Proceedings of DET2011
7th International Conference on Digital Enterprise Technology
Athens, Greece
28-30 September 2011

PROTOTYPE DESIGNING WITH THE HELP OF VR TECHNIQUES: THE CASE OF AIRCRAFT CABIN

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ABSTRACT

The main focus of this study is to develop a highly usable immersive environment for virtual aircraft products. The environment should address the modern usability guidelines regarding the design of 3D immersive interfaces. The scope is that the interface mechanisms of virtual environments be approached from an engineering point of view. The development of the environment involves interaction metaphors that will aid a designer or engineer to immersively create and test a product prototype, while exploiting the advantages of VR. In addition, it is important that the user be able to exploit these benefits without being an expert in VR. The development is made in a platform independent architecture in order for a possible integration with other VR platforms to be facilitated. Finally, the proposed interfaces are validated and evaluated based on the aircraft cabin case, using user task scenarios that have been designed for this particular study.

KEYWORDS

Engineering Simulation, Interactive Prototype, Virtual Design

1. INTRODUCTION

Modern commercial design tools, used in the process of new product development, enable engineers to design, test and simulate various parameters of the project in hand. However, there are still a lot of areas in the engineering design, where specific and customized tools are required in order for productivity to be improved and the cost of the development to be reduced. The Virtual Reality (VR) technology has been widely known for many years,, however, it still lacks being fully facilitated in the everyday practice of product development. The main reasons for this are being the complex hardware systems, required for facilitating the interaction between the human user and the computer system, hosting the application, apart from the lack in standardization and the increased cost of development. There are, however, inherent advantages of VR that together with the modern affluence of new interaction devices, mainly from the field of home games, have rekindled the interest towards this technology. Some of these advantages are the high level of flexibility and reusability of the virtual prototypes, developed with VR technology (Chryssolouris, 2006). The cost of developing a virtual prototype application, for simulating and facilitating engineering tasks and tests, is substantially smaller than that for building a real-life mock-up, which it does not even have reusable value. Furthermore, in the virtual environment, once the application has been built and set up, the engineer is able to execute limitless tests and experiments while changing and modifying the design at every step. Recent research has also focused on concurrent engineering applications, such as multi-user collaborative environments for real-time product design and review (Chryssolouris et al. 2008, Pappas et al. 2006).

There are a lot of commercial and free tools, offering possibilities and features of immersive modeling, having as their target the design and prototyping of products. In (Weidlich et al, 2007), several tools are mentioned for offering ways of product design, using predefined interaction techniques or simulation components (e.g. kinematics). The 3DVIA Virtools® (Dassault Systèmes) is a very popular authoring tool for 3D environments. It is also used as the development platform for the virtual environment, reported in this study. Nevertheless, all these tools offer limited predefined interaction capabilities, especially for complex product design and review sessions. The interaction techniques hosted, are mainly limited to tasks, such as ray intersection or look around techniques.

The product modeling and simulation technologies are constantly evolving and new ideas, which allow the facilitation of such technologies, in many other fields of engineering, are born. Regarding Virtual Reality though, it is the availability of such technologies that makes them the most important factors in supporting competitive engineering design. The advances made in these areas are greatly responsible for an engineering design's degree of reliance on physical prototypes, instead of digital ones (Stark et al, 2010). However, there is still left a large margin for improvement, mainly on the part that is responsible for the interaction between the human-user and the virtual environment.

The design and development of interaction techniques for VR use, is greatly dependent on the quality of the classification and survey on the existing technologies and methods in that field. Referring to this, common interaction techniques are usually divided into main categories, such as travel, selection, manipulation, system control and symbolic input techniques (Bowman et al, 2004). However, whereas the techniques focusing on object selection and manipulation, apart from travelling and way-finding, have already been adequately researched and tested, they are application control techniques, which are yet to be fully considered (Dachselt and Hubner, 2007). On the other hand, an engineering design environment has as its key requirement the advanced natural interaction with the user. For example, in (Moehring and Froehlich, 2010), it is suggested that natural interaction be the most important factor for the virtual validation of functional aspects in automotive product development.

This study is focusing on the application control aspect of a virtual environment prototype, along with symbolic input techniques. In order, however, for a complete interactive environment to be provided, some basic techniques have been developed for accommodating the needs for the selection and manipulation of objects.

