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3D VISUALISATION OF SUBMARINE RESCUE SYSTEMS AND RESCUE MISSION SIMULATION

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SUMMARY

The three-dimensional representation of complex mechanical structures has recently received substantial research attention as it assists significantly during the design review process. Being the epitome of engineering products, submarine designs have an additional need for not only structural visualisation but also for mission rehearsal and analysis of on board procedures. This paper presents the visualisation process of a submarine rescue vehicle (SRV) and the re-enactment of a rescue mission in a 3D virtual environment. This case study was primarily used by the contractors for processes evaluation and potentially for training. Finally the paper discusses the potential benefits of presenting the systems and processes in a real time, direct manipulation, virtual environment.

Keywords: 3D design and construction, 3D mission rehearsal, Inspections techniques.

1. INTRODUCTION

Current CAD programs enable review of the mechanical systems by assessing the 3D models. It possible to animate operation sequences as non-interactive, off-line rendered video using fixed cameras. However, it is a rather challenging, if not impossible, process to assess operational aspects in real time. Our system, developed upon existing VR capabilities, can provide a substantial level of flexibility through the free manipulation of time, moving cameras and cutaway views within an animated sequence (Naef et al, 2006). This is feasible by employing a number of interaction techniques relying on visual, haptic and auditory cues.

Notably our core research does not focus on the technological advances of the aforementioned VR system, but to the Human Computer Interface (HCI) and the VR simulation which was developed explicitly in a user-friendly virtual environment. Hence this study is user-centred, as the main objective is to enhance and accelerate the understanding of complex mechanical systems and operational procedures.

During the development of the VR simulation system, the team of naval architects and engineers highlighted that our type of VR system could provide them with a unique toolkit for three different purposes; aiding the design process, explanatory presentations to the end users and, potentially, to assist with operational planning. These three aspects will be explicitly analysed in the following sections.

The paper is structured as follows: Section 2 offers a brief overview of the initial predetermined simulation with regard to the development process and the original outcomes. Section 3 discusses the rationale behind the development of an agile system which could facilitate the three aforementioned requirements. Section 4 presents the simulation requirements for valid structural representation and operating scenario re-inaction with emphasis on the development of an interface which will follow closely current human-factors norms. The final Section 5 discusses the potential benefits and pitfalls of the proposed system. The paper concludes by outlining the imminent research areas and a tentative plan for future work.

2. PREDETERMINED MODELLING AND SIMULATION

Advances in digital modelling and simulation have fostered the development of complicated structures with minimal design time and implementation costs during the development process (Anderson et al, 2002). This occurred mainly due to the elimination of intermediate levels of physical prototyping which can be exceptionally costly and lengthy processes. Thus the vast majority of structural alterations and design evaluation can be achieved considerably faster in CAD programmes. Additional evaluation of large scale virtual models can be achieved in large virtual environments (Charissis et al, 2007). However, due to the unusual and inherently hazardous nature of submarine rescue, the engineers and end users face a number of additional engineering and operational challenges particularly in the area of human factors. In the case of submarine rescue, the most obvious challenge lies in the difficult task of safely transferring potentially injured and pressurised, submariners (Rescuees) from a distressed submarine back to the surface and into a decompression / medical treatment facility.

James Fisher Defence (JFD) and the Digital Design Studio (DDS) jointly developed a predetermined simulation of the rescue process based on highly detailed 3D models in order to provide the users with a simple and understandable communication method of the procedures involved in a rescue mission. Additionally, the final visual reconstruction was effectively used as a presentation and to provide explanatory material to demonstrate the SRV's capabilities to potential customers. As such the 'Submarine Rescue System' project was divided into two levels of development.

2.1 MODELLING

The scenario under simulation, defined by James Fisher Defence (JFD) engineers, comprised of three main systems: the SRV and rescue equipment provided by JFD, the mother-ship (MOSHIP) carrying the rescue spread, and a damaged or distressed military submarine (DISSUB), randomly selected, which in this case was an SSN Akula Class (BARS Type 971).

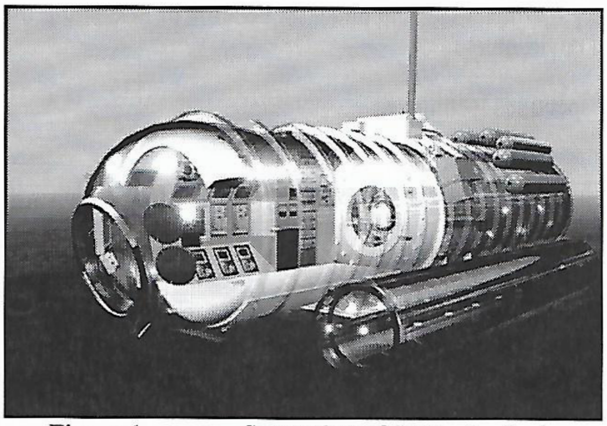

Figure 1. Screenshot of SRV selectively transparent sections.

