Virtual Reality Demonstrator of an Advanced Boiling Water Reactor

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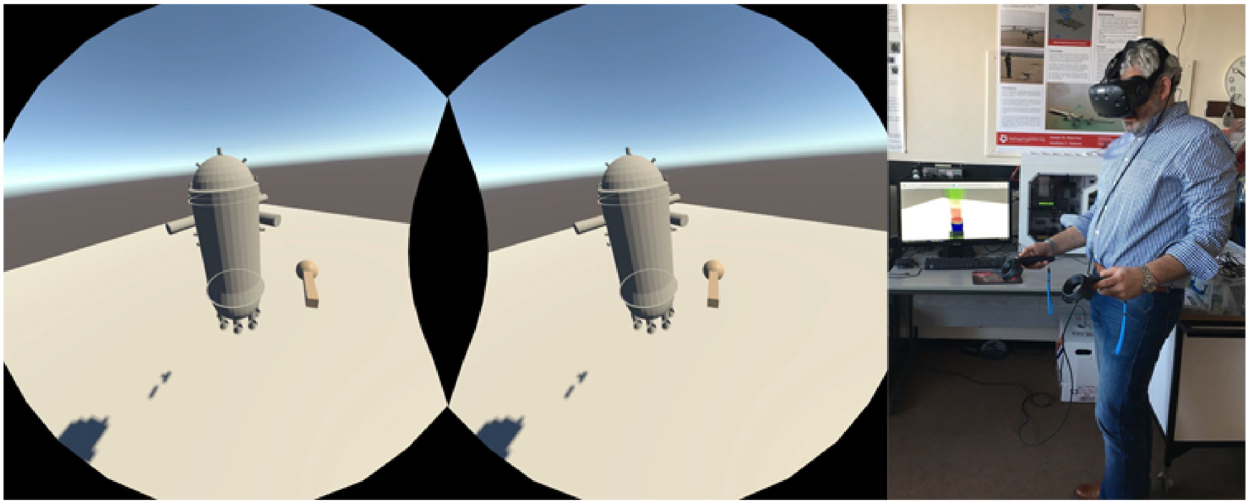

Fig. 1: In-world view (left) of the first reactor model through the HTC Vive HMD (right). The handheld controllers allow the user to 'touch' elements of the model, and to switch highlight between them. The environment allows a second user (instructor) to be present in VR and interact with the trainee. Future versions will allow for remote co-presence in the VR space.

Abstract— This feasibility study presents an overview of the development of a prototype HMD-based VR demonstration of an ABWR facility. The demonstration aims to present to the user 3D simulations of how an Advanced Boiling Water Reactor looks like, and eventually how it works. By providing this immersive demonstration, users can learn about this technology, its significance, explore the facility virtually and learn about the potential of nuclear power in an immersive, interactive and highly engaging manner. The prototype was designed from the outset to be extensible and adaptable to include additional information in the future, such as data-driven informational annotations and immersive visual analytics. The feasibility study demonstrated the ease and flexibility of modern game engines and VR interfaces, in prototyping a VR simulator, intended as a for demonstration tool for an ABWR. However, it also highlighted the need for high-quality 3D models of the elements of the reactor that are to be depicted, in enhance immersion and realism of depiction. Moreover, if any informational overlays are to be used, in conjunction with the 3D information, these need to be sourced from informative and accurate datasets, that would accompany the aforementioned 3D models. Finally, as the set-up used in this effort is not mobile, and outreach activities would benefit from such mobility, we have started exploring the development of a Web-based, mobile solution that uses a simpler, highly-portable infrastructure.

Index Terms—Radiosity, global illumination, constant time

1 INTRODUCTION

In the last few years VR has become one of the most discussed technologies in computing, with recent popularity mainly driven by the emergence of affordable consumer VR-specific interfaces. Examples include head-mounted displays (HMDs) such as Facebooks Oculus Rift, HTCs Vive, and the smartphone-based GearVR and Daydream, from Samsung and Google respectively. The availability and affordability of these interfaces has made the use and development of VR applications much more accessible, with many different technological ecosystems emerging. VR is nowadays being increasingly used in several domains, to provide new methods of simulation, training and public engagement.