2. INTERACTIVE PROTOTYPE DESIGN AND REVIEW FEATURES

The interaction metaphors and features, developed for the prototype design environment, are presented in this section. Regarding the application control, a 3D immersive interface, which uses a menu structure, is developed in order to facilitate all the functionalities of the environment. Its architecture aims at allowing a platform independent implementation, while maintaining usability aspects such as the user's natural task flow. Another three variants of alphanumeric input metaphors are designed to accommodate the functionalities of the 3D interface, for tasks that require numeric data input from the user. Since it is of first priority that all user tasks be facilitated immersively, these techniques are designed to easily and intuitively accommodate the requirements for numeric data input. In addition, an advanced object position control metaphor ensures that the engineer be able to control precisely the objects and parts during the design sessions. Finally, some basic interaction metaphors support the usability of the environment.

2.1. 3D IMMERSIVE INTERFACE

The 3D immersive interface template (see Figure 1) is an application control metaphor designed to control various parameters in the Virtual Environment (VE). The interface is represented by a 3D geometry that works as a touch screen. The screen can be naturally manipulated by the user, with the use of a virtual hand, or through a device that controls a virtual pen. The main concept of the 3D immersive interface is that certain predefined functional features be used inside the menus. There are two main aspects that have been taken into consideration during the development of the 3D interface. The first aspect has to do with mapping the features, displayed in the interface and the second with the classifying those features.

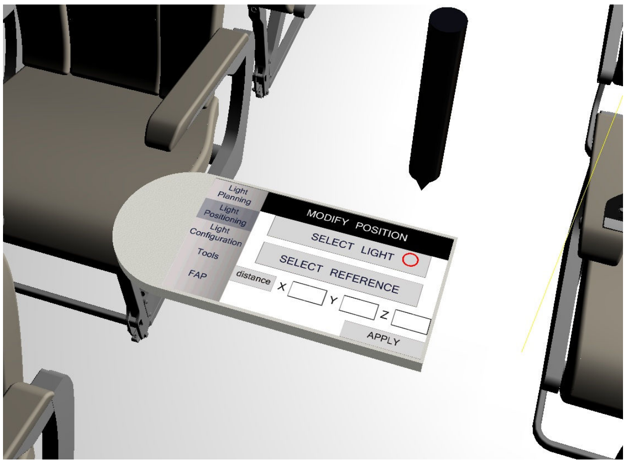

Figure 1 - A visualization of the 3D Immersive Interface.

Before continuing with the more detailed description of these aspects, it is important to explain that the term "feature" refers to the functional objects used for interaction, such as buttons or text fields. Regarding the mapping of the interaction features and their respective functionalities, the 3D interface screen area is divided into a grid with a certain resolution so that it is much easier for the interaction features to be correlated with those of the application behavior and functionality. Taking also into account the importance of having a platform independent architecture, a 3D interface is hierarchically structured in order to accommodate the various features. The interaction area of the screen is divided into two main areas, the tabs and the menu areas. Using the same notions, the tabs are the highest hierarchical objects of the 3D interface and each one of them contains interaction features that could either lead to another sub-menu or to certain application behaviors.

Figure 2, shows the generic architecture of the 3D interface. The interaction features accommodated by the 3D interface developed, are buttons, numeric or text fields, scroll fields and texture fields. Buttons are simple rectangular objects that are linked to a certain sub-menu or behavior in the application. Their activation and selection is made by the user with a ray while they are being immersed in the environment. Numeric and text fields are used, together with the alphanumeric metaphors (see section 2.2), for inputting data in the application. Scroll fields visualize predefined text data, stored in a repository, to be used in the application and the texture fields accommodate predefined textures and images, which are difficult to be transformed into the generic interaction features, provided by the interface. In Figure 3, an example of menu implementation, showing the different areas and interaction features, is being depicted.

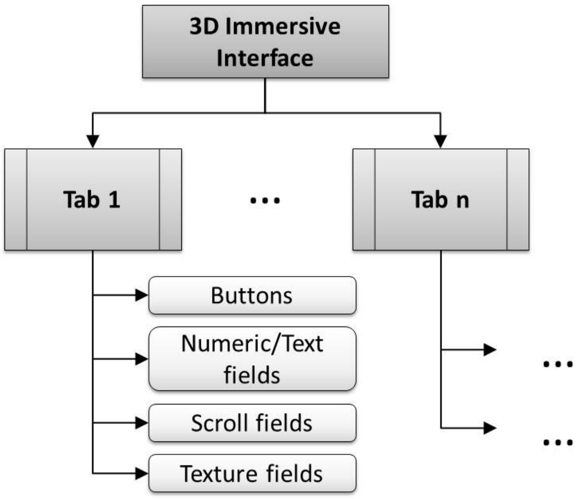

Figure 2 – generic architecture of 3D Immersive Interface.

