CONFIGURING CUSTOMIZED PRODUCTS IN VR USING HMD

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Abstract: *Until recently the Virtual Reality (VR) and its related technologies, e.g. Augmented Reality, Mixed Reality etc., were often thought of separately. However, in the Industry 4.0 model all they are observed as key elements and enablers. It is expected that the combination of VR related technologies with the advancements of Industry 4.0 will disrupt the traditional manufacturing, the existing business models and value creation chain and will reshape dramatically the industrial environment. According to White Paper of IDC considering the Digital Transformation in the Manufacturing industry published in 2016 a third of the industrial enterprises worldwide aims to use VR in their production and engineering environment in the upcoming five years aiming at applying VR for retail showcasing, customized products development, on-site assembly, engineering design, training, etc. Within this context, the so-called Head Mounted Displays (HMDs) represent a significant interest as promising end user devices that enable the wide penetration of VR into the engineering routines such as design activities, product configuration and validation. We make a brief overview of the common HMDs, their features and limitations. Further, a generic process for configuring the customizable product features using of HMD and its programming implementation are presented following by discussion of the results from the usability testing of the proposed interaction paradigm.*

Keywords: VIRTUAL REALITY, PRODUCT CONFIGURATOR, PRODUCT CUSTOMIZATION, HMD,

1. Product Customization and Virtual Reality

Nowadays the trend for creating the products precisely according to specific requirements of each customer is already a common practice of the product manufacturing companies. In order to be successful and competitive they, regardless of their scale or specialization, have to seek diverse innovative ways in order to adapt their products satisfying the individual needs of each customer while keeping the costs at the mass production level. Here, the innovation management has moved from a manufacturer to a customer centric process leading to anticipation of a new design and manufacturing paradigm for customization of the products wide known as Mass Customization. Nowadays the trend for creating the products precisely according to specific requirements of each customer is already a common practice of the product manufacturing companies. In order to be successful and competitive they, regardless of their scale or specialization, have to seek diverse innovative ways in order to adapt their products satisfying the individual needs of each customer while keeping the costs at the mass production level. Here, the innovation management has moved from a manufacturer to a customer centric process leading to anticipation of a new design and manufacturing paradigm for customization of the products wide known as Mass Customization.

According to [Dellaert & Stremersch 2005] two most serious issues related to the implementation of product customization from the customer perspective are the **cognitive cost** and the **complexity**. When the customer has a significant number of alternatives for making a choice, the cognitive effort for their evaluation may exceed the increased benefit from the availability of options to select from. This creates frustration due to so-called "paradox of choice". The existence of too many alternatives decreases their subjective value to the customer, which in turn shall lead to a postponement of the decision or shall classify this product as a "difficult" and undesired [Piller & Tseng 2010]. The most commonly used approach to avoid this is the use of a product configuration system also referred to as product configurator. The customer is given the opportunity to build a structured model of their needs and to obtain information on appropriate solutions based on interactive test between the model and the options available.

The product configurators can be observed as software tools that are used for performing “co-design” activities in an act of manufacturer-to-customer interaction [Khalid & Helander 2003]. The customer selects the attributes and attribute values from a finite set of options and combines them into a final customized product. The configurator systems perform various tasks and contain much more than calculating algorithms. The configurators check the specification of an individual product configuration for *completeness* (that all the necessary selections are made) and for *consistency* (that no rules are violated). Additional functionalities such as price and delivery time calculation, layout drawing etc. may be provided.

In the context of the product configuration the Virtual Reality (VR) and its related technologies respectively are considered as enablers for proactive participation of the customers in defining their needs, requirements and boundary conditions and for interactive multimodal validation of the configured product and its properties in near-real conditions and showcasing. By using VR the customers are allowed to carry our more efficient “mapping” of their requirements into the physical domain and they are able not only to observe or simulate the individual creation, but also to experience the product (through multiple sensorial modalities).

2. Product Customization and Virtual Reality

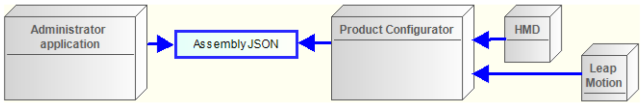
Head-mounted display or HMD is a display device worn over the user’s head. It features a display in front of one or both of the eyes that stream data, images and other information. Additionally, HMDs may feature position tracking and stereo sound, providing high level of immersion for the user. There are many variants of implementation of the head-mounted display system for various purposes with different characteristics starting with the very simple cardboard box and ending with sophisticated wireless devices [Romanova, 2017].

