VIRTUAL REALITY EMPOWERED DESIGN

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SUMMARY

In much the same way as other advanced technologies in the past, Virtual Reality has been used until recently only in few professional environments due to its relatively high cost. Remarkably, in engineering projects whose final product is available as a digital mock-up allowing immersive interaction, VR has already shown its great potential for design review, ergonomics and usability studies and simulation of assembly operations, among other practical applications.

At present, the increasing availability of affordable VR gear and amazing portable devices is favouring the development of new solutions in many more fields of application, including home entertainment, which will let us interact with the virtual world like never before. Definitely, VR has burst into our lives.

How these new ways of man-computer interaction are being translated into the shipbuilding business? In particular, how computer aided design and manufacturing systems are incorporating VR technology? How will the new generation of naval architects and marine engineers design?

Starting with an overview of the state of the art of this technology, our paper addresses the above questions and describes the benefits arisen from the immersive experience of true VR in the ship design and production process. Particular attention is paid to the latest VR-related features in Sener's Foran software.

NOMENCLATURE

CAD	Computer Aided Design
CAVE	Cave Automatic Virtual Environment
DLP	Digital Light Processing
GPU	Graphics Processing Unit
HMD	Head-Mounted Display
HVAC	Heating, Ventilation, Air Conditioning
LCD	Liquid Crystal Display
LCoS	Liquid Crystal over Silicon
LED	Light Emitting Diode
MTS	Motion Tracking System
OSVR	Open Source Virtual Reality
PLM	Product Life-Cycle Management
SDK	Software Development Kit
UHD	Ultra-High Definition
VR	Virtual Reality
WQXGA	Wide Quad eXtended Graphics Array
WUXGA	Wide Ultra eXtended Graphics Array

1. INTRODUCTION

The Virtual Reality (VR), which we can define as "a computer-generated digital environment that can be experienced and interacted with as if that environment were real" [1], is rapidly consolidating in response to the industry demand. It is no longer just about having 3D visualisation, moving objects or querying their properties. Now, those objects are expected to have the same behaviour as they would have in the real world, and immersive systems with much more advanced interfaces and a more natural interaction are required.

This paper is intended for ship designers and builders to get an idea of what is required to apply VR. We start with an overview of the most frequent solutions and their key components. Then we introduce the relevant features of Sener's Foran software, outline the main applications of VR in shipbuilding, and describe the new devices that are revolutionising our access to the virtual worlds. Finally, we dare to look into the future of CAD enhanced by VR.

2. VR SOLUTIONS AND CONFIGURATIONS

There are different VR solutions available in the market that are especially suitable for the shipbuilding industry. The decision on which one to implement is not easy, as they require specific hardware components that are in a constant process of improvement and there are a series of factors that may condition the choice, such as space, budget and intended use.

The simplest (and often only viable) way to easily and quickly create a practical VR environment is a transportable, self-contained system. Basically, it consists of a stereoscopic projector with a wide angle lens, a portable tracking system and a laptop computer, all packed in a suitcase, and a screen with foldable aluminium frame. When bright ambient light is a problem, a wide-screen 3D television may replace the screen and projector.

If the purpose is to set up a VR-specific room, there are several large format options. A good compromise between cost and performance is the high-resolution display wall or *powerwall*. Typically, a *powerwall* features a screen with a width larger than 4m and a rear projector to avoid shadows. In front of the screen, the working area is limited by the scope of the tracking system. These large flat screen systems allow a wide field of vision, which provides an excellent feel of immersion and interaction with the full-scale 3D objects shown.

By way of example, Sener provided a *powerwall*-based Virtual Design Center to Navantia Cartagena (pictured) in

2011, which has been widely used in the S80-class submarine programme, and another to Navantia Ferrol in 2012, for surface warship projects.

Figure 1: Cartagena VR Room (*courtesy of Navantia*)

With more space and budget, the solution may include more screens or projection faces, each one displayed by one stereoscopic projector. There are many possible configurations, from the basic two-wall (front and the floor or corner-type), through some additional side walls, to the most complete solution, the Cave Automatic Virtual Environment.

The CAVE consists of four, five or even six projection faces (typically to the front, left and right of the viewer, plus one on the floor, sometimes also on the ceiling and to the back) and delivers the greatest feel of immersion. Several persons can stand and walk freely between the screens and are immersed in the 3D world being displayed.

