Configurable Virtual Reality Store with Contextual Interaction Interface

Krzysztof Walczak
Department of Information Technology
Poznań University of Economics and Business
Poznań, Poland
walczak@kti.ue.poznan.pl

Jacek Sokołowski
Department of Information Technology
Poznań University of Economics and Business
Poznań, Poland
sokolowski@kti.ue.poznan.pl

Jakub Dziekoński
Department of Information Technology
Poznań University of Economics and Business
Poznań, Poland
dziekonski@icloud.com

***Abstract*—In this paper, we discuss the problem of building configurable virtual reality environments, with a particular focus on user interaction allowing convenient creation and exploration of such spaces. The use of a novel Contextual Semantic Interaction Interface is proposed, which is dynamically adapted in real time to a particular context of interaction. We also present a modular design of a VR shopping space, which may be configured with the presented approach. The shopping space is created dynamically as a combination of three elements: exposition model, product models, and virtual store configuration. The first element visually reflects an existing or planned 3D store layout and is designed by an architect or a 3D modeling expert. The second element provides 3D models of particular products that can be presented in the exposition. The third elements is a configuration file, which connects the two previous elements. The presented configurable VR shopping space may be used to perform various types of research experiments in the fields of merchandising and e-commerce.**

***Index Terms*—virtual reality, immersive visualization, user interfaces, e-commerce, merchandising**

I. Introduction

Significant progress in the performance and the presentation capabilities of contemporary IT equipment offers the possibility to transfer various physical spaces into virtual reality. One of prominent and interesting examples are virtual reality models of shopping spaces. In this paper, an immersive configurable virtual reality store environment, designed for immersive interactive presentation in a four-sided CAVE is presented. Realistic three-dimensional visualization of a store in VR has two main purposes.

The first purpose are merchandising tests to verify how different product arrangements in a modeled physical exposition influence perception of the products by customers. The goal is either to increase the total store turnover (by influencing customers to buy as much as possible) or to promote a certain product or a group of products (by influencing buyer choices). Currently such merchandising research is typically performed with the use of physical mockups of real stores [1].

Virtual reality spaces offer important advantages over traditional ”physical” spaces by permitting quick and easy rearrangement of products and enabling to carry out tests with customers in a well-controlled environment. Also, there is no need to posses physical versions of all different kinds of products, which may quickly become unusable, because of their expiration date or changing product design.

The second purpose of building realistic immersive 3D stores are tests with customers to examine their impressions and the sense of reality. This is an important step in moving daily shopping to the virtual world – the process that has already begun with the creation of the first on-line stores and is constantly gaining importance and popularity in the modern economy. Shopping is one of the most popular online activities worldwide. In 2016, retail e-commerce sales worldwide amounted to 1.86 trillion US dollars and e-retail revenues are projected to grow to 4.48 trillion US dollars in 2021 [2].

2D shopping websites commonly used today, have their natural limitations, such as the lack of interaction with products, limited perception of the product size and properties, and the lack of social interaction in such systems, which is a particularly important element of shopping in some groups of customers and products. The use of 3D avatars to navigate and collaborate in a virtual environment introduces a social aspect into this activity, which is not achievable in traditional forms of e-commerce. These aspects can have a significant impact on the popularity of new forms of shopping [3].

Retailing in 3D virtual environments, including social virtual worlds (SVWs), is considered an evolution of the traditional web stores, offering advantages and an improved shopping experience to customers [4]. Research demonstrates that the use of virtual reality can have a positive influence on marketing communication [5]. However, VR technology is not yet ready for mass use in on-line shopping systems. In [6], authors argue that the use of virtual reality in e-commerce must rely on a mixed platform presentation to account for various levels of usability, user trust, and technical feasibility. The authors propose that e-commerce sites that implement VR commerce provide at least three layers of interaction to users: a standard web interface, embedded VR objects in a web interface, and semi-immersive VR within an existing web interface.

978-1-5386-5024-0/18/$31.00 2018 IEEE

In this paper, we present the design and implementation of a configurable VR store, which is meant to allow quick and easy reconfiguration of the virtual shopping space and the placement of particular products. It is also important to be able to store several different configurations of the exposition designs to enable quick reconfiguration of the virtual store for series of tests with different groups of users.

