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Multifunctional Virtual Screen: a 3D User Interface for stylist and mechanical engineer

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ABSTRACT

Nowadays, companies need to use cross-disciplinary collaborative and human centered design methodologies for product design to remain competitive. In order to achieve this kind of methodology, cross-disciplinary actors need tools to understand each other. Virtual Reality and 3D User Interaction tools are good solutions to provide these intermediate resources. This study presents a tool dedicated to stylists and mechanical engineers so that they can converge more rapidly and efficiently to an acceptable product. This tool provides mainly a dynamic real-time cross-section view and a multi-material window for a 3D model.

RESUME

Actuellement, les entreprises se doivent d'utiliser des méthodologies de conception collaboratives et centrées sur l'utilisateur afin de rester compétitives. Pour pouvoir mettre en place ces méthodologies, les différents acteurs impliqués dans le processus de conception, provenant de différents métiers, ont besoin d'outils pour se comprendre et travailler efficacement ensemble. La Réalité Virtuelle et les interactions 3D centrées utilisateur sont de bonnes solutions pour fournir ces outils et ressources interdisciplinaires. Cette étude présente un outil dédié aux échanges entre designers industriels et concepteurs mécaniciens qui pourront, grâce à lui, converger plus rapidement et efficacement vers un produit satisfaisant. Cet outil fournit principalement une fonction de vue en coupe temps réel et une fenêtre mobile de masquage multi-matériaux utilisable sur un prototype virtuel.

KEYWORDS: Virtual Reality, 3D User Interface, Cross-disciplinary, Collaborative tool.

1 INTRODUCTION

Within a very competitive industrial environment, every product development tends to be more rapid and technologically satisfactory while less expensive. In order to fulfill all these constraints, companies tend to underestimate aspects such as the integration of the human factors. As a result, many current products have not been designed to fulfill the end user expectations [19]. In order to help companies to add the human factors in their product development cycle while achieving competitiveness, human centered collaborative design methodologies has been developed [21][17]. These methodologies

are based on a cross-disciplinary synchronous approach [22][20] and integrates tools to facilitate interactions between the various occupations involved in the product development, such as ergonomists, stylists and mechanical engineers. Each of these areas of expertise employing its own culture, methods or even sometimes vocabulary, full collaboration is often quite difficult to achieve [12].

As shown in Figure 1, there are many interactions between ergonomists, stylists and the design office (generally mechanical engineers) where full and efficient collaboration is needed to reach the common objective (the final product). In order to ease this collaboration, the cross-occupation team has numbers of ways and tools to share and translate information such as specific software programs [11] and common representations named intermediate design representations [15]. These intermediate representations can be ideas, sketches, digital mock-ups, physical prototypes [7].

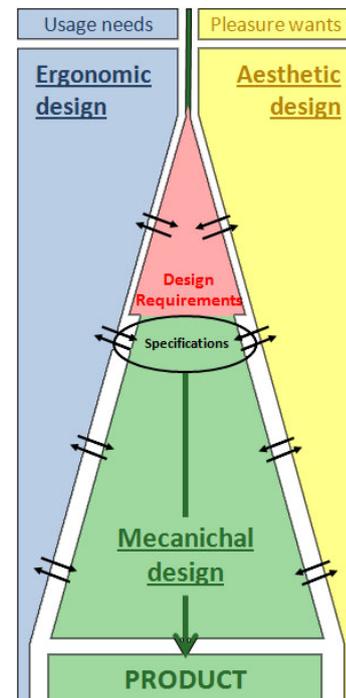


Figure 1. Principle of global product development cycle from Guerlesquin and Sagot [13]

In order to reduce the number of expensive physical prototypes in product development cycle, companies are using virtual

prototyping for some years now [24]. Within this digital framework, along with traditional CAD tools, companies have been using Virtual Reality as a tool for more efficient virtual prototyping.

According to Fuchs et al. [10], the main purpose of Virtual Reality is to allow one or more person to have sensor-motor activities within an artificial world which can be a simulation of certain parts of the physical world. So, VR can accelerate design reviews and concept research by providing a way of observing the product which was not possible before in the early development phases. In order to immerse even more the user(s) into the design review, Virtual Reality should enable the users of the virtual environment to interact with the virtual prototype.