Figure 2: CAVE (*courtesy of ESI Group*)

In any case, the VR rooms must be dimensioned in accordance with the maximum number of participants to the working sessions, the number and size of the screens required, and the space for rear projection, among other parameters.

When analysing the cost of the solution it is also important to take into account the preparation and setting-up of the room. The performance of the equipment has equally an impact on the final cost.

3. HARDWARE COMPONENTS

The VR simulators require a series of hardware components, the most important being stereoscopic visualisation system, tracking system and computer system. We briefly describe them in the following paragraphs. Usually they also include hi-fi audio system, control system and specific supports. Their perfect integration is what creates the artificial reality where the participants can interact with objects in an immersive mode.

3.1 VISUALIZATION SYSTEM

The visualisation systems used in one-face solutions like *powerwalls* and multiple-face solutions like CAVEs consist of three main elements: screen, stereoscopic 3D projector and glasses.

3.1 (a) Screens

The screens can be for front or rear projection. Front projection screens reflect the light. The surface must therefore be highly reflective, so that the audience captures the image as perfectly as possible. At equal intensity, distance and size of the image, the front projection is brighter than that corresponding to the rear projection.

Rear projection screens diffuse the light through the material. The light source is in front of the observer, behind the screen, where space is needed for equipment and projectors. The surface must transmit an image with true optical clarity and brightness, it is therefore necessary to use a source of higher intensity.

There are screens of different types such as rigid or flexible, fixed or retractable. In terms of composition, there is the possibility of using different tissues and materials specially designed to optimize stereoscopy. Some screens can be used for both front and rear projection.

3.1 (b) Projectors

In addition to the projection size, which will obviously determine the light output, the following characteristics have to be considered when selecting a projector for a VR solution:

Type of stereoscopic projection: active or passive. In both the 3D effect is achieved by "deceiving" the sight: through the use of special glasses right and left eyes see a different image. In the passive stereo, both images are created with different characteristics, such as polarized light or colour. The active stereo is based on image separation either by location or by time.

Resolution: So far, most 3D projectors have provided Full HD (1920x1080), WUXGA (1920x1200) or WQXGA

(2560x1600). For large format sizes there are already manufacturers offering projectors with 4K resolution (4096×2160) and it will not take long until projectors with 8K or UHD resolution (7680×4320) are available.

Projection technology: LCD, LCoS or DLP. In addition, DLP has two varieties: one-chip (with colour wheel) and three-chip (one chip for each primary colour).

Image quality: The three-chip DLP technology is widely regarded as the most advanced solution in terms of image quality. However, for many applications it is enough with single-chip DLP or LCD technologies, which within the same range of price, and despite their fundamental differences, offer similar quality and performance, with slight advantage for DLP in VR-related applications. DLP projectors tend to be brighter than LCDs, which lose some light as it passes through liquid crystal displays. As a result, DLP projectors can produce high brightness in small units and use less power to achieve the same brightness levels compared to LCD projectors.

Type of light source: until recently, there was only one type, the lamp. The introduction of metal halide lamps and then ultra-high pressure mercury lamps has greatly reduced the cost of bulbs and improved their life and reliability, but current projectors using LED technology offer significant advantages over lamp systems.

Maintenance costs: the projectors need preventive maintenance. If projection technology is based on lamps, they should be replaced every approximately 2,500-3,000 hours. LED technology projectors guarantee long-term projection, maintaining a stable and operational life with 80% brightness in periods of about 30,000 hours. And new models are already doubling that average life.

3.1 (c) Glasses

The glasses depend on the type of stereoscopic projection, passive or active. In the passive stereo, special glasses filter by polarized light direction (orthogonal polarizing directions for left/right eyes) or by colour (different colour –red/green or red/blue– for left/right eyes). It is light weight and cheap technology. The (cardboard) glasses are more comfortable to wear for longer, reduce eye fatigue, offer more angle of vision, but less resolution of the final image. Examples are large-screen projection systems.

In the active stereo based on image separation by location both stereoscopic images are created at different locations; each image is channeled to the respective eye by a separate optical system. It is heavy and expensive technology (typically two monitors and optics). Examples are head-mounted displays (HMDs).