The remainder of the paper is organized as follows. In Section II, the state of the art in designing VR environments and VR interaction techniques is described. Section III explains the overall concept the configurable virtual reality store and the system architecture. In Section IV, the process of configuring a virtual store exposition is presented. In Section V, different forms of interaction with the virtual environment are discussed. In Section VI, an example virtual shopping environment is presented. Finally, Section VII provides conclusions and discusses future works.

II. State of the art

A. Designing VR environments

Creation of non-trivial interactive VR content is an inherently complex task. This results from the conceptual and structural complexity of VR content models and the variety of aspects that must be taken into account in the content creation process. A number of approaches, applicable in different scenarios and contexts, have been proposed to simplify the content creation task.

Geometry, appearance and movement of real objects can be acquired using automatic or semi-automatic 3D scanning and motion capture devices. Static 3D objects can precisely digitized using active scanners based on laser ToF measurement, triangulation, and structured light. Less precise, but more affordable, are software tools enabling reconstruction of 3D objects from series of images, such as Autodesk 123D and 3DSOM. 3D scanning can be combined with other content creation methods, allowing designers to influence the process of digitization and the created content.

Modeling of both existing and non-existing objects and places is possible with the use of visual 3D content design environments. Software packages that enable modeling or sculpting of 3D content include: Blender, 3ds Max, Modo, Maya, ZBrush and 3D-Coat. Advanced professional environments offer rich capabilities of modeling various content elements, but their complexity requires high expertise. Narrowing the domain of application and the set of available operations enables development of tools that are easier to use by domain experts. Examples of such environments include AutoCAD Civil 3D, Sweet Home 3D and Ghost Productions. These tools enable relatively quick and efficient modeling without requiring users' extensive experience in 3D content creation. Such an approach, however, significantly reduces the generality of the content creation process.

High structural complexity of 3D content, combined with the requirement of being able to adjust specific content parameters, require the development of content models – well defined structures, which describe content organization and parameterization [7]. Based on such models, the final form of 3D content can be generated by content generation software – either fully automatically or semi-automatically in an interactive process. Content models offer data structures that are better organized and easier to maintain than typical 3D content representation. They also permit automatic verification of data consistency and elimination of redundancy. Content patterns provide an additional conceptual layer on top of content models, defining roles of specific elements of a content model [8], [9].

As an alternative to fixed content models, rules of content composition can be defined. Such rules describe how different types of content elements should be combined to form the final 3D model. Rules permit flexible composition of content from predefined building blocks – components [7], [10]–[12]. Components may represent geometrical objects, scenarios, sounds, interaction elements, and others. Content creation based on configuration of predefined components constrains possible forms of the final created content. In many application domains, however, this approach is sufficient, while the process is much simpler and more efficient than creating content from scratch.

To further simplify content modeling, separation of concerns between different categories of users is required. These users may have different expertise and may be equipped with different modeling tools. A non-expert designer may use ready-to-use components and assemble them into virtual scenes. Composing a scene in such a way is relatively simple, but the process is constrained. New content creation capabilities can be introduced by programmers or 3D designers, who can add new components and new ways of combining them.

The use of semantic web techniques may further simplify the process of creating 3D content [13]–[16]. Semantic web techniques enable the use of high-level domain-specific concepts in the content creation process, instead of low-level concepts specific to 3D graphics. Content creation may be supported by knowledge inference. Also, the use of semantic content representation enables creation of content that is platform independent. Several approaches have been proposed to enable 3D content modeling with the use of semantic web techniques [17]–[22]. A detailed analysis of the state of the art in semantic 3D content representation and modeling has been presented in [23].

Availability of efficient and easy to use content creation methods – in particular methods based on the semantic web techniques – opens the possibility of social 3D content co-creation by users that are both producers and consumers (prosumers), similarly as in the case of the "two-dimensional" Web 2.0. 3D content sharing portals, such as Unity Asset Store [24], Highend3D [25], Turbosquid [26], 3D ContentCentral [27], and many others (e.g., CG People Network, Creative Crash, 3d Export, Evermotion, The 3D Studio, and 3D Ocean) enable access to vast libraries of 3D content.

B. User interaction in VR environments

In order to build an easy-to-use configurable VR system, it is necessary to choose appropriate methods of user interaction with the virtual environment. Domain experts who should perform the configuration task, do not need to have technical skills. For this reason, it is important that the interaction methods are intuitive and user-friendly. This is difficult because content design is a complex task and new users often find it difficult to even simply navigate and interact in immersive VR environments, such as a CAVE. This section describes different approaches to interaction of users with VR environments.