VR provides an immersive and interactive way to learn and explore our world, by presenting computer-generated objects that can be inspected and manipulated using interactive computer graphics. VR allows us to be placed (immersed) in interactive, computer-generated graphical environments (simulations). These simulations often replicate physical spaces which are remote, dangerous, expensive to build physically, or require specialised training before we can be in them. With VR, these simulated environments become safe to use and be in, easy to replicate, can be accessed from any part of the world and can be enhanced with educational information. Consequently, VR is rapidly becoming one of the most engaging and recognisable technologies for visualizing information. It has already altered the landscape of many domains, such as healthcare, business-intelligence, entertainment and education.

There is a huge opportunity to use Virtual Reality (VR) to help people understand the BWR. Through using VR, users would be able to walk around, see how the BWR works, interact with it, learn about it and become excited about its function and technology, through the excitement of the VR experience itself. We believe that this demonstration can have a very positive effect in the perception of BWR technology, and the activities carried out in Bangor specifically.

Driven from this motivation, we describe the development of a prototype that presents the ABWR, as a basic interactive depiction. Our mid-term goal, beyond this feasibility study is to to research and

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develop a complete, interactive VR demonstrator of the BWR, with high-enough quality to be placed on an app-store (e.g., Microsofts Made for Hololens). The long-term goal of this work is to investigate tangible and haptic (touch) based interaction with the BWR model. By mixing VR with the physical world, i.e., creating a Mixed Reality (MR), users would be able to move physical objects (in the world) and the computer would control the virtual information accordingly. This MR system could be used as a training environment, be useful as an exhibit, or be used for education and demonstrations with School children etc. For example, users could physically select and take of the roof of the building, move components around and explore different aspects of the BWR in MR. In summary, the aims of this feasibility study were:

Goal I: To develop a HMD-based VR demonstration of the ABWR, depicting its main components and annotated informational content. This will serve as a platform for follow-up research and development on Immersive Visualizations for the ABWR.

Goal II: To evaluate its potential as an informative tool, for the public, in a series of demonstrations/evaluations with stakeholders and the public.

The structure of this report is as follows: Sect. 2 presents briefly the background work for this effort, Sect. 3 provides and overview of the prototype developed, in terms of hardware set-up and application features, Sect. 4 discusses our observations and results of this study, Sect. 5 outlines future work, and Sect. 6 summarises our findings.

2 Background

The use of virtual reality in nuclear industry has been discussed since the 90s [3]. Specifically, VR has been explored in the contexts of human-centred design and human factors review [7], control-room design [8], decommissioning [11], outage planning, operations and maintenance training and radiation visualization [1]. Early, non-HMD VR has been discussed as a tool to visualize construction schedules of nuclear power plants [14] or as a simulation tool for the assessment of radiation exposition, by nuclear plants personnel [1, 2, 10]. However, despite VR being explored in such scenarios, it has not been used in the nuclear industry for outreach, and we believe there is a clear gap in the market currently for immersive demonstrations of this type.

A significant contribution is HVRC VRdose [13], available to OECD Halden Reactor Project member organisations and associates. The original system was built by the Institute for Energy Technology (IFE) in collaboration with the Japan Nuclear Cycle development institute (JNC), to support the decommissioning of the Fugen Nuclear Power Station in Tsuruga, Japan . The project is using fairly old technologies for 3D visualization, as it is based on VRML97. However, it is indicative of the potential VR has as assistive technology in the nuclear industry.

Examples of other efforts, that use more contemporary tools, include the one from Lee et al. [9] who used Unity 3D (which will be used in the feasibility study as well) to construct customer experiences in the control room of a nuclear power plant. They explored the level of presence their participants had when in the VR world, arguing that VR can be convincing and offers a high level of immersion. Other recent efforts investigated the use of VR to support physical security of nuclear facilities [5]. A recent study by da Silva [6], reviews the use of VR in nuclear issues and context, whereas the IFE has a significant database of related projects, from around the world .