The VR HMDs as a concept and implementation are definitely not new, but in the last three years (2015-2017) there is a growing interest to head mounted displays (HMD) as end-user devices for immersive presentation of Virtual Reality. This is mainly caused by the investments in the sector from the major companies (e.g. Facebook, Alphabet, Sony, Samsung etc.) and the introducing on the market of a third wave of new affordable devices of different producers featuring acceptable performance characteristics including low-cost head-sets which integrate smart phones as display technology together with the correspondent SDI’s. However, the main focus for practical use of these HMDs are limited only to gaming, social VR, entertainment, showcasing and other similar topics. Engineering applications, in particular related to the product customization such as in [Yuan, 2017] are not commonly reported, but highly promising. According to the reports, it is expected that the Head-Mounted Display will reach USD 25.01 Billion by 2022 at an average annual growth rate of 38.8%. That implies high penetration in all spheres of the globalized economy, including Engineering. That means that HMDs have a significant potential to become a valuable tool for supporting engineers in performing their routines and decision making and bringing new dimensions for application of traditional CAD and CAE. In this term, the exploration of the specifics of the HMD interaction and user interface is of big importance. The analysis of the available on the market devices shows that the producers are experimenting intensively with various approaches and try to find the best relation of these properties for their customers. Another clear trend is the introduction of 3D audio components that become an obligatory aspect of the HMD device. However, the performance characteristics are still not optimal and there is a long way before reaching the required maturity.

4. Functionality and Architecture

For the purpose of this work, a simple VR-based product configurator functionality and architecture was defined as shown on Fig. 1. In term of these, it is adopted that the product, which is the main subject of the configuration process, constitutes an assembly built from multiple subassemblies and/or single parts presented in different variations (instances). The software application that implements a configuration process is known as a Product Configurator. It provides two main roles for the participants in the process: Administrator (Engineer) and User (Customer).

Fig. 1 *General architecture of VR-Based Product Configurator*



The Engineer prepares the assembly (Product) and creates a hierarchy of objects. Each object (assembly, subassembly, single part) has its own different properties that can be handled. An instance of a given subassembly can be incompatible with another instance from another subassembly. Beside other, the Engineer can configure this compatibility in order to enable implementation of real world scenarios. Upon the end of the configuration process, the Engineer can export Customer's configuration of the product as a Bill of Materials (BOM). The use of standard formats like JSON and XML enables an easy integration of the product configurator with existing or newly created upstream systems.

The Customer configures the Product based on the object hierarchy defined by the Engineer, handles it in the Virtual Reality environment and finally stores the configuration made. The configuration process can be restarted or performed multiple times. Thus, different configurations can be created, tested and compared. This provide better user experience, improved configurations and satisfaction. Both participants, the Engineer and the User, perform various tasks, which require different interactions and user interfaces. Therefore, the Product Configurator is divided in two sub-applications, which communicate through the standard JSON format. Because of this, they can be implemented using technologies that are best suited for the specific requirements. All properties of the assembly are stored in the JSON data such as id, name, color, label, position. Similar properties are available for the subassemblies and their instances. The Administrator application enables handling of this data, which is critical for the successful execution of the subsequent configuration process.

The main part of the Product Configurator is presented by the application, which provides a Virtual Reality environment accessed with a Head-Mounted-Displays (HMD) and interacted through a hand tracking system. In this environment, the user can look in arbitrary direction, move and resize the configured assembly object, change its properties (e.g. color, form, label, etc.) and undo and redo previous operations. The product configuration scenario is intended to be performed in a suitable virtual room that is near real furnished considering the specifics of the respective product as shown on Fig.2. This will provide better immersion for the users. Each operation is accompanied with appropriate sound for an optimal user experience. The user interaction with a hand tracking technology, which enables the Customer to execute most of the operations using virtual, hands (Fig. 2 *left*). The virtual hands are a graphical avatar of the Customer and represent the continuation of his/her hands in the virtual world. They react on every movement of the real hands and fingers of the Customer and repeat it in the VR. By using special gestures, the Customer can easily move the configured object, change its size and perform zoom-in and zoom-out operations. A user menu is integrated in one of the virtual hands as shown on Fig. 2 *right*. It provides access to variety of options and functions. Further, a text input is available through a virtual keyboard. The virtual room, virtual hands, virtual menu and basic gestures are presented in the following diagrams.

