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Use of virtual reality for robotic intervention preparation in unstructured and hazardous environments

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Abstract

In unstructured and hazardous environments, like the one present in particle accelerators, nuclear and power plants, the organization of the maintenance intervention is crucial to increase precision and efficiency. In this work, the use of virtual reality to prepare a robotic intervention is presented, as well as the hardware, software tools, procedures and recovery scenarios conceived.

Keywords: Precision, maintenance, procedures

1. Introduction

Intelligent robotic systems are becoming essential for space applications, industries, nuclear plants and for harsh environments in general, such as the European Organization for Nuclear Research (CERN) particles accelerator complex and experiments. In order to increase safety and machine availability, robots can perform repetitive, unplanned and dangerous maintenance tasks, which humans either prefer to avoid or are unable to carry out due to hazards, size constraints, or the extreme environments in which they take place.

To operate robots in harsh environment or in place where there are difficulties for human access, there is a strong need of intervention simulators for safety, time and costs related reasons. Mock-ups and bench test rigs are a key part of the process for remote operations development and task validation. Virtual mock-ups are used for task procedure development by default, physical mock-ups are used for testing and validation where the tasks are either novel and challenging or involve physics characteristics which cannot be reliably represented in a Virtual mock-up. At CERN, several robotic systems and robotic controls are developed and deployed to maintain remotely particle accelerators [1-2]. For risk analysis and intervention procedures preparation, a Virtual Environment for intelligent Robotic Operations (VERO) has been design and conceive to guarantee precision, safety and robustness of maintenance activities, like remote inspection and telemanipulation Figure 1.

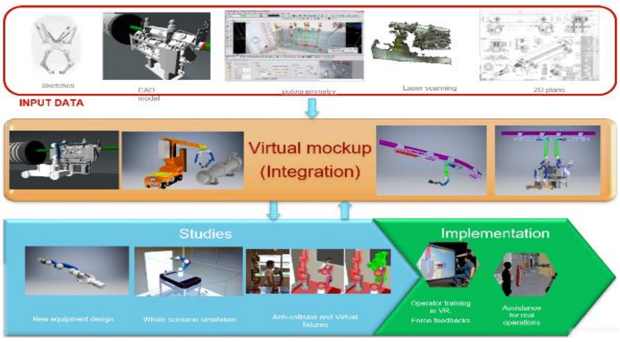

Figure 1 Overview scheme of the VERO framework

2. The VERO Framework

Virtual Reality (VR) is a simulation of an immersive environment produced by a computer. For this immersion the user can use different systems to replace the real world sensations by the computer generated ones. For example, for visual the user can use a headset, for audio a headphones, for tactile sensation different haptic devices, etc. The VERO framework takes in input all relevant CAD models and drawings, and from this data it creates a virtual environment for simulation using Unity [3-4] and has a decisional algorithms to establish if an action is safe to be performed by humans or needs remote devices, like for example robots. The core of the VERO framework is an algorithm that simulates robots behaviour and is fundamental for the design of the robotic procedures, tools and recovery scenarios that are vital in harsh and hazardous environments. The robot are modelled using a robot description format and spawned in the robotic simulator Gazebo. Control of the robot base is also modelled. A graphical user interface is used in order to interface with the simulation, and control the robot with the help of live images coming from the robot's on-board cameras (see Figure 2). The generic robotic simulator, is used to simulate the physics and the visuals of the realistic and functional custom-made model of the robots. Thus, it can provide all the sensors' states, including the state of all the joints declared in the model of the robot, as well as information on the cameras that the robot is equipped with, since these are also modelled and simulated. The user can operate the simulator using either a keyboard or a specifically designed GUI that runs on Windows. The output of virtual cameras is also streamed on a web server. This allows the user to access the cameras' data and have it displayed in real-time via the GUI. For the simulator to be as realistic as possible, both the mathematical and visual models of the robot needed to be as faithful to the real robot as possible. The mathematical model of the robot was integrated and tested. This was followed by the visual modelling of the robot using a robot description format. Furthermore, a simple test environment was also modelled for the robot to operate in. The first step in obtaining the kinematic model of the robotic arm, was to determine the Denavit-Hartenberg [5] parameters. In this manner, the reference frames could be attached properly to the links of the robot's arm. This was done by accurately sketching the robotic arm's configuration, to clearly show all the joints and their frames and a joint-by-joint control has been adopted (see Figure 3), in addition to an operational space control mode (see Figure 4).