However, very little work has been conducted with the current generation of interfaces and VR environment creation tools. As VR becomes more established and the tools become more advanced, it is now timely to investigate its use in the nuclear domain, both to offer new methods of analysis and data depiction, as well as a tool to inform and engage the public. In particular, the interest in displaying data-driven information as part of the VR world which is the ultimate goal of this research thread, beyond the feasibility study is very recent, and driven by the emerging field of Immersive Analytics [4] and beyond-the-desktop visualization [12].

[1] for info see http://www2.hrp.no/vr/projects/

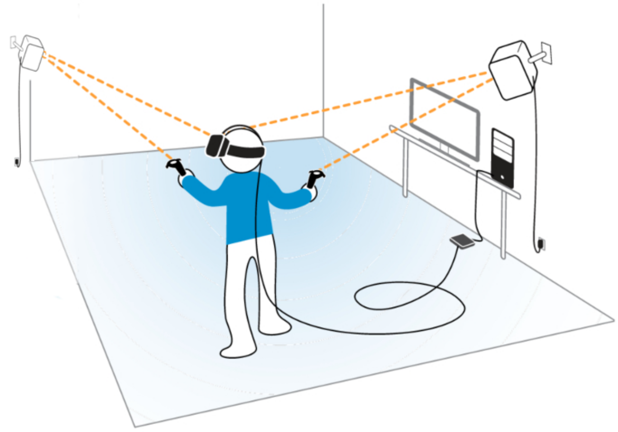

Fig. 2: The operating space of VRABWR (play area) is currently 2m x 3m. The virtual model of the pressure vessel is placed in the centre of this area. The demonstrator will be relocated and recalibrated to a larger room, where it will be accessible from stakeholders.

Fig. 3: The HTC Vive HMD, along with the handheld controllers and the tracking cubes. The controllers allow interaction with the subassemblies of the vessel model, as well as graphical-interface specific interactions (menus etc). The tracking cubes serve as reference points for the HMDs, to determine user location and gaze orientation.

3 VRABWR Prototype

Our prototype application uses contemporary technologies, that ensure extensibility and the highest possible (at the time of implementation) level of immersion. In that regard, our prototype builds upon recent advances in VR technology, forming a solid foundation upon which several enhancements, in terms of the quality of the 3D models, the environment and consequently the interactions, can be incorporated.

Our current set-up uses the HTC Vive HMD (Fig. 3 and Fig. 1) and a gaming-grade PC (Intel i5, 16GB RAM, 1 Nvidia Titan XP GPU). A second Vive HMD on a gaming PC of similar specification is serving as the instructors machine. The current placement of workstation and tracking cubes provides an operating space[2] (play area) of 6 m^2. Our set-up uses one set of tracking cubes, which are used by both HMDs (and their controllers) to determine user/device location and orientation.

The simulator itself is written in the Unity Game Engine[3] and makes use of the built-in Multiplayer Networking and High Level API (HLAPI). This enables the co-presence of two users (instructor and student) in the virtual space. The two PCs are connected over the Dean Street Ethernet network. Each instance of the game can be started as client, server or host, whereas the required network information are

[2] The set-up will be relocated to a dedicated projects showcase space in Dean Street, Bangor during Summer 2018, which will have a larger 'play area'.