The first approach is based on classic input devices such as a mouse and a keyboard. The ability to map a 2D mouse interaction to a 3D space [28] and the high degree of technological adoption make this approach preferred by many beginners in VR. However, due to the natural limitations of these devices (such as their limited number of states and the necessity to use complex key combinations), navigation using such devices is often non-intuitive and complicated. Moreover, this kind of interaction is not practical in CAVE systems.

Another approach is to use specialized equipment: gaming input devices – such as joysticks and pads – or dedicated VR devices – such as tracked controllers and haptic arms – to navigate and interact in virtual environments. A significant advantage of this approach is higher user comfort and good control and accuracy in properly designed and configured environments [29]. In the case of CAVE systems, the Flystick – wireless interaction device with six buttons and an analogue joystick – is particularly frequently used. This device meets the needs of most users. However, the limited number of buttons and the lack of reverse communication reduce the usefulness of this device for users who are content designers. In the case of more specialized devices, adapting them to environments other than those for which they were originally designed is difficult or not possible at all. Nevertheless, specialized device-based approach is often the basis for further research [30] [31].

A quickly developing approach to users' interaction in VR environments is the analysis of natural human behavior. It includes techniques such as motion capture (either using marker tracking [32] or directly, e.g., using Xbox 360 Kinect sensor system [33]), gesture recognition [34], eye tracking [35], and verbal/vocal input [36]. All these techniques focus on providing an intuitive natural interface, which is user-friendly even for non-experienced users. However, the problem with using natural interaction to design content is that it requires a significant physical effort from the user. For example, according to [37] the average time a user can comfortably use Leap Motion (device for gesture recognition) is about 20 minutes. Thus, this technique is not suitable for designing VR environments, as it is often a process that requires a long time and high accuracy.

Context-based approach is an interaction technique popular in computer games, in particular simulations (e.g., "The Sims" and "SimCity" series by Maxis) and adventure games. This approach is not in itself based on specific input devices, but focuses on the use of available devices to navigate through a real-time contextual interface. The content of this interface depends on the current state of the environment and its objects (e.g., time, position, current object state). The context-based approach is also often used in modern VR environments [38]. However, this approach is uncomfortable due to the mismatch between classic UI elements (buttons, menus, charts) and the 3D virtual environment. In addition, this technique is best suited for a limited number of possible states and is not convenient for entering data (such as text or numbers). This is a serious limitation when the interface is used for content design.

Another approach to user interaction within VR environments is to use a device with its own CPU for controlling the environment. Mobile devices, such as smartphones and tablets, are often used for this purpose due to their widespread availability and advanced user-interface features, including high-resolution touch screen displays and various types of built-in sensors, such as gyroscope and accelerometer. In this approach, a user has a specific predefined interface located on the client device to influence the current state of the environment. This interface can be generated with the use of specialized software (e.g., PC Remote application by Monect [39]) or it can be dedicated to a specific environment and released in the form of an independent application. However, developing dedicated client applications is a time-consuming and costly activity, and the applicability of such an interaction interface is limited to a single VR environment.

III. System Architecture

In this section, the overall architecture of the configurable VR store system is presented.

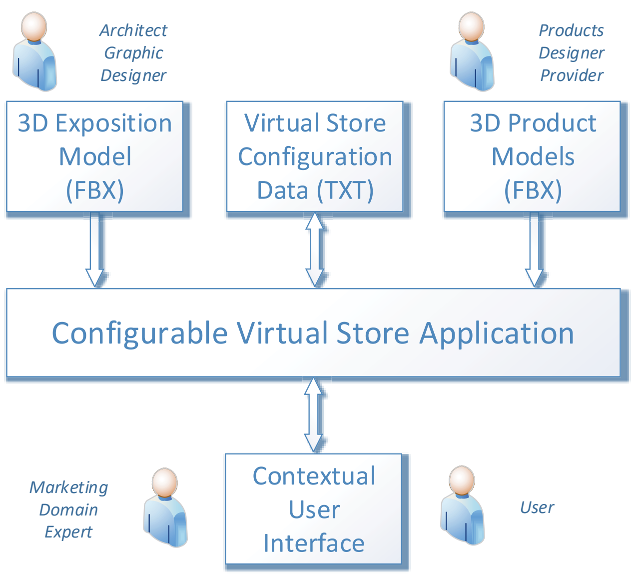

Fig. 1. Architecture of the configurable VR store system.