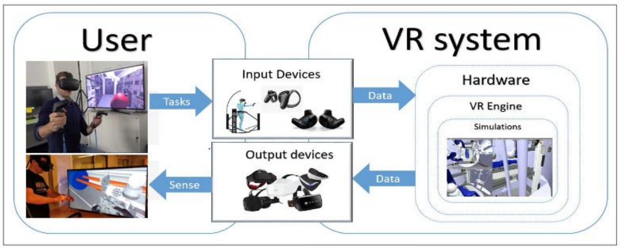

Figure 2 High-level overview of the VERO tools

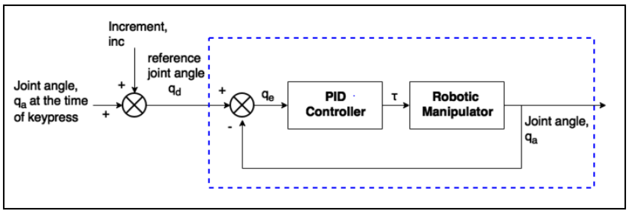

Figure 3 Joint-by-joint control scheme of the VERO framework

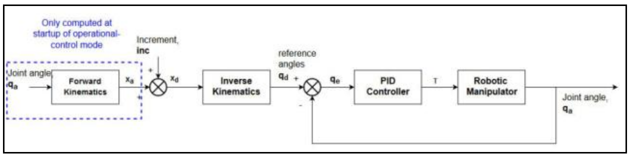

Figure 4 Operational-space control scheme of the VERO framework

2.1. Simulation environment for operators training

The immersive technology as virtual reality offers a wide variety solutions in different fields. It allows to incorporate large scale volumetric data of any complex 3D structure for visualisation, design and training propose [6]. The head-mounted display (HMD) gives the possibility to have a wide field of view of the virtual environment. Furthermore, the low latency tracking and the high-resolution displays make the experience more realistic. This technology is being used also in education to bring more intense experiences to students. For example, in the research ([7]), an educational game for History subject is developed for students in order to learn and develop historical thinking in an authentic, interactive and explorative experiences in the virtual environment. Researches prove that this technology improve the interest and the perform of the students [8-10]. Virtual reality is also been considering in medicine as a successful simulator for training propose and survey planning [11-12]. Although the major aim of VR in medicine is survey practice, it is also used in medical care with multiple professionals in a shared virtual environment for share decision making for an actual surgical intervention [13] or trauma decision-making [14].

In robotic field, virtual reality has been used for teleoperation in risky place as Tokamaks [15] or JET [16]. In both research, VR is used as a tool in Remote Handling (RH) for design robotic arm's operation and training. Applying the imitation leaning [17] the robot is able to learn and perform complex tasks or solve the complex dexterous manipulation problem [18]. By using external controller or human body tracking, bimanual robot is easily controlled performing complex manipulation tasks [19]. Moreover, it is possible to add real pictures features as texture of the virtual environment and other feedback source in order to increase of realism, help to go out from the gaming effect and decrease the fatigue and stress while using VR. Among different components of the VR system, input and output devices are crucial in this system. They are in charge of immerse the user in the virtual environment. With input devices, the user can interact with virtual scene. Output devices bring the sense and different feelings to the user. The basic input devices are used to track the position of the user together with the head orientation; normally these features are incorporated in the HMD. To capture the actions of users, different devices can be used. For example a treadmill for tracking the movement as walking or running; externals trackers for body tracking or controllers that allow user interact with objects or do different actions. Several input and output devices are presented in the Figure 5.

Figure 5 Input and output devices

A comparison of two most common known HMD is showed in the Table 1 and Table 2. VERO is based on a powerful graphics engine and a physical simulator that make possible to users feel the physical presence in the virtual environment. Furthermore, this module is practical for acquainting with the environment in order to have better planning for the interventions. In addition, with VERO, the operator can train the operations before the interventions. In this way, using this system will save time, avoid unnecessary steps or overexpose to radiation, and foresee possible dangers.

In nuclear plants and in general in hazardous environments, it is mandatory to do an analysis of the environment before starting an operation. For example, at CERN, there are several challenges to face when is working with tele-operated or semi-autonomous systems due to the complicate environments and the conditions as high radiation and temperature. This situation will be more complicate if the operation needs to be done by human.