[3] for info see: https://unity3d.com/

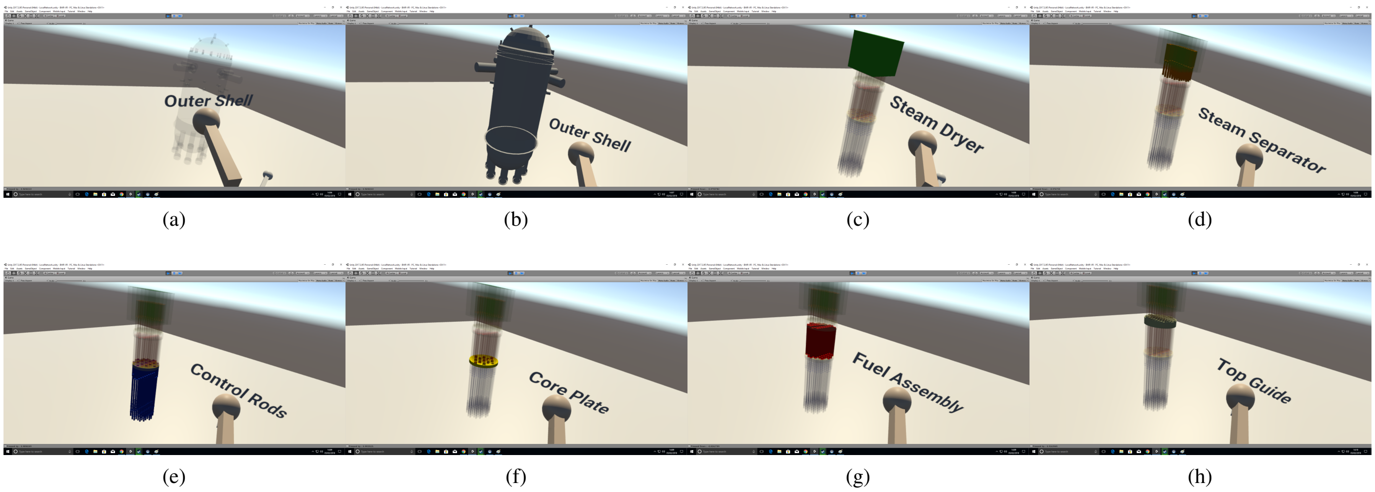

Fig. 4: Views from VRABWR, depicting different sub-assemblies of the VR, which the user can select using the HTC Vive controllers. Different pointing and selection mechanisms where implemented and can be demonstrated.

the PCs network address and port. Depending on the operating mode the application either attempts to connect to the address/port provided or listens for incoming connections.

Two artistic renditions of the pressure vessel have been used in VR space, using technical documentation as reference. The original model is depicted in Fig. 4 and was created in Blender. A more detailed model was created in Autodesk's Tinkercad (see Fig. 5). In both cases the user use the Vive controllers to switch between different sub-assemblies and display textual info (Fig. 4).

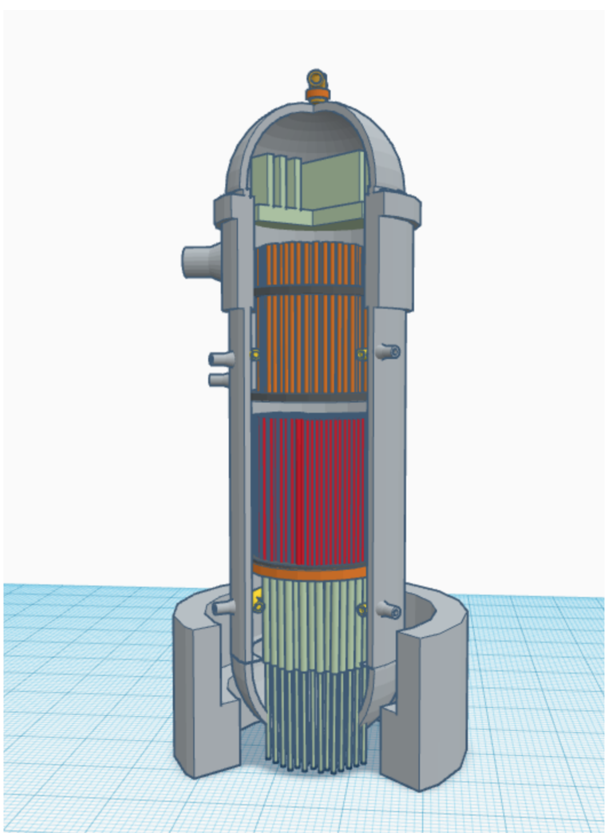

Fig. 5: Second artistic rendition of the BWR pressure vessel.

