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VR AS A SERVICE: USE OF VIRTUAL REALITY IN A NUCLEAR ACCELERATOR FACILITY

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Abstract

A nuclear plant, for energy or for nuclear physics, is a complex facility where high level security is mandatory, both for machines and people. But sometimes the status of danger is not correctly felt, inducing workers to misinterpret situations and, as consequence, not act in the best way. At the same time problems related to area accessibility can occur during normal machine operations, limiting actions related to local maintenance and environment supervision.

It would be suitable to have the opportunity to perform these tasks independently from environment limitations and machine operations. In order to overcome these limits, we applied Virtual Technology to the nuclear physics context. As consequence, this new tool has given us the chance to reinterpret concepts like training or maintenance planning. In this paper the main proof of concept implemented are described and additional information related to different VR technology usages are exposed.

VIRTUAL REALITY TECHNOLOGY IN THE RESEARCH

A nuclear accelerator laboratory can be described as a complex system composed by several functional sub-systems (vacuum system, cryogenic plant, control system, RF system, etc.) which have to be coordinated properly in order to provide the service to the end user. Every single system has to work correctly and requires a big effort in continuous maintenance in order to guarantee a stable beam for experiments. In addition, every single operator has to be fully trained to work and control every single part of the accelerator. Because of the nature of the experiments and the kind of facility, different problems and limitations related to area accessibility occurred during and after operations. These limitations cause delays and uncertainty in planning process at every level (management, logistics and operations). It would be suitable to get the access to all the restricted areas regardless limitations and machine operations. The aim is to find a method and a tool to overcome these constraints through a real representation of the area, allowing regular operations in the facility. Virtual Reality (VR) Technology is an interactive computer-generated experience taking place within a simulated environment, that incorporates mainly auditory and visual, but also other types of sensory feedback. It is rapidly diffusing among several different professional environments, such as medical, architecture, military and industry, with different level of interactions, based on the experience required.

For the developer, the VR technology is a powerful tool which allows to reproduce environments and objects with a high level of detail.

According to the actual standards and applications available on the market, we tried to design and implement a VR experience dedicated to the nuclear facilities such as linear accelerators.

CASES OF INTERESTS

This kind of technology can be adopted to help different users (managers, developers, operators) in different critical tasks. Formally, based on the principal characteristics of a VR experience (photorealism, immersion, interactivity, real time), different types of experiences can be designed and implemented, depending on the goal the application wants to achieve.

Through the experience matured in our daily work, it has been possible to focus and define three particular macro areas of interest which has been used for the first prototype of the VR application:

- Training: one of the biggest challenges in physical laboratory is having all operators properly trained to work with the accelerator machine and ancillaries. As technology evolves and new solutions are continuously implemented into the facility, every single operator has to be cyclically trained. This can be done in a secure simulated environment, independent of the physical machine. In this scenario, the trainer can also simulate emergencies and evaluate behaviour feedback, estimating the response time in a hazardous environment.
- Machine operations and maintenance: using the same virtual environment provided for the training, it is possible to evaluate and prepare maintenance planning (ordinary and extraordinary) and machine upgrades. As the entire environment is rebuilt starting from CAD models, the final 3D virtual model guarantees sub-millimetre resolution where VR users can operate in the virtual simulation to evaluate, for example, device positioning for machine upgrades.
- Data collection: the virtual model is defined starting from 3D CAD models. As different groups manage the different sub-systems constituting the facility, the tool can be very useful to test and verify data integrity and coherence. This aspect results in reducing design errors and optimizing communication and data exchange among the groups.

CONTROL PROCESS AND ITS INTEGRATON

An important aspect kept in mind during the preliminary study and design for the test-bench application was how to integrate a VR solution into the normal common design and organization process: users have their own set of tools and methodology to execute their own tasks, and these two

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factors must be taken into account by the developers because of the heterogeneity of the people involved. As consequence it was mandatory to proper define the set of tools (hardware and software) and the process required to integrate a VR experience into the regular control process: in Figure 1 it is possible to observe how the VR tool can define a secondary control process flow which can be easily integrated in the main control process cycle, due to minimize design and decision errors and optimize the entire process execution time.

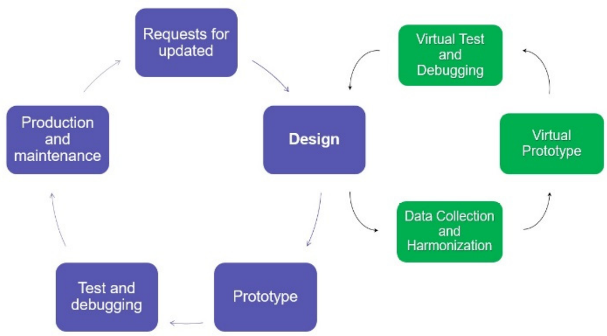

Figure 1: Double Wheel Flowchart: how to integrate the Virtual Reality tool in a common design process.

