Virtual Reality Technologies: a Way to Verify Dismantling Operations

First application case in a highly radioactive cell

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Abstract—**Dismantling is a major challenge for nuclear companies, which are faced with the clean-up of former nuclear sites. In order to increase efficiency, optimize costs and planning, intervention designers must verify scenario key points, take into account unexpected situations and provide technical answers. Simulation is a good means of visualizing and therefore understanding constraints, of testing different alternatives, and a way to train workers prior to interventions. This paper describes an application of such a technology: dismantling a chemical cell in the APM (Marcoule Pilot Workshop) facility at Marcoule (France). This highly radioactive cell will be dismantled by a remote handling system using the Maestro slave arm. An immersive room has been used to design the dismantling scenarios. For these, the Maestro slave arm has been coupled with a haptic interface and, thanks to force feedback and visual immersion, accessibility, operational trajectories and maintainability on the carrier have been verified. If problems are found, updates of the carrier design are carried out before its final construction to guarantee the system will work properly. We describe the processes of building the 3D model and verifying scenarios. Finally, we present the first results, which are encouraging, and the perspectives for the project.**

Keywords-virtual reality; dismantling operation; haptic interface; accessibility study; remote handling; collision detection; interactivity; real-time

I. INTRODUCTION

The CEA (French Atomic and Alternative Energies Commission) dismantling division runs an R&D program to provide innovative simulation tools for decommissioning projects. The various software and hardware tools are based on Virtual Reality (VR) technologies, and enable a user to interact with a computer-simulated environment, whether that environment is a simulation of the real world or of an imaginary world. VR environments, mostly based on visual immersion and displayed either on a computer screen or through stereoscopic displays, can also include additional sensory information, such as sound or touch [1].

This paper describes how VR technologies, adapted to the nuclear decommissioning context, can provide useful support to engineers in charge of scenario design. Before beginning the actual operations, such a set of tools is also well adapted to communicating and sharing information during project reviews, or to training workers and ensuring they are aware of the risks they could be exposed to. It is the first time in the world that such technology has been used to define decommissioning scenarios. VR showed its advantages in other industrial or medical fields, like automotive conception or surgical training [2].

First, the chosen VR technologies will be presented. Secondly, the first application case will be presented and explained as well as the nuclear environment and the remote handling system used for dismantling. Then, we will describe the simulator developed to validate scenarios.

In the last section, we will describe our first results and the perspectives.

II. THE MARCOULE IMMERSIVE ROOM

The CEA created the Marcoule immersive room at the end of 2008 in order to validate maintenance or dismantling operations. It is a resource shared by all the CEA decommissioning projects (about ten), and can be used for project reviews, for accessibility, ergonomics or scenario feasibility studies, and for training workers [3].

The team works on new plant design as well as dismantling projects.

A. *The hardware equipment*

1) *Stereoscopy*

The room is equipped with a very large screen, 3.7m by 2.3m. After examining the options available, we have chosen the Infitec (*INterference FIlter TEChnology)* passive stereoscopic technology and use two projectors from the constructor Projection Design to display the images by back projection. The largest resolution is 1920x1200. Special interference filters (dichromatic filters) in the glasses and in the projector form the main item of technology and have given it this name. The filters divide the visible color spectrum into six narrow bands - two in the red region, two in the green region, and two in the blue region (called R1, R2, G1, G2, B1 and B2 for the purposes of this description). The R1, G1 and B1 bands are used for one eye image, and R2, G2, B2 for the other eye. The human eye is largely insensitive to such fine spectral differences, so this technique is able to generate full-color 3D images with only slight colour differences between the two eyes [4].

The main advantages of this technology are the very light weight of the glasses and it allows the user to turn his head with keeping a good stereoscopy. The size of the screen is very comfortable to work on life-size simulations.