Along with the integration of ergonomics studies in the development process, Virtual Reality can be used as a new design tool that allows the study of usability within each phase of the product development process [5]. Within the methodology detailed by Mahdjoub et al. [18], Virtual Reality is considered as an intermediate design representation [3]. It can be used for example as a tool to allow mechanical engineers to share more efficiently with ergonomists involved in the product development, or to allow ergonomists to follow and interact with the evolution of the product design from the very beginning. In order to adopt the same philosophy with stylists, there is a need of specific Virtual Reality based tools to allow them to be part of the VR-aided collaborative design process.

Some works have already presented examples of CAD or design solutions using virtual reality, so that stylists and mechanical engineers can directly create or modify their product within the virtual environment. For example, Kavakli et al. [16] presented a gesture-based interface for designing in Virtual reality that allows the designer to access to the basics functions of CAD within a Virtual Environment. Weidlich et al. [25] presented solutions to improve efficiency of VR-Aided Design with specific design guidelines. Sung et al. [23] presented an immersive and guided design environment in which every action of the designer is monitored and analyzed to grow a knowledge base that provides assistance for the following design projects.

Some examples of virtual collaborative environments exist such as the VCEAD [8] which provides a virtual prototyping and communication features for synchronous collaboration between geographically distributed designers.

These examples address only to one single occupation, even if they are collaborative. There is a lack of inter-occupation collaborative tools, even more using Virtual Reality and specially a tool to allow mechanical engineers and stylists to share technical or specific information about the product.

This work presents a tool that has been designed to stand for an intermediate design representation between stylists and mechanical engineers. So that it can ease the setting up of a cross-disciplinary collaborative and human centered design methodology for product development in an industrial environment. This tool is more particularly dedicated to help mechanical engineers and stylists to share information and work more efficiently together.

First, we will focus on the needs of each occupation within a collaborative environment. Then, we will present the interface through the chosen interaction solutions for each of these needs. Finally we will concentrate on the technical aspects of the virtual

environment, and the 3D User Interface and present further works around this thematic.

2 3D USER INTERFACE DESIGN

Relatively to the principle of global product development cycle, there is a need for tools to ease the communication between its members. Here, we will focus more particularly on the needs of mechanical engineers and stylists when they need to share specific information and bypass the gap between their specialties.

In order to design a tool that will be able to fulfill this function, it was essential to identify all the issues encountered by mechanical engineers and stylists when working in a collaborative environment. These specifications are based on interviews with mechanical engineers and stylists accustomed to this collaborative process and on the expertise of user-interface specialists.

2.1 Needs for the mechanical engineer

In order to analyze the needs of mechanical engineers when working in a collaborative environment, we concentrated on what kind of tools and what kind of data representations they commonly use in product development cycles. Within traditional asynchronous product development cycles, cross-section views are part of the mainly intermediate design representation used to share information between process actors. These representations are used, in conjunction with office automation and 3D pictures, as intermediary objects between stylists and the design office; and between the design office and the manufacturing process.

In fact, cross-section views are used by mechanical engineers to carry out the technical validation of the design propositions. They use it in order to identify the internal interferences (internal collisions between parts), for internal clearance analysis, and for kinematics analysis. The results of these reviews are then sent to the stylists that return new design propositions and the cycle start again until every problem has been adjusted. The same process is used with the manufacturing process. As each of these trades is not able to read efficiently complex cross-section views, a lot of time is lost in remote explanations and expensive comings and goings.

In order to set up a full synchronous cooperative design process, a tool should be supplied to efficiently share the essential information between mechanical designers and the other actors of the design process. This tool will have to supply a cross-section view within the product's context to ease its comprehensibility, allow the user to choose dynamically his or her cut plan, and provide information about the kinematic of the product.

2.2 Needs for the stylist

Within a traditional methodology, stylists start working on colors and materials by defining a rough color atmosphere for the product according to their own experience, the target user and their artistic feeling. The customer and the stylist then define more precisely a few possible color directions. According to these directions, the stylist chooses material and suppliers. The chosen materials and textures are then applied to a 3D model of the future product in order to compare them in situation. The choice is then made according to the experience of the stylist and to the will of the customer.