The secondary control process cycle is composed by the following steps:

- Data Collection and Harmonization: in this phase VR developers collect data provided by every group (3D CAD models) involved and verify its coherence before designing the virtual experience. A huge but important effort is required at this stage to check misalignments and dimensional errors.
- Virtual Prototype: the real design for the virtual experience is made in this phase. The complexity and the effort required depends on the kind of experience desired (training, planning, show room, etc.): in particular cases a low-level software program design is required to produce a complete "real" virtual experience, such as a training in case of hazards. In this stage the kind of hardware used for the experience has an impact in the design and implementation.
- Virtual Test and Debugging: in this phase it is possible to use the virtual experience to verify the application itself (logic, design, etc.) as internal debug and to receive the first feedback from the end user using the VR simulation.

HARDWARE AND SOFTWARE

The most crucial steps in the secondary process cycle are the data collection and the virtual prototype design. In particular, this second step is highly dependent on the hardware and software solutions chosen. In the market there are several solutions to implement a virtual experience, both under hardware and software level. While the hardware has an intrinsic cost (purchase and maintenance), there are commercial and open-sources solution for the software. The goal prefixed by our team is to determinate the best set of software which permits to minimize costs impact related to licenses (excluding the licenses already in possession by the Institute) and to have, at the same time, the best resolution in terms of photorealism and real-time execution.

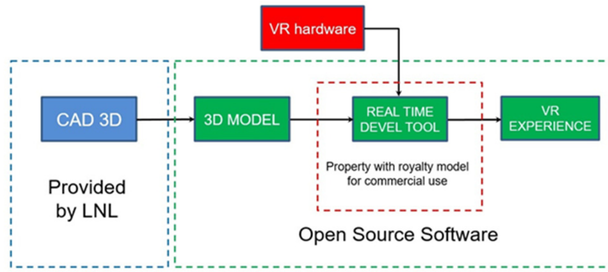

Figure 2: the schema defines software and hardware plus the correct flowchart required to provide the VR experience to the end user.

As indicated in the Figure 2, the software used in this process can be divided into these sub-categories:

- Licensed software: *3D CADs*
  different 3D CAD suites are used in the Laboratory by the different groups and costs related to them are already in charge of the Institute. The key point in this part is to determine the best file format used to export the mode.
- Open-source software: *Computer Graphic Framework and Real Time Development Engine*
  the import process of 3D models directly into the Development Engine has a bad impact in terms of performances during the final VR experiences due to the very high polygon count, even with the latest hardware available on the market. It has been necessary to insert an intermediate step and an additional software in order to simplify 3D models. Blender [1] has been chosen as Computer Graphic Framework because it meets the requirements of costs (it is available with open-source license) and performances.
  For Real Time Development Engine, different open-source solutions are available and the mostly used are Unreal Engine [2] and Unity3D [3]. Comparing the performances provided by these tools, Unreal Engine has been selected as real time development framework. Unreal Engine is a Game Engine available under open-source license if the product is not for commercial use.

For the VR hardware, several solutions are available on the market. Considering the software tool chosen and previously indicated and, at the same time, the hardware costs, we decided to focus the development using the Oculus Platform [4] for realizing the proof of concept. This system provides let users a complete immersion inside virtual worlds through dedicated headset. This device is fully integrated into the Unreal Engine framework, it has a large community support and it provides a good photorealistic immersion at high frame rate.

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Figure 3: Data Collection and Design: a real environment present in the facility (left) has been completely replicated in VR (right), providing an interactive virtual experience.

THE APPLICATION

According on the assumptions previously exposed about the cases of interest for the virtual experience, it has been developed an application devoted to test and verify all these aspects.

Data Collection and Design

As previously exposed, Virtual Reality can cover several areas of interest, with different level of complexity and immersion. Because this technology is completely new in our facility, a preliminary proof of concept was required. The double goal wanted had been:

- to demonstrate the validity of the VR process flowchart
- to have a first important feedback in terms of dimensional and data coherence

The collection of data from several sources (mechanics, plant schemas, etc.) allowed the replication of an immersive virtual environment as faithful representation of a real one as visible in Figure 3: the virtual room is in 1:1 scale and every single detail (geometry, textures, objects interactions, lights, physics) has been completely reproduced. This first test has been extremely useful because it could be possible to prove the incoherencies among the data provided by the groups involved and to correct them on design and documentation

Figure 4: Operator Training: the user simulates in VR the maintenance operation of an apparatus.

Training

The first case taken into account has been the verification of the procedures required to mount and unmount parts of the accelerator line (devices and ancillaries) where the operator can be in contact with residual radiations produced by activated objects (Figure 4). In this case the photorealism has not a key role and the environment has been defined with dedicated colours in order to emphasize the functional object the user has to interact with. On the opposite side, dimensions and objects' sizes have been deeply verified and maintained.

The results of first trials have been remarkable: the experience is ready to be used to train operators to work in new parts of the particle accelerator, giving them the opportunity to familiarize with the system while the line itself is used for preliminary tests: in normal conditions, people involved in maintenance would have to wait the end of the tests while, in the actual configuration, they will be confident and prepared to operate immediately. Until now the VR experiences defined provide a simulated environment where only a single user can operate. A preliminary test bench for a multi-user experience is under development.