The main element of the architecture (Figure 1) is the *Configurable Virtual Store Application*, which integrates data from three sources:

- *Virtual Store Exposition Model* is a 3D model of a store exposition space. It may be a reconstruction of an existing shopping space, design of an intended space or a 3D model used purely for the visualization process. The exposition model may be created by a designer/architect. Any number of different virtual store exposition models may be used within the system. The only requirement for the exposition model is to provide an identification of product placeholders, i.e., locations in the model where 3D product models will be placed. The exposition model must use standard units (e.g., metric system) to enable automatic integration with 3D product models.
- *3D Product Models* is a collection of 3D models of products, which can be placed in the exposition space (e.g., on shelves). The 3D product models may be modeled, scanned or retrieved from a library. All 3D product models must use the same scaling system as the exposition model. The process of preparing example 3D product models is presented in Figure 2.
- *Virtual Store Configuration Data* is a dataset which connects 3D product models to the exposition model by indicating products to be placed in particular placeholders.

The Configurable Virtual Store Application imports the exposition model, reads the store configuration data and imports indicated 3D models of products into specific placeholders in the model.

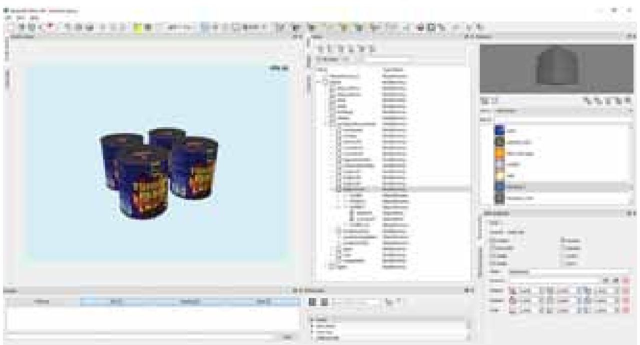

Fig. 2. A designer preparing 3D product models.

IV. Virtual store design

The process of designing a virtual store is divided into three separate steps. The first step of the process is *Exposition Design*. This step is performed by a highly skilled professional equipped with appropriate modeling tools. This step is performed rarely, in particular, it may be performed once, if a single exposition model is sufficient (e.g., for an existing real store). A ready-to-use virtual store model is presented in Figure 3.

Fig. 3. An empty virtual store model.

The second step of the design process is *Placeholders Setting*. This step is also performed by a professional, equipped with appropriate modeling tools, but it is significantly less complex and demanding than the exposition design. An existing 3D exposition model may be used for this process. The output of this step is a hierarchy of named placeholders, where 3D product models may be placed. For each placeholder, the (x, y, z) coordinates together with orientation are specified. Figure 4 depicts the process of setting a placeholder named ”Shelf 4” within the ”Stand 0”.

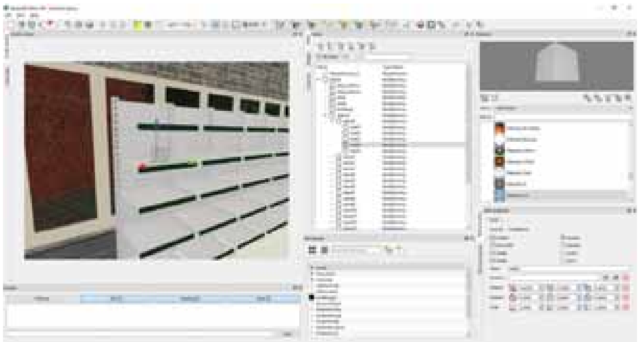

Fig. 4. A designer configuring placeholders for products in a virtual store.

The third and final step of the configuration process is assigning products to placeholders. In the presented approach, the process is performed with the use of the contextual user interface (cf. Section V-C), and the result is saved in a simple configuration file encoded in JSON. The file contains a hierarchical structure of named placeholders, which match the placeholders of the used exposition model. To each placeholder, a named 3D model of a product can be assigned. Multiple virtual shopping space configurations may be stored in named configuration files. An important advantage of such textual representation is its simplicity and readability.