All three systems were precisely modelled with the use of CAD and advanced 3D visualisation programmes. The SRV and DISSUB's level of detail are illustrated in Figures 1 and Figure 2 respectively. Particular emphasis was placed on the SRV structure and the associated launch and recovery, decompression facility and 'transfer under pressure' systems.

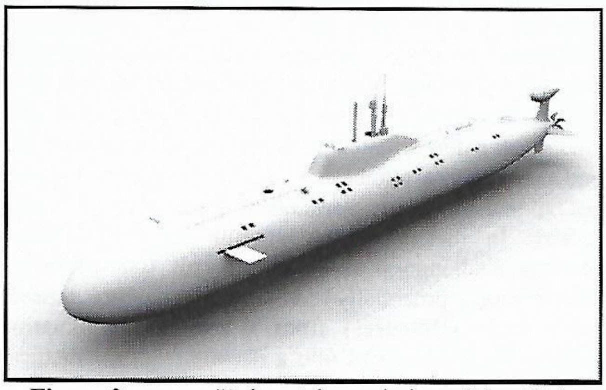

Figure 2. Volumetric rendering of the Akula class submarine

2.2 SIMULATION

The predetermined simulation scenario was developed in order to thoroughly explain the operational procedures involved in a rescue mission. The dive cycle of the Submarine Rescue Vehicle (SRV) from the MOSHIP was comprehensively described.

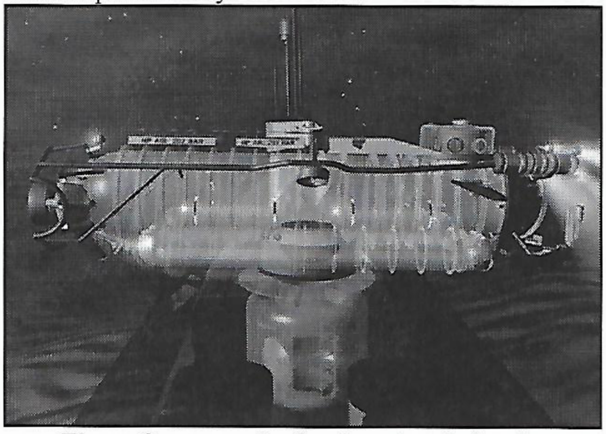

Figure 3. Explanatory shot during the connection of the SRV and the DISSUB

Wherever possible explanatory text was introduced to assist the potential users in the faster assimilation of the information provided. Low underwater visibility and accurate lighting was simulated to demonstrate the actual conditions near the seabed in realistic manner, as typically encountered by the SRV pilots. Precise manoeuvring of the SRV into position on the DISSUB was also replicated in order to mimic all the different aspects of such a mission as precisely as possible. Excerpt from the sequence is depicted above in Figure 3. The final predetermined simulation was produced as an animation, assisting users in understanding the structural elements of the system, the complex operational procedures and the human interaction. Additionally the proposed HCI system provides the users with the opportunity to revisit the explanatory information either with regard to the structural elements of the vessels or for rehearsing the rescue mission overall. Elaborating in the above objective, the following section describes the rationale behind the development of such a simulation and elaborates further on the real-time simulation scenarios that could be hosted in a virtual environment.

3. RATIONALE

Predetermined visual simulation scenarios that allow the users to maniupulate time, cameras, object transparency and cutaway views could facilitate in numerous ways the development process of complex products (i.e. Submarine Rescue Vehicles) and the overall understanding of the procedures that take place during the operation of such systems as illustrated in Figures 4 and 5. Additionally simulation of human factors and interaction could be extended to the hosting vessels (i.e. MOSHIP) with simulation through computer aided ergonomics based on the different operational scenarios (Karwowski et al 1990).

The benefits of employing such virtual representations, simulation and animation tools can be investigated with regards to both design evaluation, explanatory presentations and operation planning as described below.

