hybrid bike simulator. The first use case is from the perspective of a bicycle rental, where rental services for the users can be developed, validated, and optimized. The second use case provides the integration of mobile devices like smartphones and tablets for the development and validation of mobile services for bicyclists. The third use case is oriented on development and validation of new bicycles and urban mobility concepts like e-bikes, pedelecs, tripelecs and sharing services. Based on these generic use cases the requirements on a hybrid bicycle simulator were derived.
Why a bicycle simulator? Well, we are firmly convinced that the future of urban mobility is determined from trends such as ecological rethinking and the desire for sports and healthy life. Furthermore, it is one of the most competitive and agile markets using most innovative materials and manufacturing technologies.

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Keywords: Smart Hybrid Prototyping, Product Service-Systems, Rethinking Protototyping

1. Introduction

The increasing complexity of mechatronic systems facilitates the emergence of new technologies. Key companies and global players are working hard on their proprietary solutions. Dassault Systemes introduced in 2008 an integrated Systems Engineering approach within V6 called RFLP.[1,2] About the same time Siemens PLM introduced the Mechatronics Concept Designer (MCD) for the virtual rapid prototyping. [4,3] This and other new development technologies improve important steps within mechatronics design. However there is still a lack considering future services in combination with product development especially for mechatronic systems. [5,6]

Therefore, our motivation is to describe a novel approach for the design of Product Service Systems (PSS), where even complex mechatronic systems can be evaluated and optimized for future services.[7] In this context, a new technology is employed: Smart Hybrid Prototyping (SHP). The author's goal is to describe a development process using SHP in order to design and validate PSS. For this purpose an adaptation of the SHP technology is required. This is done on the example of urban bike mobility, the basis for our use cases.

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2. Fundamentals

2.1. Product Service-Systems and Smart Hybrid Prototying

Product Service-Systems are created to fulfill customer needs with respect to combine tangible products with intangible services. Major effort was spent in several research groups to adjust classical product development methods with service engineering approaches. [8]

Validation is a major aspect during product and service development and can ensure the quality of developed products and services. Up to now multiple methods and tools to validate the development of products exist in different stages of product development process. (e.g. functional mock-up, design reviews). Regarding service engineering also major efforts were spent in research for development and evaluation of services. [9,10] Several methods and tools already exist in this field, e.g. Service Blue-printing, questionnaires and simulation for evaluation of efficiency of developed services. [11,12] The major point of view in this area still is the concentration of evaluating existing services, rather than creating new integrated Product Service-Systems. [13,14] Especially in the field of validation of Product Service-Systems new approaches are needed to focus on the tangible product part but also on the evaluation of service activities. [15]

2.2. Understanding and Definition of SHP4PSS

To understand what Smart Hybrid Prototyping (SHP) is, the authors need to explain its background and history. The general design methodology splits the product development into several stages. [16,17] In the early stage of product creation digital representations called Digital Mock-up (DMU) are available. DMUs are mostly rigid geometrical representations of the future product. [18] A DMU can be extended within a simulation to a Functional Mock-up (FMU), so FMUs are DMUs which are extended by functional behaviors. [19] DMUs and FMUs can be visualized within Virtual Reality for Design Reviews and visual validation. A direct perceptibility especially of functionality is not given. [20,21]

SHP is a novel technology for interdisciplinary development and multimodal evaluation of virtual products. It is based upon methods of Virtual, Mixed and Augmented Reality and allows the experiencing of functional behaviors using hybrid prototypes. [22] For this purpose mechatronic parts are linked to a Virtual Environment and serve as a bridge between physical reality and digital virtuality. [23,24]

In order to develop, test and optimize PSS the presence of the product and its functionality is necessary. But even for existing products, that should be extended by new services, there are adjustments required. [25] SHP is suitable for this purpose because it combines the advantages of both Physical and Virtual Prototyping. The additional enrichment by Virtual, Mixed or Augmented Reality allows a realistic experience of future PSS by developers, stakeholders and end users. Thus, a comprehensive validation of product and service is possible.

2.3. Actors validating PSS with SHP

Main participants within product development process are the developers from different domains like mechanics, electrics, electronics and software, the decision makers, the stakeholders and end users or customers. For developers SHP provides a cross-domain platform and facilitates holistic solutions for inter-domain challenges. It facilitates the cooperation of experts from various disciplines and supports interdisciplinary solutions. At management level SHP can improve the understanding of executives for problems and challenges and support them in budget decisions so that potentials can be better recognized and supported. Customers can be also early involved in the development process, to perform product acceptance, ergonomics and usability studies.

3. Definition of Use Cases, Requirements identification and derivation of Test Cases

To close the gap between PSS and SHP development it is necessary to consider the following 3 dimensions: use cases definition specified by analysis of future business models, system requirements to involve identified customer needs and test cases for significant SHP4PSS validation. [Table 1]

Table 1: Definition of PSS use cases

Registration process:	Registration of a customer on a provider platform to sign contract and agree on rental conditions, based on cost model and business model of provider.
Booking process:	Process to rent a bike, declare availability, time scheduling and location
Check-In Check-Out:	Processes to collect and return a booked bicycle, technical unlocking and locking procedures and additional bike provision modalities
Driving simulation:	Realistic simulation of bike in use within virtual environment, providing a real driving experience
Navigation: (optional)	Assisting customer with navigation tools, providing infotainment and entertainment features, validation of user interaction
Defect: (optional)	Assisting customer within defect scenario, validation of customer support processes, manuals, repair and exchange processes

An adaption of Plug-In VR methodology [26] was used to connect PSS and SHP development. Originally Plug-In VR is used to enable the extension of product development by virtual reality technologies. Major advantages are the reduction of development time, inclusion of stakeholders and user-oriented visualization. Following Plug-In VR methodology three different phases need to be taken into account: configuration phase, implementation phase and operation phase. During configuration phase the previously defined use cases are analyzed to derive system requirements for the SHP development. Regarding PSS use cases in combination with identified requirements the system configuration can take place in the next step. The degrees of virtuality and reality and also levels of interaction and immersion are specified during system configuration phase.