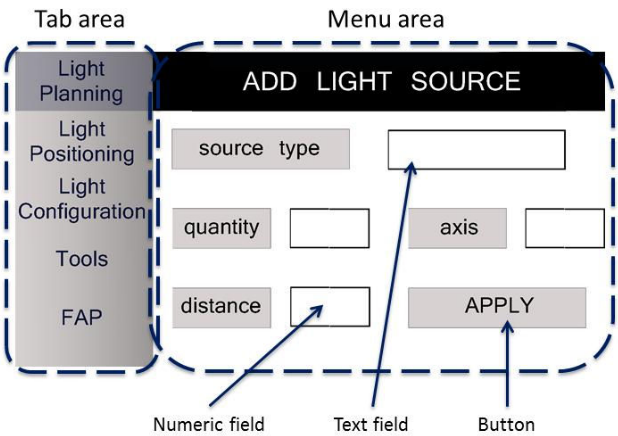

Figure 3 – Add light source screen.

The implementation is made based on the concept of building blocks. Each tab, menu and sub-menu is a building block, with its output connected to a certain behavior in the application.

2.2. ALPHANUMERIC INPUT

Alphanumeric input metaphors are used for defining numbers and text in virtual environments. This study proposes three different metaphors of alphanumeric input, called Number Input Wheel, Flower input and Alphanumeric input control.

The Number Input Wheel (see Figure 4) is a numeric input technique that uses three concentric circular geometries for the visual feedback of the alphanumeric value. When the wheel is activated, its center is attached to the position of the user's input device. By rotating his hand, the user can increase or decrease the value of the wheel. The distance from the input device to the center of the wheel, determines the magnitude of the number change. For example, if the user moves the stick a little bit further from the wheel, the magnitude of the change goes from 1 to 10 and when it is moved even further away, it goes to 100. When the change is set to magnitude 1, the small circle turns green and when it is larger, the other two circles turn green respectively.

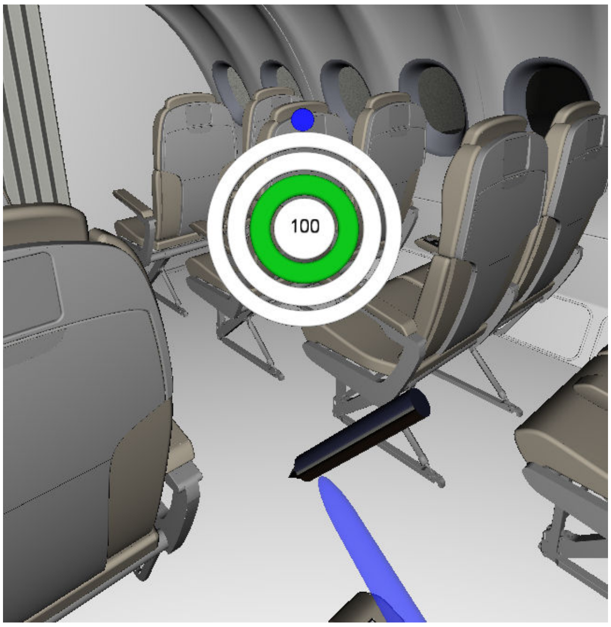

Figure 4 – Number Input Wheel Metaphor

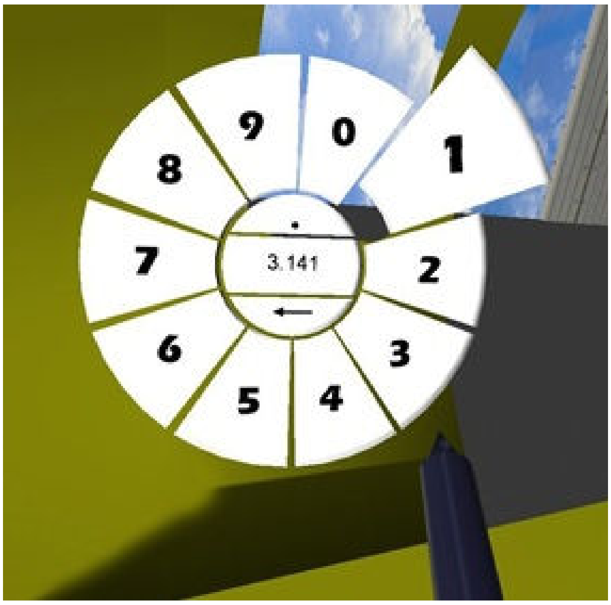

Figure 5 – Flower numeric input metaphor

The Flower Input Wheel (see Figure 5), helps the user input numbers with the use of an intuitive interface resembling a flower's petals. The symbols on the interface are rotating, while the user hovers his/her pointing device over them and the respective geometry is scaled up, towards the user, in order to provide feedback on the imminent selection. This technique requires a small movement of the users' wrist, in order to change the symbol and give more precision to the selection process.