V. Interaction with the virtual shopping space

In this section, different techniques for user interaction with the VR shopping space are discussed.

A. Interaction with dedicated input device

The basic interaction and navigation equipment in CAVE-type systems are dedicated input devices such as the Flystick controller and stereoscopic VR glasses. These devices provide comfortable navigation in the three-dimensional space, and in the context of a virtual store they allow a user to indicate particular products and areas of the store with a high level of precision.

However, configuring virtual environment content in real time is a much more complex and demanding activity than interacting with the final form of the environment. In addition to typical navigation activities (which can be performed in the same way as in the case of a store client), the designer must have a variety of capabilities for interaction with the virtual environment and the objects. Introducing the possibility of modifying the available assortment requires designing a completely new part of the user interface. This interface must allow a user to remove products currently on the shelves, add new ones (e.g., by selecting them from a list), specify the quantities or amounts, and sometimes also precisely define the options for placing the products on the shelves (e.g., whether they should be stacked, placed next to each other, at what angle they should be placed, or if they should be mixed with other products). Further development of such an environment may require additional configuration possibilities (e.g., determining the height of shelves) and improve user comfort by adding additional functions (e.g., ”copying” the contents of a shelf).

As a result, in the case of configuring a virtual shopping space, dedicated input devices lose their greatest advantage – user comfort. With a small fixed number of buttons and an analog knob, the Flystick is not able to easily handle all possible activities, and using combinations of buttons significantly complicates users' interaction with the system.

Moreover, this problem cannot be solved by adding additional dedicated input devices (e.g., second Flystick), and the use of classical input devices (such as a mouse and keyboard) is typically not possible in CAVE-type systems. All this makes it necessary to find (or develop) another method of interacting with virtual reality systems in order to enable efficient content management in virtual environments such as a virtual store.

B. Using dedicated remote interface

Another method that allows users to design VR content in real time is the use of a dedicated application implemented on a separate device with its own CPU. An independent application offers the convenience of having a tool specifically tailored for customization of the virtual environment.

However, dedicated remote user interface has important disadvantages when used for configuring virtual environments. The approach requires a great deal of development work to implement the control application. If the application is generic, i.e., it has the same interface for all virtual environments and products – it cannot implement all required diversity of functions. For example, some products may have specific configuration functionality (e.g., opening a closing a laptop on the display), which is difficult to predict at the time of implementing the control application. Conversely, if the application is specific, it may offer all required functionality, but the effort, the time and the cost of development will typically not be justified by the offered advantages.

C. Using Contextual Semantic Interaction Interface

A solution to the problem mentioned in the previous subsections is the use of a new interaction method, called *Contextual Semantic Interaction Interface* (*CSII*) [40]. This method is based on a client-server architecture, where the virtual environment engine plays the role of a server, while a mobile device plays the role of a client. The client-server communication is based on WiFi, with non-sequential variant of the UDP protocol, for real-time operation.

The client displays a user interface generated dynamically based on semantic metadata sent by the server in real time. The interface is adjusted to the particular VE and a particular context of interaction. Basic interface enables a user to navigate in the virtual environment. Initialization of interaction with an element of the VE is done by focusing the users' point of view on this element.

The semantic interaction metadata used by CSII to generate the contextual interface are assigned to particular elements of the VE in a hierarchical manner. The metadata are created with the use of a modeling tool (e.g., Unity game engine with CSII extension) and stored within the virtual environment. Different interaction metadata are assigned to different elements of the environment (e.g., shelves and refrigerators in a VR store). Also, interaction metadata can be assigned to particular objects (products) implementing their specific functionality.

This type of interface may be used both by content designers configuring the space, and by end users testing the ready-to-use environment. This solution eliminates the standard form of navigation (such as a Flystick), so that users do not need to change the input device when switching between the content design mode and the passive customer mode.

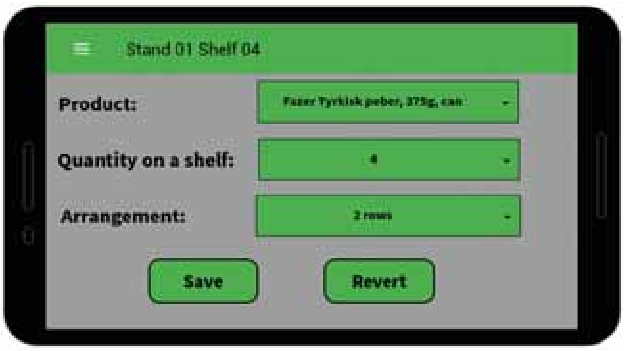

Fig. 5. Example of a contextual user interface for configuring products in a virtual store.