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2) Motion capture

A motion capture system based on four IR cameras manufactured by AR-Tracking is used to track the position of the specially-equipped glasses in real-time. As a result, when the user moves his head, the point of view of the simulation changes as if a genuine movement had taken place within the VR surroundings.

3) Haptic device

The room is also equipped with a haptic interface, the Virtuose 6D35-45 (Fig. 1), which enables the manipulation of virtual objects and force feedback to simulate the contacts. This device is developed by Haption, a spin-off of the CEA and it is the only product on the market today, which offers force feedback on all six degrees of freedom (DOF) together with a large workspace and high torques [5].

Figure 1. Virtuose 6D35-45.

B. *The software tools*

We use TechViz XL [6] developed by TechViz, a French company in order to catch the OpenGL flow of an application, generate stereoscopic images and send it to both projectors. TechViz XL notably works with 3DSMax, SolidWorks or Virtools.

Virtools produced by Dassault Systèmes is used to manage a simulation. It offers a development environment to create 3D real-time applications and thanks to its Software Development Kit (SDK), we can add our own functionalities.

III. First Application: Cell 414

A. *Presentation of the project*

The APM facility is the Marcoule Pilot Workshop. It was a prototype plant for reprocessing spent fuel, first commissioned in 1962, with production activities shut down in 1997. The plant is currently undergoing clean-up and dismantling.

Cell 414 (Fig. 2) is a part of the APM and was a chemical unit used to process liquids from irradiated fuel dissolution operations. It is a particularly large cell: 20m long, 4m wide and 6m high. There is approximately 5km of pipes. The present high level of radioactivity rules out direct manual dismantling, so the choice of a remote handling system called Maestro has been made.

The first step of decommissioning is to remove high level radioactivity (hot spots). Data was gathered from an initial inventory: hot spots were identified with a gamma camera. These hot spots like the centrifuges or some parts of the pipes have to be removed first in order to reduce cell radioactivity.

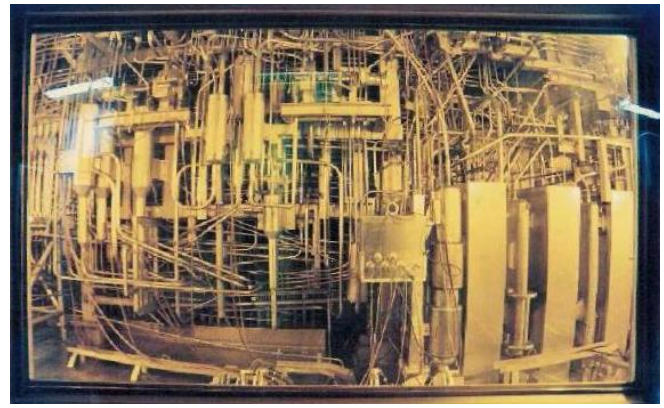

Figure 2. Cell interior seen from a porthole.

B. *The remote handling system*

1) The Maestro system

The Maestro system is the result of 10 years of collaboration between the CEA and Cybernetix in charge of its manufacturing [7]. This advanced remote manipulator is used when human intervention is not possible as if to operate in nuclear or offshore hostile environments. Maestro is dedicated to many tasks like inspection, maintenance, dismantling, cleaning…etc. Dexterity, accuracy and strength are its main advantages. It can be used in either robotic mode (automatic sequence) or in manual remote control mode with or without force feedback management.

This system is made up with two parts: the master arm and the slave arm. The master arm is a device allowing the control of slave arm end-effecter in Cartesian mode with a complete force feedback. This device is a Virtuose 6D40-40 from Haption. The slave arm is a hydraulic robot with six degrees of freedom (Fig. 3).

The cell 414 dismantling project will be the first working site where Maestro will be used to dismantle a whole cell.