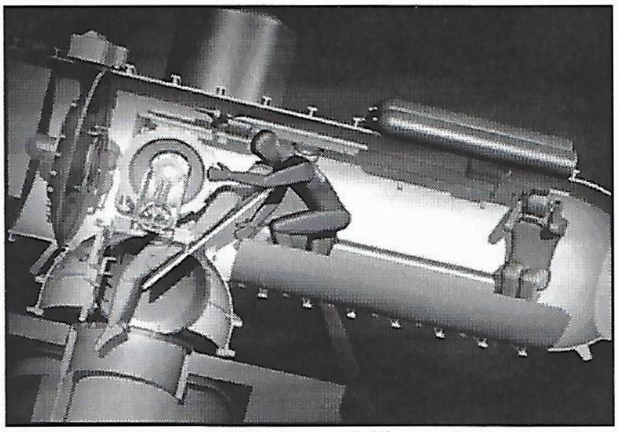

Figure 4. Human modelling and movements simulation: Evacuation of an immobile rescuee.

3.1 DESIGN EVALUATION

3D visualisation and simulation of the structural design can offer naval architects and engineers an early stage appraisal of the complete system. Such insight can significantly minimise the ergonomic errors in the design process. In turn, optimisation of the ergonomics can be achieved through digital prototyping with significantly lower cost than complete physical mock-up models for evaluation (Chaffin, 2001). Evidently the vessel developers can present to the customers a genuine insight into the complex functionalities and design features involved in such a multifaceted system. For example, an ergonomic model demonstrating the transfer of an able bodied or stretcher-bound rescuee from the DISSUB up though the submarine escape hatch, through the SRV transfer skirt and into the SRV pressure hull, was created to demonstrate the suitability of the physical layout of the SRV's hull configuration.. Human modelling and movements simulation can be introduced in order to identify potential hazards and obstructions during the operation and transfer between systems (Raschke, et al 2001).

However, in a typical technical review environment it is often difficult for the designers and engineers to portray design intent in a manner that is fully comprehensible by the evaluation team as the presentation material is typically restricted to static 3D images and 2D drawings.

In the case of the ergonomic model described above, it was only possible to extract 2D images and a fixed camera animation for review purposes. The benefits of agile system are that it would allow designers and engineers to easily demonstrate complex designs by presenting 3D models with moving parts and processes in a virtual environment, whilst allowing the evaluation team to easily extract the relevant information using a number of techniques as described below.

- Allowing processes to be repeated from multiple viewpoints and played back at different speeds
- Including transparency or cutaway views to allow the review of internal mechanisms and processes
- Allowing team members with a non-technical background, typically operators or clients, to control and manipulate the 3D environment

Figure 5. Human modelling and movements' simulation: Hatch opening procedure.

During the development process, the 3D models could be rapidly updated and newly introduced changes can be reviewed individually and within the overall context of the structure

3.2 EXPLANATORY PRESENTATIONS

For the initial study, the SRV was modelled with CAD software with a view to demonstrating the approach procedure with the DISSUB on the seabed, locking onto the DISSUB's rescue seat, depressurisation of the interlock, opening of the hatches and subsequent transfer of the Rescuees. The scenario was visually simulated with a focus on the evacuation of the Rescuees and their transfer from the DISSUB to the SRV and on to the decompression chambers onboard the MOSHIP.

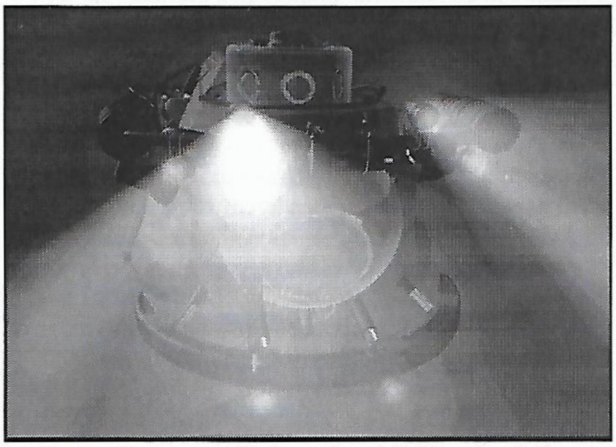

Figure 6. Underwater visibility simulation.

Generating a realistic underwater environment, visibility ranges and lighting were simulated according to the depth and the conditions of the approach as illustrated below in Figure 6.

Rendering of photo-realistic images based on these simulations and 3D representations can demonstrate effectively the relevance of newly introduced hardware to the contemporary equipment. Although such photo-realistic visualisation is a valuable demonstration, it is restricted to pre-determined series of camera paths and perspectives.

Integrating engineering CAD models and animation sequences, that are typically generated for rendered video scenes, into an environment that allows customers & users the ability to explore and control the scene could provide a much deeper understanding of the operational complexities of such a system, whilst allowing design teams and companies to capitalise on the material generated during the engineering and ergonomic development.