The alphanumeric input control (see Figure 6) is an interaction technique that incorporates a low-cost input device for the selection of the required symbol. The input device is a Wiimote®, a mass produced, gaming device that is ergonomically designed. The symbolic input is conducted in cases that there is a need for inputting values that are long and complex. In Figure 6, there is a draft representation of the concept of alphanumeric input control. The user scrolls through the values and digits of the input field with the help of the Wiimote® joystick.

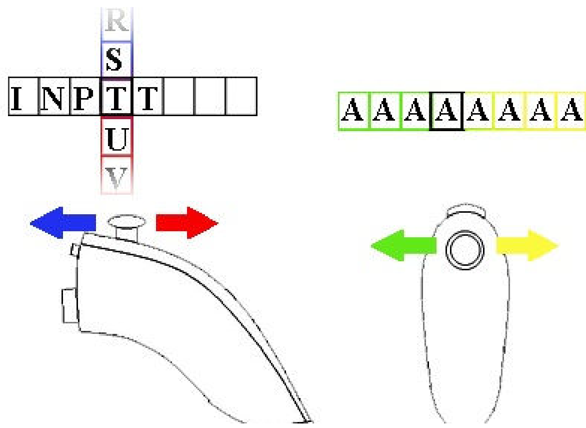

Figure 6 – Alphanumeric Input Control metaphor

2.3. ADVANCED OBJECT POSITION CONTROL

The Object Position Control interaction metaphor (OPC) is used for defining a certain pose (combination of position and orientation data) of an object and for feeding this information either to test the placement of that object or for its accurate positioning.

It consists of two stages, during which the user selects the point in space that the position control needs to be executed and then, the technique calculates the proper pose with respect to the test that will take place (see Figure 7). After the pose has been calculated, the difference between the defined pose and the object's pose is measured.

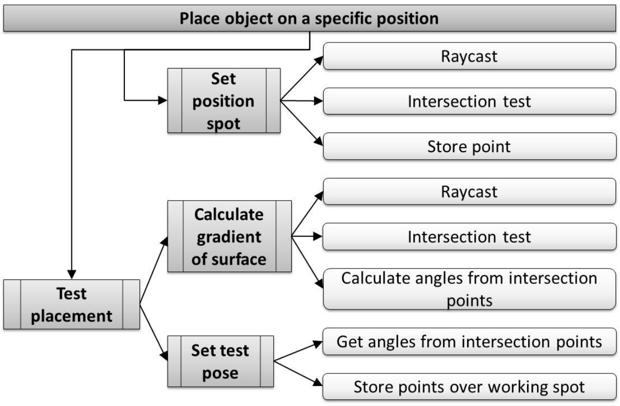

Figure 7 - Object Position Control interaction metaphor task decomposition

In more detail, during the first stage of OPC, the virtual input device is used as a pointer. A ray is casted from the device, parallel to the axis of the tool and upon intersection with an object, a small red sphere moves to the respective coordinates, thus, providing feedback as to where the tool is pointing at. The second stage, begins as the user clicks on the input device the corresponding button, which confirms the selection of the coordinates. Next, the calculations are stored as the position and orientation vectors of the point in space.