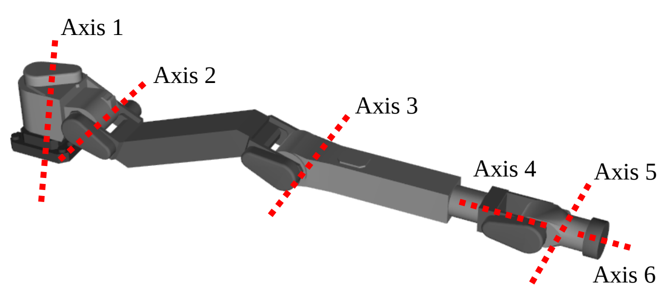

Figure 3. The Maestro kinematics

2) The carrier

The carrier was especially designed for Cell 414 dismantling, and will enable the Maestro system to reach all parts of the cell.

It works on three axes, using existing rails to move along the cell (20m), with vertical (3m) and rotating movements. A crane-type handling bracket is also set up on the carrier to hold parts during dismantling and for other handling operations. This carrier is currently undergoing tests.

The carrier-crane combination also has six degrees of freedom (Fig. 4), with four translation axes and two rotation axes.

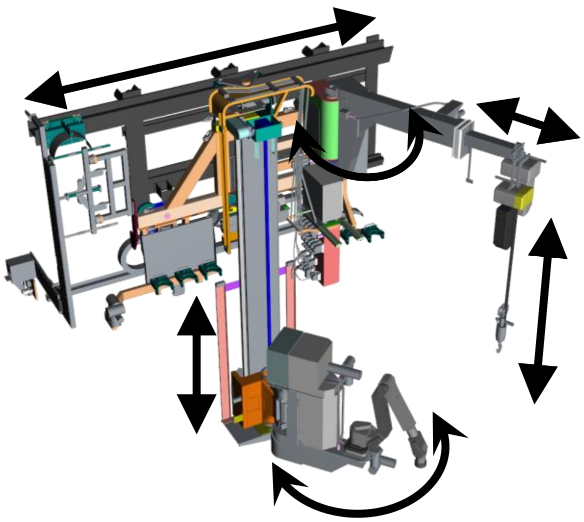

Figure 4. The carrier kinematics

IV. FROM REAL TO VIRTUAL : THE STEPS TO BUILD THE SIMULATION

In order to verify accessibility and maintainability on the carrier and to validate technical choices, it was decided to design the dismantling scenarios using a simulator and the VR technologies available in Marcoule.

A. Step one: build the 3D models

1) The cell 414 and the APM facility

First, 3D models of the environment had to be built. As the 2D drawings of facility inside were not sufficiently up-to-date to design a precise digital mock-up, a photogrammetric technique was used. A remote controlled camera was brought in the cell to take a set of pictures from different points of view. Then the 3D model was built using a semi-automatic process, to produce a model compatible with CAD or modeling software. About 200 pictures were necessary for the 3D reconstruction and only the internal parts were modeling in this way. This step was made by an external company.

Secondly, the modeling of the building containing the cell 414 was made with the plan of construction.

Finally, we merged these two parts to get a whole model into the 3DSMax software. The images below enable the comparison between a real photo and a VR view of the same scene. We can see that the 3D simulation is very close to reality (Fig. 5).

Figure 5. A real photo (left) and 3D view (right)

2) The robots

Dealing with the robots previously presented, we obtained the CAD model by the manufacturer of the real robots: Cybernetix. The modeling is in SolidWorks format and we did the necessary conversions to use it into 3DSMax.

B. Step two: develop the simulator

1) The Virtools environment

Our simulator is based on Virtools 5.0. It uses a specific script language and functions called Building Block (BB), in order to provide the interaction between the different objects, create menu, play sound, etc.

To import 3D models into Virtools, they must be in a specific format. That is why we use 3DSMax because it provides an exporter from .MAX format to .NMO format used by Virtools.

Virtools owns a basic physics engine but we use a third party physics engine because it is more precise and adapted to the force feedback. It will be presented in the following paragraph.