In the active stereo based on separation by time, both images are separated in rapidly alternating sequence; shutter glasses, synchronized with the rapid display, block out each eye's view accordingly. Examples are CAVE, monitor-based VR and certain large-screen projection systems.

The active glasses offer higher resolution, need a brighter panel (they darken the image), weigh more and can be uncomfortable after a long time. If the refresh rate is not correct, the left and right image channels may leak or bleed into each other, producing a ghosting effect (crosstalk), flickering or blinking.

3.2 TRACKING SYSTEM

The ability to add a motion tracking system (MTS) is the most effective way to improve interaction with complex 3D objects or datasets in an immersive environment. Usually motion capture sensors are placed on the head (attached to the glasses) and the wands for the hands.

There are several tracking technologies. One of the most frequently used is optical technology (visual tracking). Active or passive marks are fixed to the subject to be followed and their position is stored. Passive marks are illuminated by radiation sources (infrared or ultrasound) and the rays are reflected towards a detector. Active marks emit rays into the detector by themselves. Fast and accurate update rates are important.

Other frequently used technologies are electromagnetic, mechanical, ultrasonic and inertial.

For electromagnetic tracking, a stationary transmitter creates electromagnetic fields, within which moving receivers or sensors register an object's position and orientation. It is a popular and reliable method of tracking, but has some drawbacks, such as interferences with metallic objects and limited range. With low-cost devices, it may give problems of accuracy, stability, repeatability and latency.

The mechanical tracking uses a direct mechanical connection between the object to be tracked and a reference point. Typically, this linkage is a mechanical arm with rotating joints that allow for six-degrees-of-freedom control. It features high accuracy and repeatability, and low latency, but also restricted operational volume.

The ultrasonic system utilizes three or more stationary microphones that receive an acoustic signal from a moving emitter. The differences in signal time delay and triangulation yield tracking data. It is a low-cost approach, but has problems with occlusion (line of sight) and echoes, as well as limited accuracy in orientation.

The inertial tracking system uses a couple of miniature gyroscopic sensors to measure yaw, pitch and roll. These are not true six-degrees-of-freedom sensors because they measure only orientation, but they can be effective as head-tracking sensors where position information is not essential.

3.3 COMPUTER SYSTEM

In order to manage in these immersive environment the vast quantity of information contained in ship 3D models, a powerful computer system, tailored to get the most out of processors, memory, graphics cards and software, is indispensable. The hardware is in continuous evolution, nowadays computers with 4-, 6- or 8-core processors are commonly used. Some motion tracking systems require a dedicated computer to process motion calculations.

The main component of the computer system is the graphics card. Most hardware provided by different manufacturers for use in VR solutions features cards with powerful Graphics Processing Units (GPU). These devices allow to incorporate even several graphics cards.

When the VR simulator is equipped with more than one projection face, it is necessary to have computers of similar performance for each of these faces, typically configured in a master-slave architecture.

4. FORAN SOFTWARE

Foran is a computer system specifically developed for design and construction of all types of ship. It has been developed, marketed and maintained by Sener for more than fifty years.

One of the essential characteristics of Foran is the integration of the entire range of ship design disciplines: naval architecture, hull structure, outfitting and electrical. This, combined with the seamless continuity between the basic, detail and production stages of the design and the homogeneous development of all its modules, makes possible the highest level of concurrent engineering. Foran is also fully integrated with PLM systems such as PTC Windchill or Siemens TeamCenter.

Foran employs a comprehensive 3D product model as the single source of all data relating to the design and construction of the ship, which is defined in every detail. Associative or topological relationships between components permit the on-line construction of the model, propagating automatically modifications to all related components. Stored in an Oracle relational database, the 3D model (or digital mock-up) is created once and increases in fidelity as the design matures and progresses from concept through detail.

The design is not oriented to just 3D modelling. The Foran model contains not only each ship component, but also material definition, manufacturing data and production process.

From the outset of the VR technology, Sener incorporated it into Foran through its own and fully integrated development. Around the end of the 90's, the VISUAL3D module for walk-through design review already featured two of the necessary characteristics for creating VR: immersive navigation and stereoscopy. Contrary to the rest of the modules of the System, this program did not read the information from the database, but from proprietary format files, which brought some advantages such as faster reading, simplified geometry and smooth navigation through and around large models.