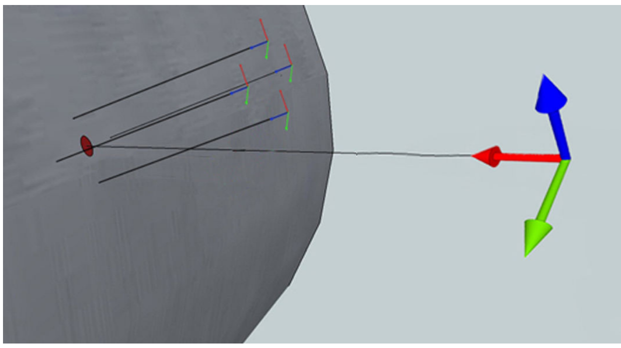

Figure 8 - Rays casted on surface of model by 3D sources

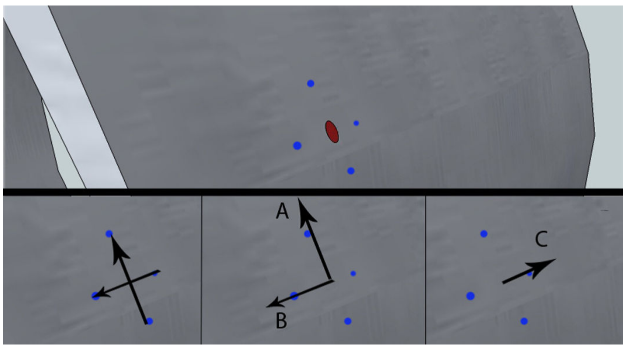

Figure 9 - Calculation of orientation based on secondary intersection points

The definition of the surface's gradient is essential for the calculation of the test pose. The calculation takes place with intersection points used between the rays casted from certain control sources and the surface of the model. The control points follow the initial intersection point (described above) and sequentially, cast new rays forming new intersection points, through which their orientation is calculated by this technique. Four sources are used for ray casting purposes. The orientation of the test pose is calculated by the cross product of the vectors, formed by the last intersection points. When the user presses a button on the device, the position from the first ray and the orientation from the other casted rays are stored as the test pose (Figure 8). The secondary raycast sources move across the surface according to the calculated orientation so as to be respectively perpendicular to the surface (Figure 9).

This way, the object position control metaphor enables the VR users to define a pose in the VE, with precision, in respect to that by which they can accurately place objects or create the position control (Figure 10).

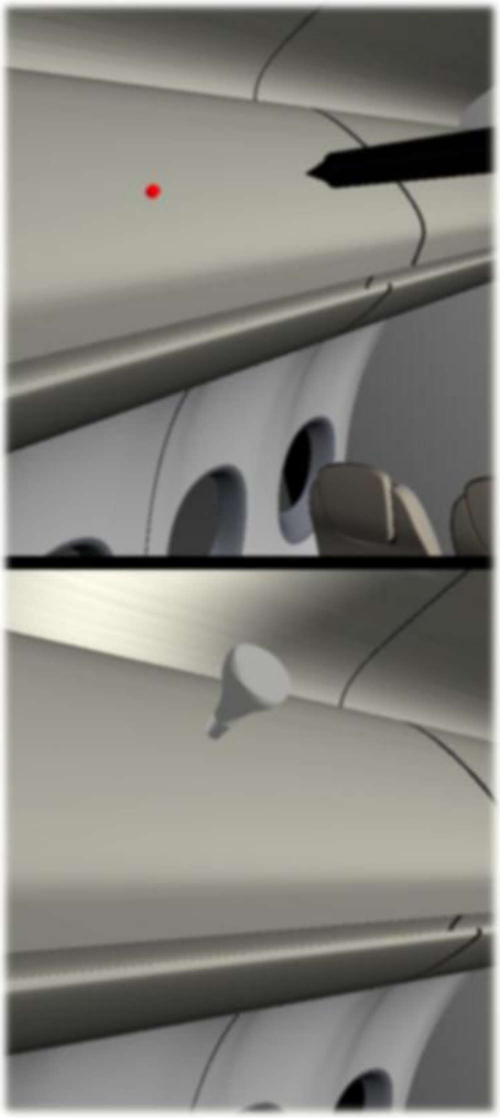

Figure 10 - Positioning of light in perpendicular angle to the gradient of the overhead luggage bins' surface.

3. AIRCRAFT CABIN DESIGN AND REVIEW TEST CASE

The above developments were implemented in a use-case, which focused on the design of the lighting configuration of an aircraft cabin and the review of the effects that this design had. For this use-case, two (2) user task scenarios were developed. One scenario was about the cabin lighting design and the second for the cabin lighting review.

The cabin lighting design test-case provides the necessary environment to a lighting engineer in order to immersively design the setup of the lighting parameters and conditions of the cabin and configure the layout of the light sources accordingly. The 3D User interface (see Figure 11) in this test-case, is used for controlling in the cabin, the light parameters, such as the luminosity of the light sources, the distance and angle of certain point sources in respect to various reference objects in the scene (e.g. passenger seats). The OPC metaphor is used in conjunction with the previous, for accurately defining the position and orientation of the lights. Furthermore, all the necessary numeric values are inputted in the system via the three alphanumeric metaphors.

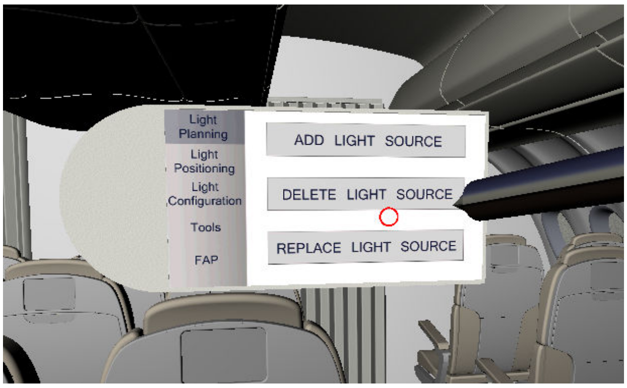

Figure 11 – Cabin design test-case.