Our tool must bring improvements to this process by allowing the designer to compare materials within an immersive virtual environment. He or she will be able to examine two different materials applied to the object in order to compare them more

efficiently. Moreover, the immersive environment allows the stylist to see the product (and the material) at full size, so that he or she can appreciate large surfaces in the case of large objects. Also, the immersive environment will allow the designer to turn around the object and observe it from different angles, which would have cost several rendered 3D views within a traditional process. Finally, our tool should allow the user to capture user's current point of view, and allow him or her to highlight specific details by drawing or placing symbols directly on the virtual screen.

2.3 Integration in a collaborative design methodology

One of the most important points in a collaborative environment is to give users tools to share information and highlight specific details that they are explaining. So, our tool should handle hand drawing and symbols placement on the virtual screen.

Of course all these marks should be erasable when needed, and an additional function should let the users save what they are currently observing for further use.

3 MULTIFUNCTIONAL VIRTUAL SCREEN: THE CHOSEN SOLUTION DETAILS

3.1 Overview

In order to implement our experimentations, we use a virtual reality platform named PREVERCOS, for Virtual Reality Platform for Systems Ergonomic and Design:

- Active stereoscopic visualization system composed by three screens (two walls - 2.10x2.80m and a floor - 2.80x2.80)
- An optical tracking system (head and two hands are tracked for this tool)
- Two data gloves

This system provides a strong immersive feeling and allows collaborative work in terms of size. For this tool we used Virtools™ Dev software environment from Dassault Systems.

Our tool comes in the form of a virtual planar object, comparable to a 2D transparent screen “floating” around the user in the virtual environment. This virtual object can be assimilated to a 3D User Interface as defined by Bowman et al [4].

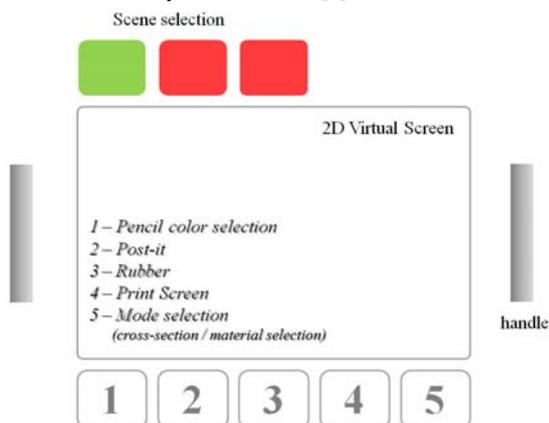


Figure 2. Multifunctional virtual screen interface

This tool is meant to be a multi-user virtual reality tool, so that the “main” user (the one who will interact with the scene) can explain and share about some specific aspects of the prototype that is reviewed. This main user is equipped with two data-gloves, one head and two hand tracking targets, so that the user can naturally grab the screen by hand, and interact with the current 3D model by intersecting it with the plane. The screen also offers a variety of functions to ease the interactions between the mechanical engineer and the stylist (see Figure 2).

The virtual screen offers two main functions: one designed for mechanical engineers and one designed for stylists. In the first case, when the screen plane intersects the 3D object model, the object is cut in real-time along this plane (Figure 3).



Figure 3. Dynamic real-time cross-section view function

In the other mode, the user can observe the 3D object model covered with another material through the screen (like a window). The user can also obtain a half-covered version of the object by intersecting the screen with it (Figure 4).