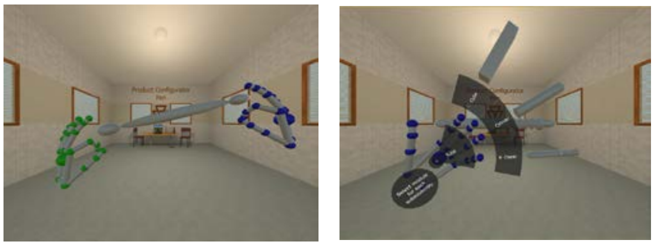


Fig. 2 *VR-based product configuration environment featuring virtual hands.*

The virtual hand menu has hierarchical structure and provides additional information to facilitate its use. It works intuitively and has a section with hints for the possible next operations. For some of the operations (like loading of previously saved configurations) an interaction with statically positioned menu is provided. The complete menu structure with possible options is shown on Fig. 3.

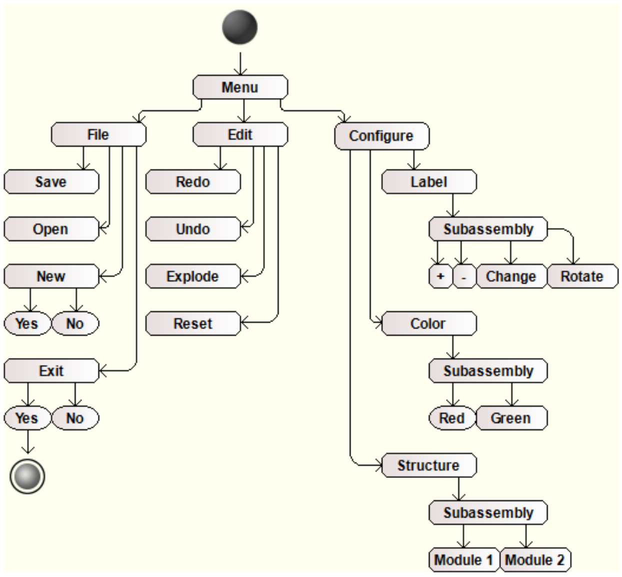


Fig. 3 *Configurator's menu structure*

5. Implementation and Integration

The Product Configurator application uses two interface devices: Leap Motion for user input and *Oculus Rift* HMD in its version *Development Kit 1* for immersive visual presentation. The Leap Motion device is placed on the front side of the HMD. In this way, the sensors can identify both hands also when the user moves his head in different directions. Both devices are connected to the computer through USB ports. The HMD is connected also through HDMI. Both require additional driver software to be installed. It was found that Oculus Rift has some compatibilities issues related to the used video cards, especially in the mobile computers. For the purpose of the development and testing the minimal computer setup with following parameters was determined: Windows 8.1 Pro 64bit, 8GB RAM, AMD A8 PRO7600B R7, 10 Compute Cores 4C+6G 3.10GHz (Fig, 3). This configuration is not powerful enough. Therefore, most of the elements of the virtual room are static and are calculated at compile time, which provides significant performance improvement and influences positively the user experience.

***Fig. 4** Minimal hardware setup*

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The Administrator application is organized using the Model-View-Controller paradigm. Different packages are created to implement this separation. Under the models package all classes defining an assembly are created: Assembly, Subassembly and Module. A separate class is defined that contains the configuration information for each object. A singleton instance of *ConfigurableObjectManager* is provided, which implements all configuration operations. Fig. 5 presents its class diagram.