In order to carry out the tasks, the user will use an implementation of the 3D interface. A part of this implementation is visualized in Figure 12. For example, the first tab of the 3D interface is dedicated to "Light Planning". It includes three sub-menus, the "Add Light Source", "Delete Light Source" and "Replace Light Source". These menus are responsible for instantiating a new light source in the scene, deleting an existing source or changing the type of the light source. The "Add Light Source" menu, hosts five interaction features, namely one text field for supplying the type of the source to be instantiated, two numeric fields for inputting the quantity and distance between multiple light source, in case of simultaneous instantiation and a scroll field that selects between the three axes of the coordinate system. Finally, a button called "APPLY" is used for applying the functions. In total, the implementation of the 3D interface for the aircraft cabin use-case has five main tabs, which are "Light Planning", "Light Positioning", "Light Configuration", "Tools" and "FAP" (Flight Attendants Panel). All these tabs host menus that support functionalities, apart from the ones described above, namely the positioning of a light source in certain coordinates or angles, the modification of color parameters (see Figure 13), or the luminance properties and measuring of dimensions.

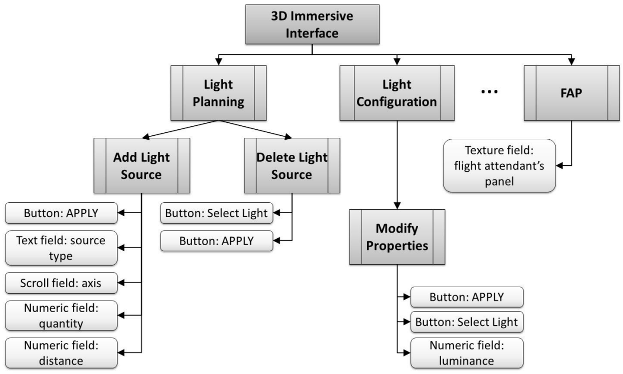

Figure 12 – Indicative implementation of 3D Immersive interface for cabin use-case.

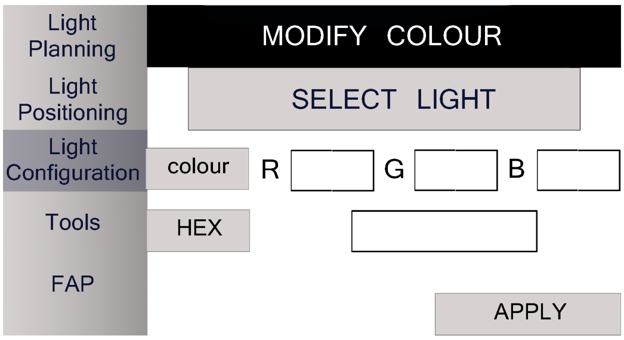

Figure 13 – Modify Colour menu.

There were many steps included in the cabin design scenario, based on the input from a European aerospace company. These steps were carefully selected in order to cover a broad spectrum of the activities, involved in the everyday practice of a lighting engineer/designer. The total length of the VR session in order for all the tasks to be executed, was approximately 45 minutes without the frequent breaks for the immersive user to rest, so as for any simulation sickness to be avoided. In Figure 14, there is an indicative part of the tasks involved in the scenario, together with the respective development used for the carrying out of the task. First, the user positions a spot light in the service unit above the seat and aligns the light beam towards the seat. Next, the beam should be directed towards the entertainment system and move the spot light 532 millimeters towards the y axis. Then, the position is placed perpendicularly to the sidewall with a 10 millimeter offset and the color of the light is modified with the indicated RGB values.

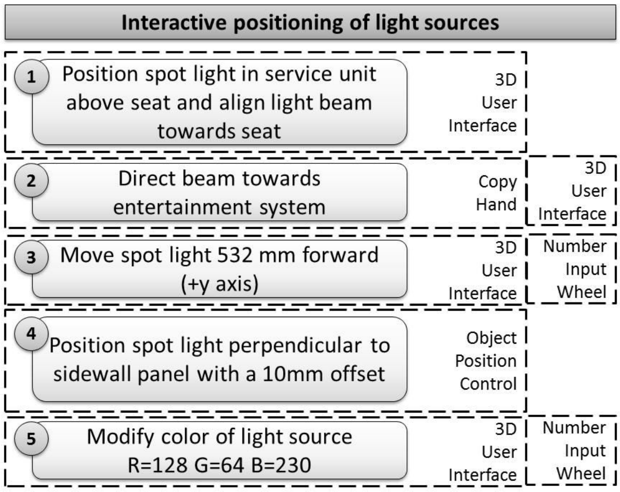

Figure 14 – Indicative user task scenario for cabin light design.