In the launching of the version 80 of Foran, in 2012, the FVIEWER module superseded VISUAL3D. The new module was developed for 64-bit platform, which allowed using much more RAM and therefore possibility to navigate throughout large 3D models with fluidity and ease, even when the stereoscopy is activated.

Like its predecessor, the use of special 3D files to load the information continued to be the choice in order to get acceptable performance in the rendering of the scene of a whole ship. As to its features, we could highlight the following:

- Native 64-bit / OpenGL
- Immersive navigation
- Access to different product trees
- Consultation of object technological data
- Measurements (distances, coordinates, angles)
- Annotations
- Different clipping planes of the model
- Interference detection
- Simulation of assembly/disassembly of equipment
- Movement paths
- Incorporation of light points and textures
- Multiple camera positions
- Creation of screenshots and videos at 4K resolution
- Virtual humans in different work positions
- Stereoscopy
- Motion tracking system support
- Connection to HMD devices

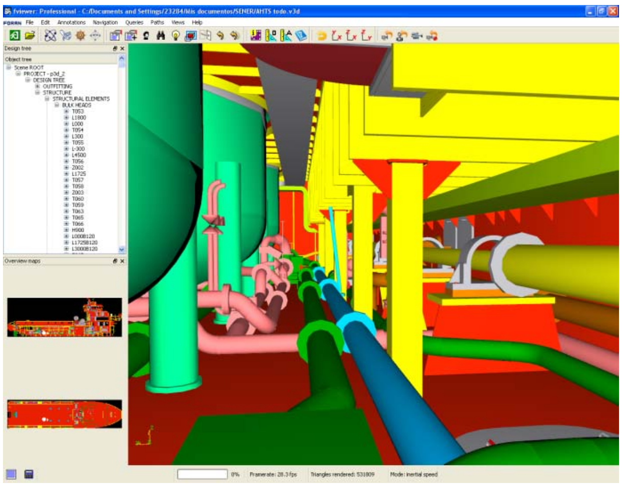

Figure 3: Screenshot of FVIEWER module

This is a complete set of functionalities oriented to design review, evaluation of design alternatives, ergonomic studies, simulation of construction, operation and maintenance tasks, and sales and marketing [2].

Taking the implementation of VR technology one step further, Sener and ESI Group, a leading simulation software company, have teamed up to provide the most advanced solutions for the shipbuilding industry by perfectly integrating Foran with IC.IDO.

IC.IDO is a powerful VR solution by ESI Group that combines high-end visualisation and real-time simulation of product behaviour in its actual size, and allows product operation very close to reality. It offers an excellent compromise between performance, working efficiency, visualisation quality, real time physical simulation of dynamic components and real time user interaction.

The integration of Foran with IC.IDO add some advance features to the above mentioned for FVIEWER, including:

- Advanced immersive user interface
- Advanced rendering of models
- Realistic presentations and animations
- Advanced ergonomics with virtual humans (in any position with total freedom of movements and field of vision)
- Tools operation
- Part and assembly behaviour
- Point cloud management
- Data import from different CAD sources
- Physics simulation (collision, friction, gliding, flexibility, kinematics, ...)
- Multi-channel support (optimized for complex CAVEs or rooms with multiple projection screens)
- Cluster infrastructure
- Multi-site collaboration

5. VR APPLICATIONS IN SHIPBUILDING

VR is one of the technologies that has the greatest future for engineering and manufacturing since it can be used to improve the design and planning in an interactive collaborative environment, providing an unprecedented understanding of the product in a complete 3D immersion.

VR can be used in different phases of the ship project, from the initial stages of engineering to the maintenance phase when the ship is in service.

A constant review of the engineering can avoid unnecessary development costs and delays in the production phase. Designers may make mistakes that can easily be identified in a virtual validation process.

The VR allows, in a much easier way than with a classic 3D CAD environment, to locate faults in the model. In addition, VR users can attach annotations related to problematic elements and share them with designers.

At this stage, it is also vital to consider different design alternatives, especially in complex projects where the information needs to be constantly reviewed, analysed and verified.