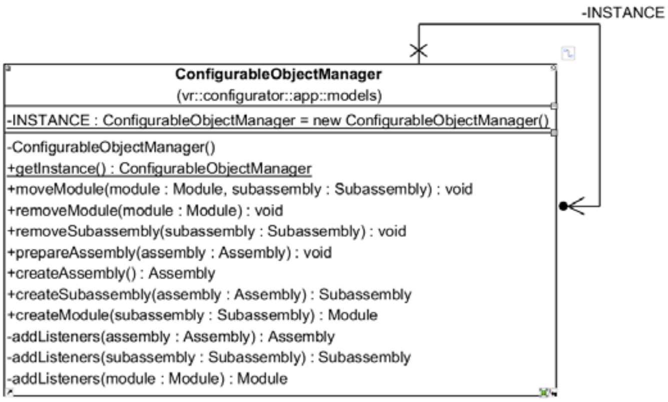

***Fig. 5** ConfigurableObjectManager class diagram*

The User application has more complex structure, because it models different kinds of interactions in the VR environment. The components are organized in packages based on their role in the overall architecture. The *Behavior* package contains again the definitions of all assembly related objects, but this time from the perspective of their manipulation and configuration. The *Config* package provides all settings prepared by the Administrator application. The architecture of the VR application is mostly event-driven. The user can perform operations in any order. Therefore, the Service package contains services, which are called when a specific event is fired. Fig. 6 shows the facade used for access to the object, text-material, sound, message and redo-undo services.

The Menu package contains definitions of all kinds of elements used for the VR interactions. They build an object hierarchy (Fig. 7), which is constantly manipulated and changed through the execution of the program.

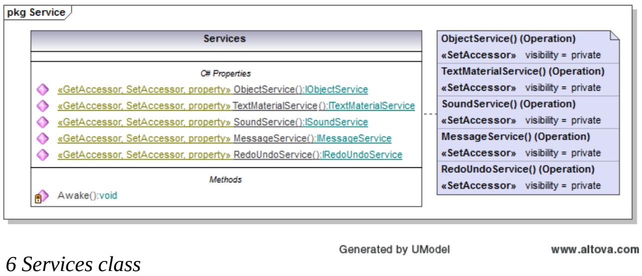

***Fig.** 6 Services class*

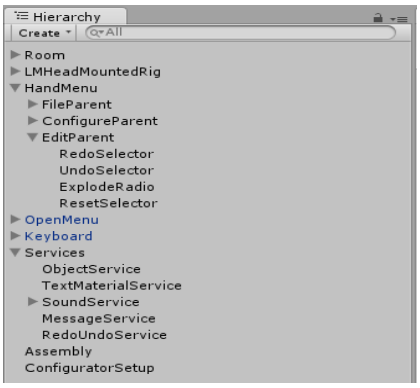

Fig. 7 Object hierarchy

6. Usability Testing

A simplified usability evaluation based on predefined testing procedure is performed to evaluate the proposed interaction paradigm as shown on Fig. 8. 16 participants took part in the testing with equal count of males and females. The age distribution is presented on Fig. 9. The participants of age of 18 - 24 years prevail.

***Fig. 8** Performing testing of the product configuration using HMD*

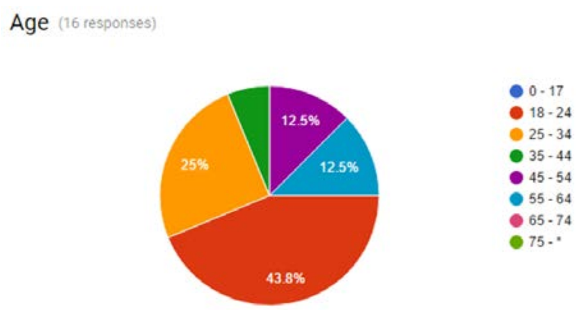

***Fig. 9** Age distribution of the participants in the usability study*

In the performed study, every testing person should configure his/her individualized version of a simple consumer product (a pen). The product consists of three subassemblies, each of them has three different variants (instances) as shown on Fig.13. Additional compatibility constraints are defined between some of them. At the beginning of test procedure, the purpose of the study is explained to the testing person. After that, he/she receives instructions about the way of use of the configurator and the virtual hands mechanics is explained. Each participant puts on the HMD by himself/herself and performs following tasks: assembly move, size change, configuration of the structure, color selection, defining and positioning of a label, saving the configuration. The first impressions are registered trough a personal interview upon completion of the testing procedure and then the user should complete a usability questionnaire.