3.3 VISUALISATION-ASSISTED OPERATION TRAINING

From a procedural point of view the accurate depiction of the rescue systems onboard the mother-ship can provide the different rescue teams involved during the rescue mission with crucial information regarding the timing of each action and the required procedures of each group.

Furthermore the simulation of on-board procedures would allow the user to assess simultaneous operations to be viewed and repeated from various angles and ranges, maximising the preparation level of the involved groups. For example, there are a number of complex operations involved during recovery of the submersible from the sea to the deck of the ship, some of which are occurring simultaneously and are difficult to portray in a single animation. Notably in such operations the human simulation and animation could significantly benefit the designers to estimate the interactions between the groups and the vessel equipment (Badler et al, 1993).

4. REAL-TIME SIMULATION ENVIRONMENT

The off-line visual simulations described in the previous sections were created and rendered using a combination of Autodesk Inventor to generate the engineering CAD models and Maya create the scenes and perform the rendering, responding to an immediate need of the customer. The availability of the test case and the models, however, provided the opportunity to start an investigation into other, more flexible modes of presentation.

Virtual reality and real-time visualisation systems were associated with often prohibitive hardware and software cost in the past. However, mass market items designed for high-end home entertainment are often perfectly suitable and exceed yesteryear's high-end technology in features and performance while costing a fraction of the amount. The cost of virtual reality applications today is dominated by the man-power required to prepare CAD models and add the interactivity for real-time display.

The following sections describe the environment and tools we use to interactively visualise designs before going into details about the modes of presentation and evaluation.

4.1 HARDWARE

Real-time visualisation in this context is used as a powerful means of communication within a team or to external stakeholders. A reasonably large display environment is critical to enable group discussions and interaction with the 3D model, hence a projector-based environment is considered a necessity.

We use a range of VR display environments for our experiments, including stereoscopic projection (providing a sense of depth) that enables better understanding of the spatial structure, and a high-resolution wide screen (2800 x 1050 pixels on 4.4m x 1.65m) to convey a feeling of the actual size of the SRV. All our display systems are driven by PC workstations with dual Xeon processors and nVidia Quadro FX4400 graphics hardware. While those display systems offer superior quality and performance, the processes described in this paper could also be run successfully on less expensive hardware for the enthusiast gamers in combination with a decent quality presentation projector.

4.2 INTERACTION DEVICES

We have developed a range of interactive design review tools that enable direct interaction with the 3D model in a semi-immersive environment (Naef et al, 2006).

These hands-on interaction paradigms require 3D tracking and a data glove with tactile feedback. The less complex presentation tools only allow manipulation of time, viewer position, layer visibility and cut-away plane manipulation and are therefore served well through a combination of a 3Dconnexion SpacePilot ("3D mouse") for navigation and a joystick to control the cutting planes.

4.3 SOFTWARE

Given that the major cost factor in VR today is in the data and simulation preparation aspects, efficient software tools are crucial for an effective solution. We base our recent real-time activities around the platform offered by Presagis (formerly Multigen-Paradigm) including Vega Prime for the real-time simulation and Creator for model preparation. Although cheaper solutions exist, including open source scene graph and virtual reality toolkits, we found that in our case development time is sufficiently decreased using the commercial solutions to offset the license cost.

4.4 LEVELS OF INTERACTIVITY

Interactivity is the key contribution of our visualisation environments over existing rendering options available in most CAD packages or off-line animation tools such as Maya. While the visual quality does not fully approach that of a Maya rendering, particularly regarding lighting effects such as shadows, real-time rendering can produce a realistic impression of the design. Unlike pre-rendered videos, the real-time system enables spontaneous reaction to requests from the viewers.

On the most basic level, the interactive environment allows free control over time, enabling the team to set the pace of a review or presentation session, whereas the basic transport controls for videos are somewhat awkward to use.

It is the free viewpoint and motion control capability that gets most users excited, as it allows inspecting any part of the design from a range of angles that may not have been foreseen during the planning of a review session. Consequently, most commercial VR add-ons to CAD system provide exactly this type of flexibility enabling real-time walk-through. As long as the CAD model remains within moderate complexity, this feature comes almost "free" as it requires little or no expert involvement for set up. We typically use a SpacePilot device for free navigation and a range of preset viewpoints in our simulations.