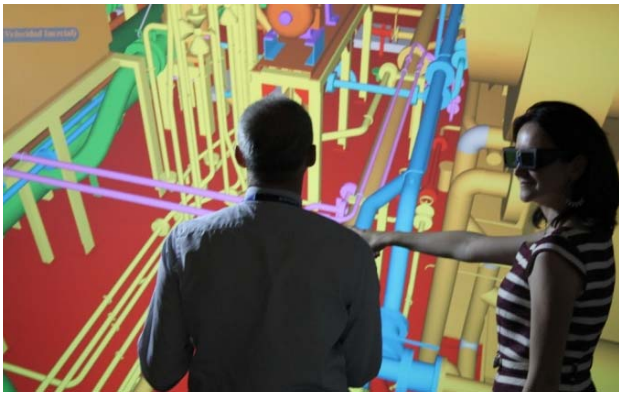

Figure 4: VR-supported design review with Foran

Another important application of VR is the validation of the production information, since any problem not detected will have an impact on the construction cost and schedule. Virtual manufacturing allows to assess if the design can be built and likewise help to define the best sequence of assembly operation.

On the other hand, having a tool that allows to simulate any manufacturing task can help to efficiently train the operators that will execute it and produce documentation, either images or videos, of the whole process.

Once the ship is delivered, regular maintenance should be scheduled. If the design does not consider this fact (which will have to be done in any case) the maintenance operations will be inefficient and will incur increased costs. All service and maintenance operations can be simulated in the immersive system. The goal is not only to learn and practice these operations, but also to optimize them. There are situations in which the crew must make repairs in difficult navigation situations and the optimal training can help. As a complement, creating 3D documentation as videos can help facilitate the work of operators and in many cases overcome barriers such as language.

During and after the development of the project it is necessary to present it to customers, suppliers and other ship-owners. In this regard, VR is a very effective way of communication. The image of the company is reinforced when performing a sales or technical demonstration in which the ship looks real even before it has been built. Definitely, VR can be one more tool for the sales and marketing team.

6. NEW DEVICES

VR has come to our homes. The race to offer new forms of entertainment and open new markets encourages major video game manufacturers to launch new devices and develop games specially designed for them.

For years, the use of HMDs has been reserved to the business world due to their high cost. Segments such as military or aerospace have been the first to adopt this type of devices in different programmes. The picture has changed radically and now there are affordable VR gear and amazing portable devices that allow us interact with the virtual world like never before.

There are from complements to adapt our smartphone to a housing equipped with lenses so that we can experience a stereoscopic visualisation with certain apps, to 3D glasses equipped with displays that provide us a feel of immersion very similar to what we would experience in a sophisticated CAVE.

Here we focus on those portable devices that currently meet the requirements of VR for shipbuilding with acceptable performance, in other words, with graphic processing capability enough for handling the heavy 3D models of a ship. Good examples are Oculus Rift or HTC Vive, in combination with a powerful personal computer equipped with a graphics card suitable for stereoscopic rendering (nVidia GTX 970, AMD Radeon R9 290 or superior) and at least 8GB RAM.

These devices, comfortable and light, offer the possibility of using motion tracking controls as an extension of our body, include different sensors like accelerometers and gyroscopes.

And the manufacturers supply software development kits (SDK) for third parties, for instance CAD programmers, to develop applications, built upon a powerful and complete rendering kernel, that exploit the full capabilities of the new devices.

When developing said applications some fundamental aspects must be considered:

- The design of the motion system within the scene cannot follow the conventional rules, as special care must be taken not to cause excessive dizziness in the user.
- The ability to interact with nearby objects in a more natural and flexible way requires higher quality in textures.
- The interaction with the environment is different: not only through the use of pads, but also by hands tracking.
- The high resolution of the screens (usually 2169x1200) requires graphic processing capability to achieve from 60 to 90 frames per second.

Rendering, image ratio, working resolution, head-tracking operation, point-of-view control, position tracking, scene acceleration control, motion speed, camera position, stereoscopy settings, user interface, … are just some of the aspects that software developers must be aware of to obtain the desired result in the immersive experience.