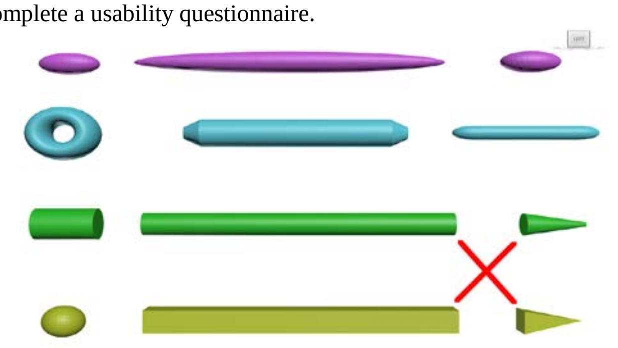

Fig. 10 *Test product structure*

The most of the user have good experience with the system as shown on Fig. 11. A half of them is completely satisfied with the product. One of the most important issue related to the Virtual Reality is the physical comfort of the user. Often after longer exposure to a virtual environment users show symptoms of so called cyber sickness such a general discomfort, headache, stomach awareness, nausea, vomiting, pallor, sweating, fatigue, drowsiness, disorientation. Manifestation of some of these symptoms with different extent are reported from five of the participants. The symptoms were severe only in one case.

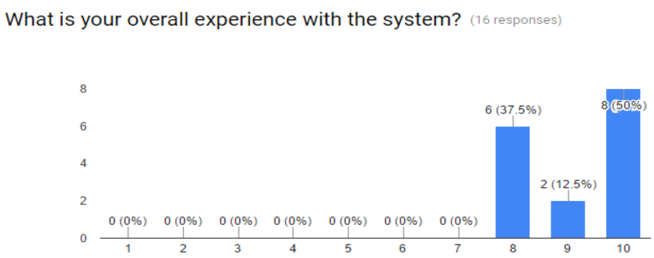

Fig. 11 *Overall experience with VR-based Product Configurator*

One aspect that plays important role is the resolution of the HMD. The experiments is performed by using the first Oculus Rift model and shows expected results. For most of the participants is the text with low readability and this hinders the interaction with the system. Nearly two-thirds of the participants like the control with the virtual hands. The rest report difficulties, which they overcame after a short period of time. This is valid for the most of the older participants who have problems to use the virtual hands. The size of the hand menu should not be so big because it is considered as an integral part of the hand. According to the majority of the users the menu is well structured and organized, but not perfect. It has to many options and is regarded as difficult. One possible solution of this issue is the use of voice commands or gestures related to additional tracking sensor. The menu icons and the menu colors facilitate the work. In the first version of the Product Configurator no icons or meaningful colors were used. Based on the feedback of the testing person these were implemented and 70% of participants find that the icons and colors provide them with important support into the configuration process.

Other important component for VR are the sounds. In the Product Configurator various sounds and audio effects are used for the occurring events. 60% of participants find these for appropriate and meaningful. According to the most of the participants, the immersion in VR environment enhances the experience as a whole. However, the opinions here varies in a wide range. On the one hand, VR supports and augments the configuration process and alters the user experience in disruptive way. On the other hand, some of the participants (10 %) rate the VR environment as distractive. Evident here is the problem for keeping balance between photorealistic appearance and functional requirements.

Generally, the results from the testing are positive and motivate the future development of the system. The negative aspects are not provoked form the Product Configurator itself, but from the performance characteristics of the user hardware equipment itself. The technology is improving continuously, therefore the low resolution, the latency and related to them sickness symptoms can be gradually overcame. In order to get better understanding the Product Configurator should be tested systematically with other HMD models. In our opinion the most of the reported issues can be avoided by the use of headset with better performing characteristics, e.g. HTC Vive. Based on the collected information from the testing the application can be improved in various ways. The user interface can be extended with new components, e.g. better color selector. The hand menu should be revisited, because it cannot support subassemblies with more than five modules. More optimal feedback mechanism should be provided for the single operations, e.g. when a given instance has been chosen it can change its appearance VR. The virtual room can be also improved. Additional spaces should be designed that support configurations of different assembly types. Another improvement that can provide a better immersion is the introduction of voice commands.

7. Conclusion

The field of Virtual Reality is rapidly going forward and givens new opportunities for software applications. Its integration in the Mass customization process involves even more the user and provides unique user experience. A new set of challenges arise from this innovation. The lack of standards and well-established methodologies motivates the experiments with new platform independent architectures, which should utilize all existing and future VR technologies. This work studies and proposes a generic architecture for product configuration, which can be easily deployed in an existing IT environment. It implements different approaches for the interaction between the user and the system. The described goals and principals are tested using a usability test. This evaluates the created system and gives guidance for the possible improvements. The overall positive results can be used as evidence for the growing potential of the VR technologies and strengthen its position in the constantly changing and evolving information technology world.

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8. Literature

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