Table 1 Specifications of Oculus Rift

Display Type & Size	Dual low-persistence Samsung AMOLED
Display Size	90 mm x 2,456 ppi
Resolution	1200 Ã — 1080 (per eye)
Refresh Rate	90Hz
Field of View	94H x 93V–degrees at optimal 12mm lens-to-eye distance
Sensors	Accelerometer, gyroscope, magnetometer
Tracking Technology	6 DoF Constellation camera optical 360-degree IR LED tracking
Audio	Microphone, integrated supra-aural 3D spatial audio headphones
Dimensions	171 x 102 mm
Weight	470g

Table 2 Specifications of HTC Vive

Display Type & Size	Dual low-persistence Samsung AMOLED
Display Size	91.9 mm x 2,447 ppi
Resolution	1200 Ã— 1080 (per eye)
Refresh Rate	90Hz
Field of View	110H x 113V-degrees at optimal 8mm lens-to-eye distance
Sensors	Accelerometer, gyroscope
Tracking Technology	6 DoF IR Laser-based 360-degree tracking using "Lighthouse" Base Station
Audio	Microphone, jack for external headphones
Dimensions	190mm x 127mm
Weight	563g

Taking all of this into account, a module of robot controller and master – slave training are developed. Through the module of the robot controller, the operator can move the robotic arm join by join and move the robot base around the scene (see Figure 6). In this way, it is possible to simulate the operation more realistic and check if the robot will reach the target. In addition, with this tool it is able to analyze the viability of the robot in small area.

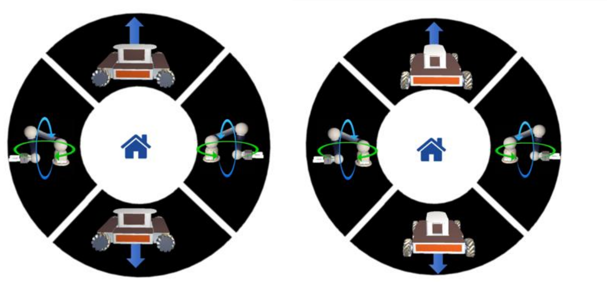

Figure 6 Full control of robotics arms and CERNbot: Application button + Trigger to choose DoF to move, Left/Right to move the joints, Up/Down to move the robot base

Due to the differences challenges described above for hazardous areas, the main aim of this module is build a virtual environment as similar as possible to the real environment. For this reason, the input data are the different components of the environment. This input data can be sketches, CAD models, photogrammetry or laser scanning or 2D plans of the environment, robots and tools (see Figure 7).

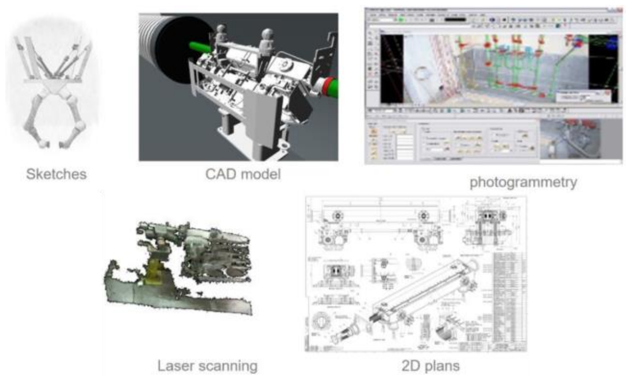

Figure 7 Type of input data of VERO

2.2 Integration

VERO system is designed to be modular; each input is exported as an independent 3D model. In addition, different actions or interactions with the environment are developed as different modules, each module has a specific function. Depending on the requirement of the intervention, different 3D model and function modules will be added to the virtual scene. In this way, repetitive actions can be easy imported to different simulations.

The flowchart from receiving a requirement to having the plan for intervention is shown in Figure 8.

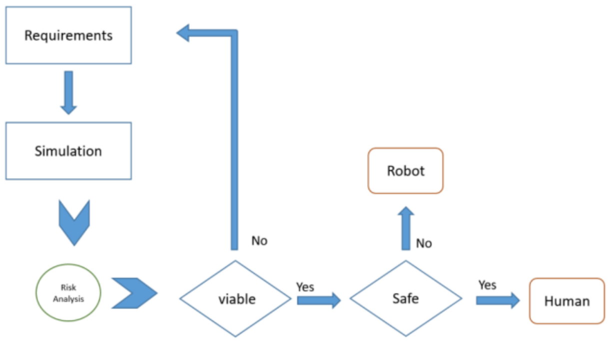

Figure 8 Flowchart interventions planning with VERO

- Requirements: the requirement needs to be most detailed as possible, describing the goal of intervention, all the possible risk and giving the necessary input data model of the environment.
- Simulation: after understanding the requirement, it is necessary to create the virtual environment for simulation. Each requirement needs to be studied in different simulators. This simulation includes the 3D model of the environment and all the modules necessaries for the intervention. For example, in some cases it is necessary unscrew, then the module of screw/unscrew is needed to be incorporated in the virtual environment.