It is not easy however to develop a valid application compatible with different devices. That is why the OSVR project presents an open SDK to create universal content for VR that can be targeted by device manufacturers as well as the open development community. The adoption of this SDK by all manufacturers would allow in the future the compatibility of third-party software with a wide variety of glasses and new VR devices that may appear in the market, with few modifications at the code level.

The OSVR project is led by Razer but other leaders in VR devices such as Nod and Leap Motion also participate in it. OSVR also has its own hardware development kit, which includes a device (OSVR HDK2) similar to the Oculus Rift.

Oculus Rift, HTC Vive or OSVR HDK2 are examples of VR gear currently available, but new hardware and software development kits are appearing on the market, for a growing community of developers to design more and better applications. The growth of this market will make prices even cheaper and VR definitely incorporated into our everyday life.

7. THE FUTURE OF SHIPBUILDING CAD

In the industry in general, the shipbuilding field in particular, most VR tools have their application when a 3D product model is available. For uses such as analysis of the production information or operators training, their application is possible as the 3D information is practically the final version given the design maturity.

As previously mentioned, main applications of VR in ship design and engineering are the review of the model aimed at identifying errors and the evaluation of alternatives. This review-and-modification process is realized mainly in projects where there are complex zones, such as the engine room of a ship or a cramped submarine, and it is necessary to iteratively refine the 3D model, moving from the CAD workstation to the VR simulator successively until the project is validated. This process is costly, as it implies generating the 3D models, transferring them to the VR software and reviewing them with some additional information.

The immersive environment, with the designer “inside” the scene, permits much better understanding of the space in a much more natural way. And it would be nice to be able to act directly over the 3D model and make the necessary changes there. This would save time, especially in those of high complexity.

Some typical tasks for which this new way of working would be really feasible are: equipment layout (positioning and displacing items and even affecting surrounding elements), routing of pipes, cable trays and HVAC ducts, insertion of fittings, definition of supports and other outfitting structures, …

Having a CAD system that allows modifying elements directly within an immersive environment would also be very useful in collaborative sessions in a *powerwall* room or a CAVE where different engineers make decisions. The possibility to make the changes in real time can result in significant time and cost savings.

Another field of application where VR may do the job is production organization. The 3D model is created according to design criteria, but it must also be organised into a product structure based on a build strategy, that is, a breakdown of elements adapted to the different production units. The assignment of objects to the different units could be done easily and intuitively within the virtual scene. This would be applicable to structural assemblies as well as to pipe piece fabrication and mounting.

In our opinion, the CAD systems should evolve in order to ensure that VR technology be used directly whenever necessary or convenient. Thus a new future would open to designers, who could place themselves inside the scene and create or modify elements in a way never experienced before.

The incorporation into ship design of CAD tools compatible with devices such as those described in precedent paragraphs (HTC Vive, Oculus Rift, Razer OSVR HDK2 or similar) would allow designers to use VR more generally and at a less cost, shortening the overall design-review-modification process.

For a CAD system to allow working in an immersive environment, it must evolve in the following aspects:

- Graphics engine: modelling tools must include advanced graphics and rendering engines that allow a fluid immersive navigation with stereoscopy as well as compatibility with VR gear.

- Performance and massive use of data: the system should be prepared for handling huge volumes of information, which may be stored in a database and must be loaded dynamically in the scene during the working session.

- User Interface: the monitor has been replaced with VR glasses; the mouse, with handheld devices such as wands or joysticks. The designer cannot see the traditional keyboard. The interface in traditional CAD does not serve anymore and the commands must be invoked in a much different way (voice, gestures, …).

Sener software engineers are now working on the development of a new, modern graphics engine, the heart of Foran. This involves not only a visual change, with photorealistic rendering, stunning animations and new visualisation modes (shadows, cell rendering, point clouds, textures, stereoscopy), but above all a functional change to endow the System with new features (object handlers, interactive 2D/3D handling, walk-through navigation mode) to exploit to the full the potential of all the different graphics cards currently available and to connect the visualisation system to new technologies such as CAVEs and HMD devices.

8. REFERENCES

1. JERALD, J., 'The VR Book: Human-Centered Design for Virtual Reality', *Morgan and Claypool Publishers*, 2016.

2. ALONSO, V. et al., 'Advantages of Using a Virtual Reality Tool in Shipbuilding', *Proceedings of COMPIT*, 2012.

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