Based on the analysis of product, service and Product Service-System components previously defined PSS use cases for urban bike rental were specified for SHP4PSS development. [27]

Starting with PSS use cases of a business model for urban bike rental and the corresponding processes the technical requirements for SHP development need to be identified. The Plug-IN VR methodology was used to identify the following system requirements: interaction, usability, perceptibility concerning the level of user experience and functional, visual and haptic validation to ensure significant results during SHP4PSS evaluation. These system requirements were matched with the previously defined PSS use cases to identify key factors for test case derivation [Table 2].

Table 2: Requirements evaluation of PSS use cases

	Interaction	Usability	Perceptability	Functional validation	Visual validation	Haptic validation
Registration	X	X		X		
Booking	X	X		X		
Check-In, Check-Out		X	X	X	X	
Driving simulation		X	X	X	X	X
Navigation (optional)	X	X		X	X	
Failure case (optional)	X	X		X		X

A special focus on SHP development needs to address the potential for validation and evaluation of Product Service-Systems. Concerning defined PSS use cases and identified system requirements the following SHP components for derived test scenarios were determined.

- **Physical components:** A real prototype for physical user interaction needs to be developed to fulfill functional and haptic requirements. Also a realistic perceptibility of driving experience needs to be supported.
- **Virtual components:** A digital model of a bicycle needs to be developed to increase the level of visual validation. Due to synchronization with physical components a high level of perceptibility and user interaction can be achieved.
- **Infotainment:** An application needs to be developed to realize user interaction for reservation, booking processes and additional use cases (navigation, defect). These are also subjected for functional validation and usability evaluation.
- **Environment:** To increase the level of perceptibility an adequate representation of targeted environment needs to be developed. A higher level of detail can extend the feeling of immersion during validation process.

4. Development of the SHP4PSS simulator

The development started with some conceptual prototypes using virtual 3D representations of some targets of interest for urban mobility like bicycles, pedelecs and tripelecs. In the first stage of our development a static virtual simulator was implemented consisting of a Smart Tripelec CAD model. The Smart Tripelec is a joint project of Fraunhofer IPK and TU Berlin. At this time there were several concepts of the Tripelec that had to be tested in order to choose and build the best one. The 3D geometry of the Smart Tripelec was visualized in the CAVE at Fraunhofer IPK Berlin. The virtual prototype is not interactive. The user can test basic visibility and ergonomics. [Figure 1]

Figure 1: Smart Tripelec validation in the CAVE

In the next stage a hybrid simulator is build. It consists of a physical mock-up for direct user interaction. The physical mock-up is coupled with a virtual environment which is implemented in Unity 3D engine. The user can drive and interact with the hybrid prototype. The visualization of the virtual environment is first realized by the use of Oculus Rift HMD later with a stereoscopic powerwall.

Figure 2: CAD of the hybrid simulator into a Virtual Environment

Figure 2 shows a CAD model of the hybrid prototype inside of a Virtual Environment. The construction on the backside of the bicycle is using pneumatic muscles from FESTO. They contract depending on the air pressure inside. This way the tilt of the bike simulator is realized. The rear wheel of the bicycle is coupled with a magnetic particle brake which generates the simulated resistance when driving and outputs as a haptic feedback to the user.

Figure 3: A smartphone app providing infotainment services

A main part of the hybrid simulator is the infotainment and entertainment app [Figure 3] which represents the most important interface for the planned services. Basic functionality of the app is to support the registration of the user. For the registration process a valid pay way is required, e.g. credit card, PayPal, Apple pay, etc. After registration the user can search, reserve and book a free rental bike. The app helps also customers to find the bike location and to perform the check out and check in of the product. Other services like billing, cost model or help and assistance can be integrated later.

Figure 4: 3D city models for realistic Virtual Environments

In the first stage, the visualization is realized using the Oculus Rift HMD. While the Oculus Rift is a VR HMD it obscures the real environment completely and the user needs some evidence. For this reason the real bike simulator is overlapped by a virtual representation in the Virtual Environment. The scene is built with Unity 3D and consists of the city models [Figure 4] and the bike model. The bike model is sensory coupled with the physical prototype, so basic interaction from the user like steering and cycling is reacted directly by the visualization

Other main part is the physical simulation which is also part of the Unity 3D environment. Basic user interactions like acceleration, bricking, steering and tilting is sensory coupled with the Unity simulation. Output actuators on the physical side provide haptic feedback to the user. Tilting is supported by pneumatic muscles from FESTO and cycling feedback is generated by magnetic particle brake.

Figure 5: The physical part of the hybrid bike simulator

In Figure 5, the simulator currently under construction is shown. The framework is implemented as a welded structure. The rear axle of the bicycle is coupled with the framework.

5. Outlook

The research and development project is in the final stage, which means that most of the interim results are available. The main components of the urban bike simulator are the Android app for mobile devices integration, the hybrid bicycle prototype as hardware device, the virtual environment and a bicycle simulation within Unity 3D. The visualization is running with a CAVE, a power wall and an Oculus Rift HMD. These components must be integrated into a demonstrator.

The future plan is to complete the demonstrator until end of 2014 and start with usability studies and other PSS evaluation activities at the beginning of 2015.

Objectives for 2015 are to find industry partners to test this new approach within a proof of concept project. Therefore, the authors will perform the SHP urban mobility simulator at fairs and other events.

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