4 Study Results and Observations

Our preliminary investigation highlighted a number of challenges that need to be addressed before the simulator is used by the public:

Model and scene quality: The models used in the current version of our simulator are artistic renditions of the pressure vessel, and not accurate technical depictions. In order to enhance the realism of the simulator, as well as to display meaningful, accurate and content-rich textual overlays, more precise and detailed model are required. In our effort to find said model we have been informed that such information may not be publicly available, for commercial reasons. Nonetheless, there are a number of 2D depictions of the BWR vessel available on the Web. These depictions are more convincing than our renditions and would be sufficient for our simulation if they were available in 3D formats (`.obj`, `.fbx` or `.gltf`).

Physical demonstration area: The space available to us, in the Visualization laboratory of the School of Computer Science is not optimal for the co-presence of two users in the VR world. For that, there has to be sufficient space for two users in the corresponding physical space. Moreover, the arrangement/placement of the two HMDs needs to be such that the wiring into the devices does not cause any health and safety concerns. These issues will be addressed in a new laboratory space, available since July 2018.

Mobility: Although the current simulator has significant potential for improvement, in terms of the sense of presence and realism, it is only available in our facilities. Mobility is an issue, due to the HTC Vive tracking cubes, which would need to be mounted on tripods and re-calibrated for each location, which makes re-deployment a tedious activity. We are therefore working on a mobile, web-based system that will make ad-hoc demonstrations feasible (see next section).

5 Future Work

By conducting this feasibility study, we have established foundational elements for follow-up projects and have met our original goals. The results obtained and the infrastructure developed will enable us to investigate further the use of VR in data analysis and sense-making, within the nuclear science domain. The outputs from this feasibility study that contribute to such follow-up work, (and effectively match our original goals) are:

A **VR infrastructure** upon which we can built an immersive analytics platform for scientific, data-driven ABWR demonstrations and analyses. This also fits with the strategic research goals of the School Computer Science and the Vision, Modelling and Graphics research group. Although the presented demonstrator is using game-engine technologies, we have explored in parallel the use of open-standards, web-based technologies, in order to create a browser-based, light-weight version of our demonstration intended for public engagement[4]. The latter allow us to deploy a simulator of similar quality, which can also be experienced in mobile headsets, such as the Oculus Go (see Fig. 6), and therefore be easier to use for outreach activities. Nonetheless, the full-featured set-up will be available in a new projects showcase space from August 2018.:

A knowledge-base of ergonomic considerations for VR systems used in the domain of nuclear science, as well as ABWR management and training. Our current exploration serves as a pilot study of available set-ups and thus forms the basis of future experimentations. The most important element that will facilitate further development is access to high-quality 3D renderings of the ABWR. As the modelling of 3D objects, such as the reactor vessel, is beyond our immediate scientific interest and expertise, we have to rely on input from the BWR network. By having access to **good quality 3D models** we will be able to improve the level of immersion of our demonstration. As the quality of the depictions improve, we intent to use both demonstration versions during outreach and engagement events (e.g, open days, candidate days etc.), promoting our research activities, as well as the activities of the BWR Research Network. By developing further the current prototypes we intent to facilitate a foundational study of the overall user experience associated with such demonstrations and the requirements for more effective engagement.

Fig. 6: The Oculus Go mobile HMD, used along with our web-based solution for our simulator.

6 Conclusion

This feasibility report presents an initial investigation into the use of VR as a medium for simulation and outreach, for the nuclear industry and in particular for the BWR Research Hub and Network. We have presented a basic prototype, that uses contemporary VR interfaces and a game engine, to immerse users in a virtual world which includes interactive depictions of the BWR reactor vessel. In addition, the prototype allows the in-world collaboration of two users (e.g, instructor-trainee pair). Our prototype is extensible, much like a computer game and can be significantly enhanced to offer additional information depictions, either in the form of 3D models, or data-driven information. Nonetheless, this requires significant input from the BWR community, in terms of realistic 3D models and related data. Finally, we have explored the development and use of a more light-weight, browser-based demonstrator that uses open-standards web technologies and can be experienced via a mobile HMD, such as the Oculus Go. This system is highly mobile and can be easier to use in different outreach activities.

[4]The development of this web-based solution was done for an unrelated (to this feasibility study) project.

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