Continuing with the cabin review scenario, Figure 15, shows a part of the tasks involved. This scenario is carried out by the engineer/designer in order to observe the effects of his design in the cabin. It also utilizes the "FAP" tab of the 3D interface, through which the user is able to simulate the functionalities existing in a flight attendants' panel, such as opening or closing a group of lights located in the grip rail, or individual reading lights above the seats. Another available functionality is that the user can open and close the cabin's window shades. Based on the figure, the user first observes the lighting conditions over the grip rail and next on the cabin ceiling. He/she then opens and closes the window shades and the reading lights above the seats 1B and 1C.

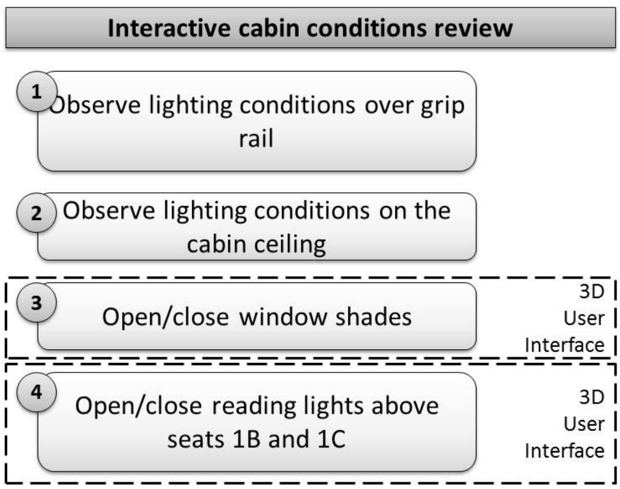

Figure 15 – Indicative user task scenario for cabin lighting conditions and effects review.

Finally, some additional interactions were facilitated in order for the immersive functionalities to be ensured in a complete context. The user controls through his/her input device a virtual pen inside the environment. This pen is used for selecting points in space and for navigating in the menus of the 3D interface. In addition, through the intersection test, the user is able to grasp and manipulate directly the 3d objects of the scene. Another manipulation technique developed for the environment is the "copy-hand" technique, through which the user can remotely change the orientation of a light source and consequently, its light beam, by changing the orientation of his/her hand. At last, a measuring tool function is accommodated that allows the user to select two points in space and measure the distance between them.

3.3. EVALUATION AGAINST INDUSTRIAL REQUIREMENTS

The evaluation and validation of the VR environment, developed in this study, was based on industrial requirements from the aerospace industry. The scenarios of the use-cases were developed, based on the "essential user task scenarios" template, specifically designed for developing scenarios validating the technologies together with the human factors requirements. In brief, for every scenario, this template included the targeted actors, the plot, goal/objective, the human factor objective and measurement of the human factor. The measurement of the human factors was based on questionnaires that took into account the plot of the scenario. For example, for the cabin design, questions like "How easily does the user position the light source?" were addressed to the immersed user in order to extract qualitative feedback. The evaluation process was carried out by both experienced and novice users in the area of virtual reality. However, all users were experts in the area of engineering and design. The immersive evaluation was carried out on a step-by-step basis. The person conducting the test was reading to the immersive user the plot of the scenario and the user then made its execution as he/she thought appropriate. In Table 1, the evaluation outcome of certain industrial requirements is presented.

Table 1 – Industrial requirements and evaluation of interactions used in the test case simulation

Place object in proper position/orientation
The OPC satisfies the requirement by helping the user place an object in reference to another object's surface.
Direct manipulation, natural interaction with objects
The user is able to directly and naturally manipulate light sources either by grasping the lights through the intersection of the virtual pen, or using the copy hand function.

Integration of human body for interaction visualization
All the tasks that are carried out through the use of the techniques require the use of the user's hands. The user either controls the virtual hand with a data-glove or a tool through a tracked input device (e.g. wand). Both ways require the integration of the human body since the tracking data come from the movement of the user's body.
Interaction metaphors must work for head mounted displays (HMD) and projection walls
All the techniques can be utilized with the use of HMD or projection wall displays since none of them depends on the devices used for visualization purposes.
One hand manipulation
The techniques provide one hand manipulation of objects through selection and movement.
Intelligent interactions with objects
The OPC can be characterized as intelligent technique since it uses algorithms that recognize the surface gradient.
Facilitate the execution of complex interactions
The 3D interface metaphor helps VR users to perform complex functions in the environment.