Fig. 6. Using CSII to arrange products on shelves in a virtual store presented on a Powerwall system

Fig. 8. A user inside a CAVE interacting with a virtual reality shopping space.

An example of a contextual user interface for configuring products on a store shelf is shown in Figure 5. In this case, a user is interacting with one of the empty shelves associated with a placeholder for products. The displayed interface contains options for choosing a product, as well as setting the quantity and the arrangement of the products on the shelf. Saving the changes will modify the virtual store configuration file (JSON), which can be reloaded by VR engine in real time.

The CSII can be easily used in CAVE-type systems and other semi-immersive VR setups. An example of a designer using the CSII to design the content of a virtual store displayed on a Powerwall system is shown in the Figure 6.

VI. Example virtual store

The virtual store environment, presented in this paper, has been implemented together with a small part of the city in order to increase the sense of realism. It allows a user to see the store from the outside. It also creates a feeling of entering the store, which enables to examine user's first impressions and identify the first things that draw customers' attention. The outside view of the store is presented in Figure 7.

The main element of the interior is a configurable store shelving, which is divided into particular shelves that may contain products. The products can be food and commodity items for everyday use, such as soft drinks, corn flakes, cosmetics, etc. For the experimental evaluation, three-dimensional models of products from open on-line repositories have been used. To perform real tests, we plan to acquire realistic 3D models of real products, for example by scanning them with the use of a photogrammetric scanner.

Fig. 7. A user inside a CAVE walking towards the virtual store entrance.

Apart from the shelving and the products, there are also other elements in the environment that can be typically found in real stores, such as the lighting, windows, counter and an animated model of a salesperson. In Figure 8, a view of a user immersed in the virtual reality shopping space is presented.

VII. Conclusions and Future Work

New forms of interaction that enable convenient and intuitive use of a priori unknown and dynamically changing virtual environments, in various context and different roles, are essential to make the use of immersive VR systems simpler for non-expert users, and therefore applicable in more application domains.

In this paper, possible approaches to the problem of designing product arrangement in a virtual store by marketing experts as well as interaction with such a space and the available products by end users have been described. New forms of interaction are essential to achieve a user-friendly content management by domain experts and enable merchandising research to be carried out in an efficient way.

The developed configurable VR store is intended to enable performing two kinds of experiments. The first kind of tests will be conducted with marketing experts – who will be offered the possibility of using the CSII interface to arrange products in the virtual store exposition space. The second kind of tests will be conducted with end users, who will use the CSII to interact with a ready-to-use virtual store environment. These users will be allowed to navigate in the virtual environment and to interact with particular products in an intuitive way, without memorizing complex interaction rules, which is typically required in current immersive VR environments.

REFERENCES

[1] B. Borusiak, B. Pierański, and S. Strykowski, "Perception of in-store assortment exposure," *Studia Ekonomiczne*, vol. 334, pp. 108–119, 2017.

[2] Statista. (2018) Retail e-commerce sales worldwide from 2014 to 2021. statista. [Online]. Available: https://www.statista.com/statistics/379046/worldwide-retail-e-commerce-sales/

[3] K. C. Lee and N. Chung, "Empirical analysis of consumer reaction to the virtual reality shopping mall," *Computers in Human Behavior*, vol. 24, no. 1, pp. 88 – 104, 2008. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0747563207000155

[4] D. Hassouneh and M. Brengman, "Retailing in social virtual worlds: Developing a typology of virtual store atmospherics," 2015.

[5] H. Van Kerrebroeck, M. Brengman, and K. Willems, "When brands come to life: experimental research on the vividness effect of virtual reality in transformational marketing communications," *Virtual Reality*, vol. 21, no. 4, pp. 177–191, Nov 2017. [Online]. Available: https://doi.org/10.1007/s10055-017-0306-3

[6] A. Rea and D. White, "The layered virtual reality commerce system (lavrcs): An approach to creating viable vrcommerce sites," in *MWAIS 2006 Proceedings*, vol. 11. AISeL, 2006.