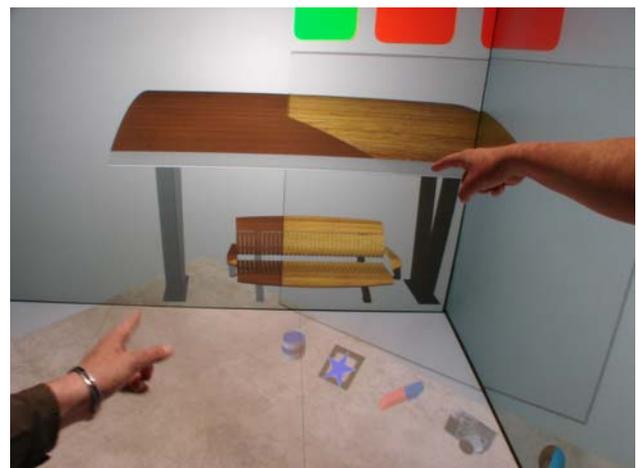


Figure 4. Multi-material masking function

3.2 Detailed description of each element

3.2.1 Hand manipulated screen

In order to move the screen in the virtual environment, and interact with the 3D model, the user can grab it with its hands by one or both of the two handles. The action of “grabbing” is detected by the data-gloves. In order to allow a maximum of flexibility, a handle has been placed on each side of the screen, so that either a left-handed user or a right-handed user can easily move and orientate the screen easily. Anytime the user grabs a handle, the virtual screen will follow the position and orientation of the active user’s hand. If the user grabs the two handles simultaneously, the center of the virtual screen will follow the center point between the user’s hands, *ibid* for its direction.

An intuitive 3D User Interface using hand gestures has been chosen for the handling of this tool. Indeed, here we exploit a mental representation (schema) of moving a flat object through space to cut a 3D model, which is basically the mental representation of actions carried out by a mechanical engineer when he wants to draw a cross-section view. Using a schema often makes an interface “transparent” (as defined in [10]) – they do not need any learning to be used efficiently by the user. Depending on how the user grabs the screen, the handling will be provided by either a bimanual or an asymmetric bimanual interaction technique [4].

In order to help the user to grab the handle more easily in the 3D environment, a behavioral software help has been set up around each handle. When the user’s hand (cursor) is close to one of them in the virtual environment, an automatic software behavior change the shape of the cursor (by a hand shape) and magnetize it to the related handle, so that the user can grasp it more easily.

3.2.2 Moving around the object

In order to review the virtual prototype in its wholeness, the user(s) must be able to move all around the object and get closer as much as he (they) wants. Once the global position of the user relatively to the object is satisfactory, the user will obviously be able to orientate the viewing direction by moving his own head. This way of moving for the user is meant to imitate the way of moving around a physical prototype.

As the user’s hands are already used to interact with the virtual screen, we chose to provide him with a feet interface, so that his hands remain free at any time. We used an 8 buttons dance mat (Figure 5) with which the user interacts with his feet. Using the left and right arrow, the user can rotate around the object and using the up and down arrow he can get closer or move away from the object.

As studied in [2] with children, the dance mat is a body-centered travel technique. This technique allows the user to use a locomotion metaphor for travelling in the virtual environment; indeed the user must physically make a step in the direction of movement. The previously quoted study highlights the fact that the main drawback of this physical interface is the continuous pressing of the user foot on the direction arrow that can lead to fatigue or loss of balance in case of long distance travel. In our case, the dance mat interface is only used for short distance travels in the virtual environment (moving around the virtual prototype) so that the main advantage of this interface, let the user’s hands free while travelling, is prevailing.



Figure 5. 8 buttons dance mat

3.2.3 2D User interface attached to the screen

More than a simple window movable in space, the multifunctional virtual screen provides access to a number of additional functionalities. In order to allow the user to access these functions when he needs them, we enhanced the virtual screen with a Graphical User Interface. We used the specifications presented in the Dachsel et al. taxonomy [6] to choose the type of our interface. We needed to display a limited number of items and let them visible all the time, so we chose to implement a *Single Menu*. This type of menu includes toolbars and tool palettes. In order to attach the interface to the virtual screen while not blocking up the user’s point of view, we decided to choose a free arrangement structural layout for the menu items. In order to avoid the problem of text readability in VEs, we chose to display standard symbolic 3D icons. The virtual palette is the most similar menu type among the types referenced in the taxonomy, so we adapted this menu type to our virtual screen as depicted in Figure 2.

In order to activate the menu items, the user just needs to touch them with one of the virtual cursors attached to his hands through a 3D collision detection. The three color squared buttons above the screen allow the main user to switch between available scenes (between 3D models). Below the screen, the user can (from the left to the right): Choose the color of the pencil to draw on the screen, choose the shape of the symbol to draw on the screen (or deactivate symbols), erase everything printed on the screen, save a picture of the current point of view, and switch between the two main modes (cutting plane or material window).

As briefly mentioned before, the main user can draw directly on the screen using his hand. He can either draw random shapes using the basic pencil function, or print some symbols (predefined shapes to annotate information). We chose here to exploit another schema, the drawing board. Indeed, it is very difficult to annotate or draw directly in space. Here the 2D virtual screen can be assimilated to a 2D virtual prop to hold the annotations and sketches.