2) Physics engine: IPSI

IPSI [8] is a physics engine provided by Haption. It enables the testing of intersections between volumetric solids, in order to calculate trajectories and impact points. The real-time collision detection disables penetration between objects. Volumetric existence is given to geometric objects by taking the external skin of each 3D object.

IPSI allows the creation of the kinematics of a robot: hierarchy between the different segments of a robot, the kind of degrees of freedom and its values, etc.

Finally, IPSI can attach a virtual object to the Virtuose device and calculate the force feedback in case of collisions.

3) The simulator

Thanks to the Virtools SDK and the IPSI API, we can use Virtools for the graphical part and IPSI for the physical part. We created a Dynamic Link Library (DLL) for Virtools to add the abilities of using the functionalities of IPSI.

In the initialization of the simulation, all the 3D objects we want to add to the physical simulation are sent to IPSI as well as the information about robots (hierarchies, degrees of freedom, etc). So we create kinematics of the Maestro arm

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and the carrier. As a matter of fact, we can consider both objects as robots and describe very precisely their motion. It consists in giving properties, by defining rotation or translation axis and end stops given by Cybernetix. Virtual robots can then be manipulated with their constraints as in real.

The graphical representation of the objects is updated in Virtools by IPSI which calculates the new position in real-time. During the simulation life, we use a callback function to match graphical and physical objects.

C. *Step three: control the simulation*

To control the robots, two gaming joysticks are used to pilot the carrier and the crane. The first one controls the three DOF of the carrier and the second one those of the crane. These controls are very similar to the interface which will be used for the final dismantling system.

The Maestro arm has been coupled to the Virtuose 6D 35-45 haptic interface. The Virtuose enables manipulation of the Maestro end-effecter, and thus control of the Maestro extremity while respecting the kinematics chain and all the end-stops.

The entire robot can be maneuvered in real-time with these devices.

D. *Step four: add interactive functionalities*

An interactive real-time simulator was developed where the whole cell, the Maestro slave arm and the carrier are loaded. The Maestro arm and its carrier can be maneuvered using the joysticks and Virtuose. Any of the nine available tools like drill or angle grinder can be connected to the Maestro arm or changed, as necessary.

The points of view of the six cameras (two available in the cell and four embedded on the carrier) are also displayed in the simulator. It has been checked that every part of the cell is visible. Indeed, the operator will not perceive the cell directly during the dismantling. He will be in a room with six monitors to view the pictures being transmitted from the six cameras. There will be also a microphone in the cell, so the operator will can hear the sound of collisions in the monitoring room. Therefore we associated a sound with collision in the simulator, to enhance the information sent to the user.

Lastly, automatic scenarios, such as the carrier entry in the cell, are programmed.

V. FIRST RESULTS

Tests carried out on the system had two objectives : first, to check that the carrier design was suitable for the Cell 414 environment, and second, to verify the whole dismantling operation design [9].

Two interface problems preventing the forward movement of the carrier were quickly identified: while the first obstacle could be avoided by raising the Maestro base, the second will have to be dismantled by existing in-cell equipment, before the carrier enters the cell.

We have then verified the detailed dismantling scenario from the carrier entry to the cutting of centrifuges. We found a lot of technical key points which need to be clarified because the feasibility of the task is not easy. For example, the tool grasping seems to be a problem because the Maestro slave arm is in a limit configuration and the carrier has to be in a specific position (Fig. 6). It disables the grasping in some parts of the cell. This kind of problems was not yet identified and the manufacturer has to take into account these issues.

The last work we have done focuses on the centrifuges dismantling. We proved that the planed scenario was not feasible. With the simulation we brought alternative solutions.

Thus, from the first simulation runs, the project has already brought vital information to implement in its dismantling scenarios. The chosen VR technologies have proved their worth, and the various capabilities of the Maestro system and carrier will continue to be tested as the dismantling project enters its next phase.