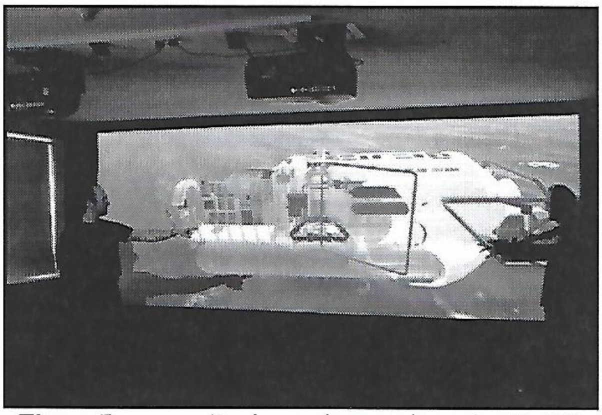

Figure 7. Design review session using the VR system.

When transferring models from a CAD into our custom real-time environment, we generally equip the data with a range of switches to toggle the visibility of key components or layers between visible, semi-transparent or hidden. The transparent stage is particularly interesting when the position of modules must be shown within the context. For example, showing the Rescuees transfer from the DISSUB into the SRV from a camera positioned outboard of both boats.

Interactively placing a cut-away plane enables looking inside the design and complements the layer functionality as shown in Figure 7. We dynamically place the plane using a joystick. Enabling cut-away for selected layers only allows to interactively "strip away" parts of the design to gradually reveal the inside without losing the context information.

4.5 USE OF ANIMATION

The tools and techniques described above enable inspection and review of the static design model. Our main interest, however, lies in the communication of procedures. While switches enable the visualisation of discrete stages, continuous animations are much more powerful to convey a process flow. The tools (Maya) described in the first part are extremely powerful for defining and rendering complex animated sequences. Unfortunately, these sequences are not directly portable into our real-time, interactive environment. Instead, animation sequences are pre-defined in the application code by a programmer. As such predetermined simulation scenarios developed in the original CAD program (Maya) have to be re-introduced in virtual-prototyping and simulation suites (i.e. VEGA). Evidently an initial appraisal of the simulation requirements and client expectations can be achieved in a first level through animation sequence. Typically the animation can be further exploited as explanatory tool presentation

5. DISCUSSION

Submarines have been categorised amidst the most valuable warships ever deployed as their operational results have proved repeatedly through different situations. However their operating environments and tactical operations have created numerous constrains which have been resolved through meticulous structural design and exhaustive experimentations. Such extensive evaluations were considered mandatory in order to maximize performance and ensure human safety. Additionally submarines must be able to respond efficiently to a plethora of manoeuvres (considerably more complicated than a typical ship) such as surface and dive swiftly, operate safely underwater for months, communicate and move quietly to avoid detection. Finally submarines have to provide a habitable space for the crew. Regardless of the type of submarine, the aforementioned tasks are accomplished equally well from each vessel in a similar fashion.

Adhering to the above observations derived from Digital Design Studio's collaboration with JFD it was made obvious that modern submarine design could use virtual reality and 3D technology in order to circumvent potential design and ergonomics issues well in advance of the completion stage. Our initial approach was through a gentle introduction to the complexity of mechanical structure and operational capabilities. As such we tried to develop a meaningful initial simulation, which provided an explanatory animation of rescue mission. Although beneficial to the design evaluation process, these preliminary studies were clearly limited in their capability to genuinely demonstrate the complex systems and multi-layered processes involved in a Submarine Rescue System / Operation.

As video-recordings of such operations are difficult to reproduce, a manipulatable, real-time simulation of a predetermined series of events depicting meticulously the real-life processes could provide potential users or collaborators an unobstructed multi-view of the operation.

6. CONCLUSIONS

Based on the success of this case study, we intend to expand our future work to the development of the real-time visualisation of the SRV and associated Rescue Equipment. We are particularly keen to enable non-expert users in CAD to explore and interact with the 3D environment in real-time using a virtual-reality-based interface and allowing them to easily inspect, review and analyse the physical and human interactions.

Finally, to prevent or minimise onboard or procedural accidents we envisage developing a series of simulated scenarios which will demonstrate human interaction with the various systems under difficult situations. Utilising the aforementioned information we aim to offer the means for submarine developers to evaluate in real-time and in a controllable and safe environment the structural designs and the human factors involved in their operation.

7. ACKNOWLEDGEMENTS

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Dr. Vassilis Charissis obtained his BSc (honours) in Technology of Graphics Arts, Mechanical Engineering specialisation, by the Technological Institute of Athens, Greece, his MPhil in Advanced 2D/3D Motion Graphics and Virtual Prototyping and his PhD in the development of Human-Machine Interfaces for automotive Head-Up Displays both by the University of Glasgow / Glasgow School of Art department of Digital Design Studio. His research outcomes include two patents and over 40 international publications, in areas of human-machine interaction, wireless networks, virtual prototyping and advanced automotive engineering and electronics.

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