[7] K. Walczak, "Structured design of interactive vr applications," in *Proceedings of the 13th International Symposium on 3D Web Technology*, ser. Web3D '08. New York, NY, USA: ACM, 2008, pp. 105–113. [Online]. Available: http://doi.acm.org/10.1145/1394209.1394231

[8] B. Pellens, O. De Troyer, and F. Kleinermann, "Codepa: A conceptual design pattern approach to model behavior for x3d worlds," in *Proceedings of the 13th International Symposium on 3D Web Technology*, ser. Web3D '08. New York, NY, USA: ACM, 2008, pp. 91–99. [Online]. Available: http://doi.acm.org/10.1145/1394209.1394229

[9] N. Polys, S. Visamsetty, P. Battarechee, and E. Tilevich, "Design patterns in componentized scenegraphs." Shaker Verlag, Proceedings of SEARIS, 2009.

[10] R. Dachselt, M. Hinz, and K. Meissner, "Contigra: An xml-based architecture for component-oriented 3d applications," in *Proceedings of the Seventh International Conference on 3D Web Technology*, ser. Web3D '02. New York, NY, USA: ACM, 2002, pp. 155–163.

[11] S. S. S. Visamsetty, P. Bhattacharjee, and N. Polys, "Design patterns in x3d toolkits," in *Proceedings of the 13th International Symposium on 3D Web Technology*, ser. Web3D '08. New York, NY, USA: ACM, 2008, pp. 101–104. [Online]. Available: http://doi.acm.org/10.1145/1394209.1394230

[12] K. Walczak, "Flex-vr: configurable 3d web applications," in *Proceedings of the Conference on Human System Interactions*. IEEE, 2008, pp. 135–140.

[13] T. Alpcan, C. Bauckhage, and E. Kotsovinos, "Towards 3d internet: Why, what, and how?" in *Cyberworlds, 2007. CW'07. International Conference on*. IEEE, 2007, pp. 95–99.

[14] L. Van Gool, B. Leibe, P. Müller, M. Vergauwen, and T. Weise, "3d challenges and a non-in-depth overview of recent progress," in *3DIM*, 2007, pp. 118–132.

[15] T. Zahariadis, P. Daras, and I. Laso-Ballesteros, "Towards future 3d media internet," *NEM Summit*, pp. 13–15, 2008.

[16] M. Spagnuolo and B. Falcidieno, "3d media and the semantic web," *IEEE Intelligent Systems*, vol. 24, no. 2, pp. 90–96, 2009.

[17] O. De Troyer, W. Bille, R. Romero, and P. Stuer, "On generating virtual worlds from domain ontologies," in *Proceedings of the 9th International Conference on Multi-Media Modeling*, Taipei, Taiwan, 2003, pp. 279–294.

[18] M. E. Latoschik, R. Blach, and F. Iao, "Semantic modelling for virtual worlds a novel paradigm for realtime interactive systems?" in *VRST*, 2008, pp. 17–20.

[19] S. Chaudhuri, E. Kalogerakis, S. Giguere, and T. Funkhouser, "Attribit: content creation with semantic attributes," in *Proceedings of the 26th annual ACM symposium on User interface software and technology*. ACM, 2013, pp. 193–202.

[20] K. Walczak and J. Flotyński, "On-demand generation of 3d content based on semantic meta-scenes," in *Lecture Notes in Computer Science; Augmented and Virtual Reality; First International Conference, AVR 2014, Lecce, Italy, September 17-20, 2014*. Springer International Publishing, 2014, pp. 313–332.

[21] K. Walczak and J. Flotyński, "Semantic query-based generation of customized 3d scenes," in *Proceedings of the 20th International Conference on 3D Web Technology*, ser. Web3D '15. New York, NY, USA: ACM, 2015, pp. 123–131. [Online]. Available: http://doi.acm.org/10.1145/2775292.2775311

[22] J. Flotyński and K. Walczak, "Ontology-based creation of 3d content in a service-oriented environment," in *Business Information Systems: 18th International Conference, BIS 2015, Poznań, Poland, June 24-26, 2015, Proceedings*, W. Abramowicz, Ed. Springer International Publishing, 2015, pp. 77–89.