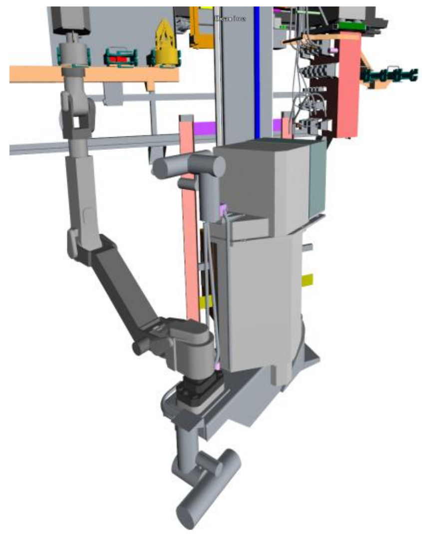

Figure 6. The tool grasping

VI. LIMITS AND PERSPECTIVES

A. *Current limits*

First, the mismatch of information relevant to reality can affect safety and performance. For instance, if the modeling accuracy of the robot or the cell is not enough, we cannot be sure that the scenarios that have to be tested with the simulator are reproducible in practice. The robot model directly comes from the CAD model of the manufacturer, so it can be considered as identical as the real one. The modeling incertitude is brought by 3D reconstruction. As a matter of fact, photogrammetry is accurate with 5cm precision. The most difficult task is to obtain a right model of the cell. The actual model created by photogrammetry is accurate enough for the first steps of scenario study but because of the layout of the cell, the complete model of the pipes could not be rebuilt with this technique. Only the first row of pipes were modeled so we have to update the cell modeling after the first steps of dismantling if we want to fit to the reality.

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Secondly, we are limited by the physics engine. In deed, it is directly dependent on the computing power. With the current hardware, we cannot physicalize the robots and the whole cell with a high precision for the collision detection and get a real-time simulation. That is why we only physicalize the robots and some interesting parts of the cell. These parts depend on the tested scenario. Collision detection precision has to be inferior or equal to 10mm so that the accessibility studies could be realistic.

B. Add the radioactivity dose rate information

The CEA in collaboration with Euriware, a French company, developed an application called NARVEOS [10] capable of calculating the radioactivity dose rate. It is specifically used to simulate scenarios in nuclear environments. In NARVEOS, we can import a 3D model of a nuclear facility, specify the kinds of materials (steel, lead, concrete …) and add radioactive sources, protection screens, and measurement points in the 3D model. The software is able to calculate the radioactivity level in these points in real-time. For instance, we can measure the radioactivity dose rate on an operator moving in the facility.

In a near future, we want to assembly the functionalities of NARVEOS with our simulator. In this way, we will be able to follow in real-time the decrease of radioactivity level during decommissioning and calculate the new levels after the removal of hot spots.

C. Train the operators

From the beginning of this project, the idea of training operators was predominant. The models are very closed to the reality and we can work with a life-size simulation. Currently, the control of the robots with the joysticks plus the Virtuose device, allow testing the real robot motion in the cell. For instance, we can find the most fitted carrier positions to work at best with the Maestro slave arm. We can also use the simulation to increase the operators' awareness of the risks they could be exposed to, like collisions between carrier and equipments or robot damage.

Moreover, the main purpose of the training is to avoid nuclear incidents like workers' irradiation. That is why we want to use the radioactivity dose rate simulation to train operators and inform them where the radioactive areas are located.

Another advantage of the training is to show operators that there is no direct vision, so they will get used to working with only video and sound monitoring from the cell.

VII. CONCLUSION

This project shows that VR technologies can contribute to improve knowledge regarding project preparation and validate technical choices. The simulator involved is generic and can load any 3D model of a building. It is already functional and useful for the operator's training. The CEA has also compiled a comprehensive robotics library and can therefore run VR versions of scenarios with any of these systems in order to test alternative solutions.

Given the first results, the CEA proved VR tools open up new perspectives for studies, for decommissioning cost and deadline management, as well as for communication between project teams, contractors and Nuclear Safety Authority.

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