Most of the comments were positive about the usability and intuitiveness of the interactions. Besides fulfilling the industrial requirements though, the users expressed their preferences and likes and dislikes during a post-evaluation debriefing. For the 3D interface, the users indicated that it provided an easy way of controlling all those complex functionalities in the environment. It was also very important that the structure followed the logical flow of the tasks. This helped a lot especially where the novice users were concerned. On the other hand, the position of the screen, in front of the user, was not always in a very ergonomic position. It needed a better calibration in respect to the distance between the screen and the head of the user. The object position control together with the rest of the manipulation techniques were easy to apprehend and intuitive to use. Regarding the three different alphanumeric input metaphors, the users expressed a preference to the flower input wheel, because of its usability. Although the other two metaphors were also very interesting to use, the flower input gathered most of the positive comments. As a whole, the environment developed, provided a satisfactorily complete platform for prototype design and review, since it could accommodate many design tasks, related to the aircraft cabin.

4. CONCLUSIONS

The study shows the potential of new VR techniques for use in prototype designing and review. The developed techniques are provided as tools in support of the complex tasks, related to design and are validated in an industrial use-case, derived from the everyday practice of the aerospace industry. The evaluation was conducted based on the fact that the use-case highlighted the potential of the techniques and the usability and flexibility that they provide to an engineer/designer. The new arising technologies reignite the interest around VR and stress the advantages of virtual prototyping. In this context, Figure 16, depicts two images of the same simulation test. The upper image is a screenshot from the simulation environment developed for this study, while the lower image is a real-life photo from the inside of a modern airliner cabin during the testing of interior lights. The virtual cabin has been set up to closely resemble some key light sources from the real cabin in order for the capabilities of the application to be demonstrated. The most important aspect of this comparison is the fact that a light designer would need only a few minutes to adjust, modify or even create a new light source in the cabin and observe the effects in the environment, while it would take him many hours to do so in a real cabin prototype. The value of the design environment developed can also be reckoned with the fact that the application itself is designed in such a way so as to enable designers and engineers, who do not have great experience in the VR technology to make use of it.

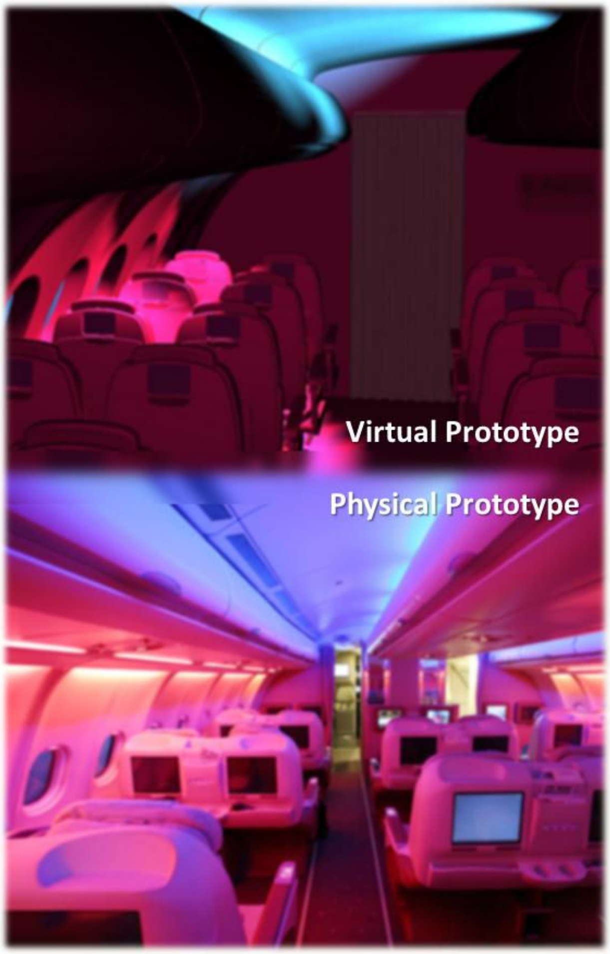

Figure 16 – Comparison between simulated cabin lighting and real aircraft light testing.

5. ACKNOWLEDGMENTS

This study was partially supported by the project VISION/ AAT-2007-211567, funded by the European Commission in the context of the 7th Framework Programme.

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