In order to print something on the virtual screen, the user can use equally both of his hands; he just has to use one of the gestures recognized by the data gloves (closed hand or pointing forefinger), and touch the screen with one of the virtual pointers attached to his hands (Figure 6). This annotation function is particularly useful when the mechanical engineer needs to illustrate some particular point by highlighting some details directly on the cross-section view or when the stylist needs to highlight a specific aspect of the product design for a next review.



Figure 6. Bimanual asymmetric sketching/drawing function

Here the two handed interaction is particularly justified. Indeed, even if the user can choose to draw on the screen when this one is “floating” in the air, the action to hold the screen by one handle and drawing with the other hand provides a substitute to a real prop. As described by Guiard [14], this task of drawing on a hand supported prop is part of the bimanual asymmetric tasks (cooperative manipulation). In this particular case, the holding hand defines a spatial framework for the actions of the drawing hand, which efficiently compensate the lack of physical drawing prop.

3.2.4 3D models

In the current demo version of the virtual environment, three 3D models are provided to test functionalities.

The first one is a prototype of a public bench and shelter. This model is mostly dedicated to test the stylist functionalities.

The second one is a mechanical part of a water pump. This model is mostly dedicated to test the mechanical engineering functionalities.

The last one is a full lint razor. This model can be animated when pushing the on/off buttons in the virtual simulation. It is mostly dedicated to experiment on the multi-actors information sharing.

4 SPECIFIC TECHNICAL SOLUTIONS

Adopting a more technical point of view, in order to fulfill the two main functions of our tool, we needed to find efficient and satisfactory solutions for 3D real time cross-section views and multi-material objects. These two specific points can be very challenging to achieve using traditional and simple computer graphics techniques.

4.1 Solution for volumic 3D and cross-section view in Virtools™

In order to render the real-time cross-section view of the object, we used a computer graphics technique in Virtools™. A 3D frame is linked perpendicularly with the virtual screen. Then for every object, we apply an alpha map from which the orientation is defined by the orientation of the 3D frame attached to the virtual screen. This alpha map creates the effect of cutting the 3D object (the part of the object located over the screen becomes transparent Figure 7).

The problem of the thickness of the 3D models is handled by a pure infographical technique. For every 3D object that the plane can cut, we create a copy of this object with every normal inverted. Then, we modify the material of this copy to set the emissive component to its maximum in order to deactivate inner shadows. This technique gives the impression of thickness for any traditional 3D mesh and the visual result is quite satisfactory for the simulation.

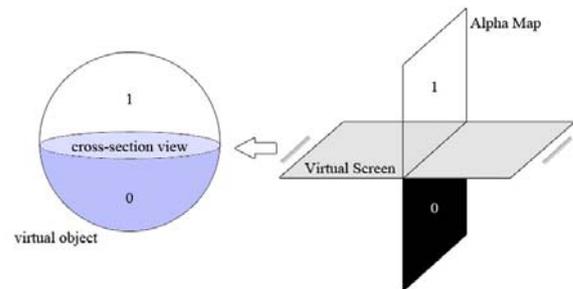


Figure 7. Technique for real-time cross-section view

4.2 Multi-material on the object

The multi-material functionality is handled by a masking technique. We apply a multichannel material to each part of the 3D model. Each channel corresponding to one material to test out. Then, the choice of the displayed material is made according to a masking technique, using the virtual screen as the referential mask.

5 FURTHER WORKS

In order to improve and evaluate our current version of this collaborative tool, we will enlarge the number of interviewees and identify the weaknesses and the lacks of the current version. We will also try alternate solutions for the interface such as a physical prop (translucent Plexiglas prop), and alternate travelling interfaces in order to set up comparative tests.

In order to provide better tools, we will also focus on how to evaluate and how to design efficient 3D user interfaces dedicated to this human centered synchronous and collaborative design methodology. We will identify the specific needs for each steps of the collaborative product development cycle through interviews and provide new tools when needed. We will set up specific test sets and evaluation for each tool provided, in order to create a

complete set of tools including the whole product development cycle.

As a final purpose, we will try to determinate clear and efficient design and development guidelines for Virtual Reality 3D user interfaces creation.

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