[23] J. Flotyński and K. Walczak, "Ontology-based representation and modelling of synthetic 3d content: A state-of-the-art review," *Computer Graphics Forum*, 2017. [Online]. Available: http://dx.doi.org/10.1111/cgf.13083

[24] *Asset Store*, Unity Technologies, 2017. [Online]. Available: https://www.assetstore.unity3d.com/en/

[25] *High Quality 3D Models, Scripts, Plugins and More!*, Highend3D, 2017. [Online]. Available: https://www.highend3d.com/

[26] *3D Models for Professionals*, TurboSquid Inc., 2017. [Online]. Available: https://www.turbosquid.com/

[27] *3D ContentCentral*, Dassault Systèmes, 2017. [Online]. Available: https://www.3dcontentcentral.com/

[28] G. M. Nielson and D. R. Olsen, Jr., "Direct manipulation techniques for 3d objects using 2d locator devices," in *Proceedings of the 1986 Workshop on Interactive 3D Graphics*, ser. I3D '86. New York, NY, USA: ACM, 1987, pp. 175–182. [Online]. Available: http://doi.acm.org/10.1145/319120.319134

[29] A. Kitson, B. E. Riecke, A. M. Hashemian, and C. Neustaedter, "Navichair: Evaluating an embodied interface using a pointing task to navigate virtual reality," in *Proceedings of the 3rd ACM Symposium on Spatial User Interaction*, ser. SUI '15. New York, NY, USA: ACM, 2015, pp. 123–126. [Online]. Available: http://doi.acm.org/10.1145/2788940.2788956

[30] A. Alshaer, H. Regenbrecht, and D. O'Hare, "Investigating visual dominance with a virtual driving task," in *2015 IEEE Virtual Reality (VR)*, March 2015, pp. 145–146.

[31] G. Thomann, D. M. P. Nguyen, and J. Tonetti, *Expert's Evaluation of Innovative Surgical Instrument and Operative Procedure Using Haptic Interface in Virtual Reality*. Cham: Springer International Publishing, 2014, pp. 163–173.

[32] G. Cortes, E. Marchand, J. Ardouinz, and A. Lcuyer, "Increasing optical tracking workspace of vr applications using controlled cameras," in *2017 IEEE Symp. on 3D User Interfaces (3DUI)*, March 2017, pp. 22–25.

[33] M. Roup, P. Bosch-Sijtsema, and M. Johansson, "Interactive navigation interface for virtual reality using the human body," *Computers, Environment and Urban Systems*, vol. 43, no. Supplement C, pp. 42 – 50, 2014. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0198971513000884

[34] J. J. LaViola, Jr., "Context aware 3d gesture recognition for games and virtual reality," in *ACM SIGGRAPH 2015 Courses*, ser. SIGGRAPH '15. New York, NY, USA: ACM, 2015, pp. 10:1–10:61. [Online]. Available: http://doi.acm.org/10.1145/2776880.2792711

[35] T. Piumsomboon, G. Lee, R. W. Lindeman, and M. Billinghurst, "Exploring natural eye-gaze-based interaction for immersive virtual reality," in *2017 IEEE Symposium on 3D User Interfaces (3DUI)*, March 2017, pp. 36–39.

[36] D. Zielasko, N. Neha, B. Weyers, and T. W. Kuhlen, "A reliable non-verbal vocal input metaphor for clicking," in *2017 IEEE Symposium on 3D User Interfaces (3DUI)*, March 2017, pp. 40–49.

[37] J. Pirker, M. Pojer, A. Holzinger, and C. Gütl, "Gesture-based interactions in video games with the leap motion controller," in *Int. Conf. on Human-Computer Interaction*. Springer, 2017, pp. 620–633.

[38] S. Gebhardt, S. Pick, H. Voet, J. Utsch, T. al Khawli, U. Eppelt, R. Reinhard, C. Bscher, B. Hentschel, and T. W. Kuhlen, "flapassist: How the integration of vr and visualization tools fosters the factory planning process," in *2015 IEEE Virtual Reality (VR)*, March 2015, pp. 181–182.

[39] Monect, "Monect pc remote," https://www.monect.com/, 2017, [Online; accessed 27-September-2017].

[40] J. Sokołowski and K. Walczak, "Semantic modelling of user interactions in virtual reality environments," in *Technological Innovation for Resilient Systems*, L. M. Camarinha-Matos, K. O. Adu-Kankam, and M. Julashokri, Eds. Cham: Springer International Publishing, 2018, pp. 18–27.