Machine Operation and Maintenance

Having a complete and immersive environment based on CAD information gives the opportunity to replicate objects and spaces with high precision. The first user case was the preparation of a new area in the facility under construction where several different parts developed by different groups must be placed in a limited space. As a consequence, dimensional verification was crucial in order to avoid interferences between devices.

The complete area and all the systems, devices and ancillaries have been reproduced with the same precision provided by the 3D CAD models and placed with an error less than 1mm.

The advantages coming from this new methodology gave us important boosts in terms of efficiency: for example, it has been possible to find interferences between two pieces constituting a more complex apparatus, enabling us to modify pieces' design, to save material used for the prototype and to minimize production time.

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FURTHER DEVELOPMENTS

Starting from the preliminary promising results and the feedbacks coming from users involved in the tests, we tried to extend the cases of interest where the VR Technology can improve the tasks efficiency. In this operation, we also considered the possibilities of involve additional emerging hardware solutions, such as Augmented Reality (AR) and Mixed Reality (MR).

Particular interests are related to the idea of integrating and merging heterogeneous data and information into the VR environment: for example, it could be possible to integrate data results coming from beam dynamics study which can be used to verify its possible interaction with the beam lines. This is a new way to use and visualize common information available in our laboratory for physical experiments and accelerator setups.

The principal areas of investigation are:

- Data integration in VR: data provided by software different from 3D CADs have been manipulated and imported into a virtual simulation in order to visualize different details. Figure 5 represents an example of data integration: the information produced by a laser track system has been used into the virtual environment to visualize and verify objects positions and alignments. This kind of information can be useful in machine operations and maintenance. Other tests are related to the integration of data coming from the control system inside a VR environment: info coming EPICS Process Variables can be mapped in a VR application.

  Multi-users experiences: thanks to the improvement of the actual hardware and software, we are now able to achieve multi-users experiences based on different and heterogenic fields and applications; actually, we are focusing and testing proof of concepts for:
  - virtual control room (training and control operations)
  - remote training and assistance with customers
  - live meeting between different divisions
  - real-time cooperative design

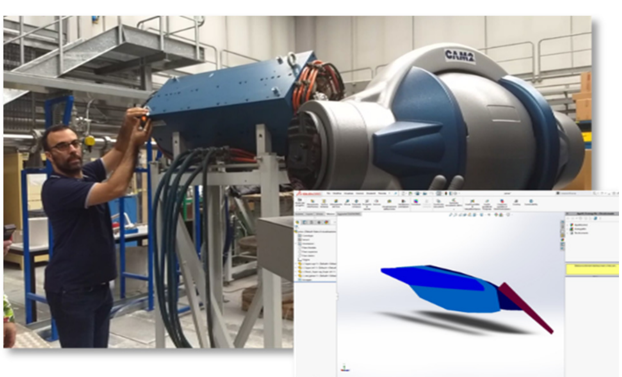

Figure 5: Heterogeneous data used into the virtual reality.

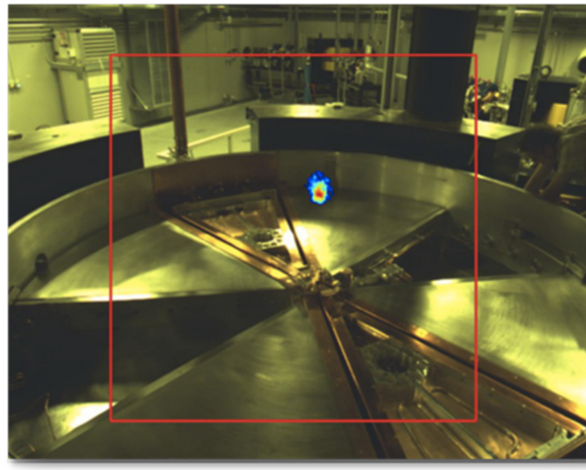

Figure 6: Example of AR visualization: information provided by Radioprotection Service (D. Zafiropoulos, L. Sarchiapone) are used to generate a live map.

- Augmented Reality (AR) and Mixed Reality (MR): These two technologies introduce an additional degree of interactivity between real and virtual worlds. In this scenario the user can use particular information data to be aware of dangers. For example, data produced by Radioprotection Service can be used in a AR solution to perform a live radioactivity's map for the user that has to operate next to a particular apparatus (Figure 6). For this solution different hardware technology is required.

CONCLUSION

In a complex system like a nuclear facility, many tasks such as training and planning can be difficult to execute because of the limitations (in terms of time and availability) coming from the normal operations. In this scenario, the usage of Virtual Reality Technology can be an extraordinary way to overcome these limitations.

The studies executed and the proof of concept designed and implemented verified the maturity and the versatility of this technology: the application developed gave us preliminary good feedbacks for the main areas of interest where we focused the work (training and maintenance planning). The tests results were very promising and pushed us to extend studies and application functionalities of the prototype, embracing different hardware solutions and integrating heterogeneous data and information, but more effort is required to extend and optimize the user experience.

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