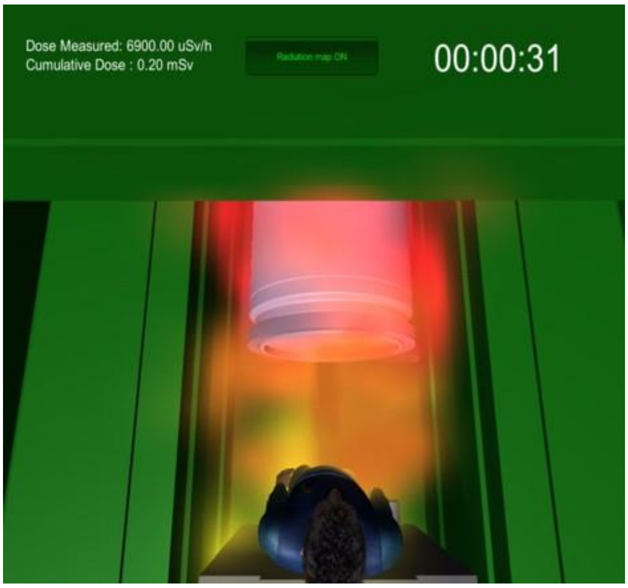

Figure 9 Danger estimation system incorporated in TDE maintenance planning; radiation map and animated body are incorporated

- Risk Analysis: the simulator is crucial in the sense that with this is possible to do a risk analysis and to know if the plan scheduled is viable or not. In addition, it is very important because in this step the radiation dose that will receive the human (see Figure 9) or robot during the intervention is calculated. Depend on the result of this analysis, the operation could be done by operator or robot.

2.3 System validation

The presented virtual reality system has been tested and validated in interventions mockup and in real scenarios for maintenance tasks in the CERN accelerators complex. It has been used for intervention procedures preparation, as well as risk analysis assestments for human intervention and recovery scenarios procedures conceptions. The framework has been also adapted for environmental integration purposes of different machines elements being part of CERN experimental complex. In addition, techniques like learning by demonstration has been integrated to prepare the robotic systems for autonomous behaviour in the fulfilment of the remote handling tasks (see Figure 10). Signals from operator body (e.g. heartbeat) could be added to simulate operator status.

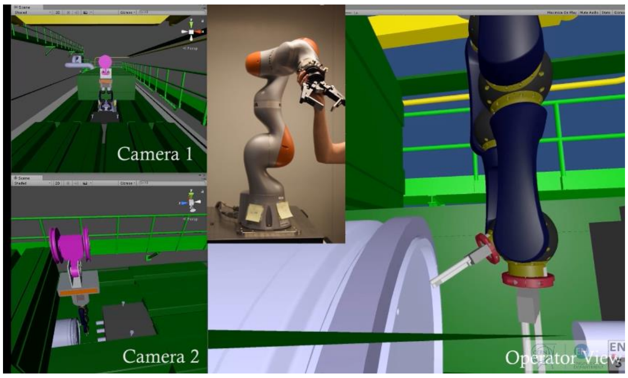

Figure 10 Learning by demonstration integrated VERO. In the middle of the shown VR scene, a picture of an operator teaching a robot trajectory is superimposed.

The developed framework has been used also to simulate multiple robots autonomous collaboration checking the best combination of robot positions and cameras angle of views for specific interventions in hazardous and harsh environments (see Figure 11). The strategy adopted for the human-robot collaboration is explained in [1].

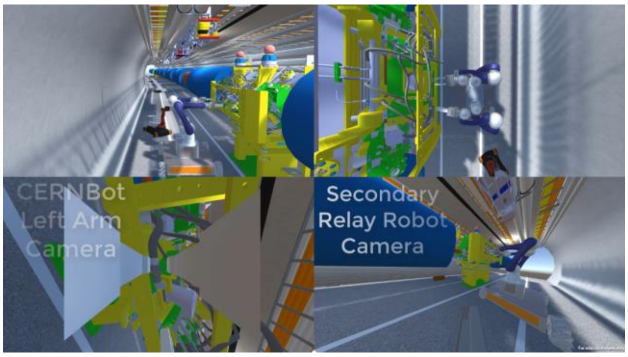

Figure 11 Example of collaborative robots scene and the different field of view from the robots in the virtual scene.

3. Conclusions

A novel virtual reality based framework for remote intervention preparation, procedures, tooling, as well as safety and dangers estimation for maintenance in big science facilities has been presented. The framework is under operation at CERN for maintenance operations of particle accelerator complexes. In the future, it is planned to endorse the current framework with automatic texturing to reduce the gaming effects of VR systems and to add artificial intelligence algorithms.

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