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3D virtual world remote laboratory to assist in designing advanced user defined DAQ systems based on FlexRIO and EPICS

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HIGHLIGHTS

- Assist in the design of FPGA-based data acquisition systems using EPICS and FlexRIO.
- Virtual Reality technologies are highly effective at creating rich training scenarios.
- Virtual actions simulate the behavior of a real system to enhance the training process.
- Virtual actions can make real changes remotely in the physical ITER's Fast Controller.

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ABSTRACT

iRIO-3DLab is a platform devised to assist developers in the design and implementation of intelligent and reconfigurable FPGA-based data acquisition systems using EPICS and FlexRIO technologies. Although these architectures are very powerful in defining the behavior of DAQ systems, this advantage comes at the price of greater difficulty in understanding how the system works, and how it should be configured and built according to the hardware available and the processing demanded by the requirements of the diagnostics. In this regard, Virtual Reality technologies are highly effective at creating rich training scenarios due to their ability to provide immersive training experiences and collaborative environments. The designed remote laboratory is based on a 3D virtual world developed in Opensim, which is accessible through a standard free 3D viewer. Using a client-server architecture, the virtual world connects with a service running in a Linux-based computer executing EPICS. Through their avatars, users interact with virtual replicas of this equipment as they would in real-life situations. Some actions can be used to simulate the behavior of a real system to enhance the training process, while others can be used to make real changes remotely in the physical system.

1. Introduction

The iRIO-3DLab platform has been designed to facilitate the learning process for personnel responsible for the design of intelligent data acquisition systems implemented on devices based on PXIe technology. A good example of this kind of systems has been established by ITER CODAC with the definition of its Fast Controllers. They use embedded technology, and are implemented on industrial controllers running Red Hat Enterprise Linux (RHEL) and EPICS [1]. These controllers are characterized by the need for very high sampling rates and highly demanding real-time control loops that require the ability to run pre-processing algorithms on the acquisition hardware itself. UPM and CIEMAT have developed a methodology and a series of prototypes based on the use of reconfigurable and intelligent data acquisition systems designed using FlexRIO, FPGA-based acquisition devices [2]. This technology is based on an FPGA mounted on a PXIe format card and an adapter module including the interface and/or digitalization functions.

The proposed architecture unquestionably provides an optimal solution to the dynamic configuration needs of the acquisition system tailored to the specific requirements of each application. However, the integration of this type of technology into a distributed acquisition system such as EPICS presents several challenges, as these cards do not have fixed resources and depend on the adapter module to which they are connected. Consequently, the Input Output Controller (IOC) also needs to be reconfigured [3]. To

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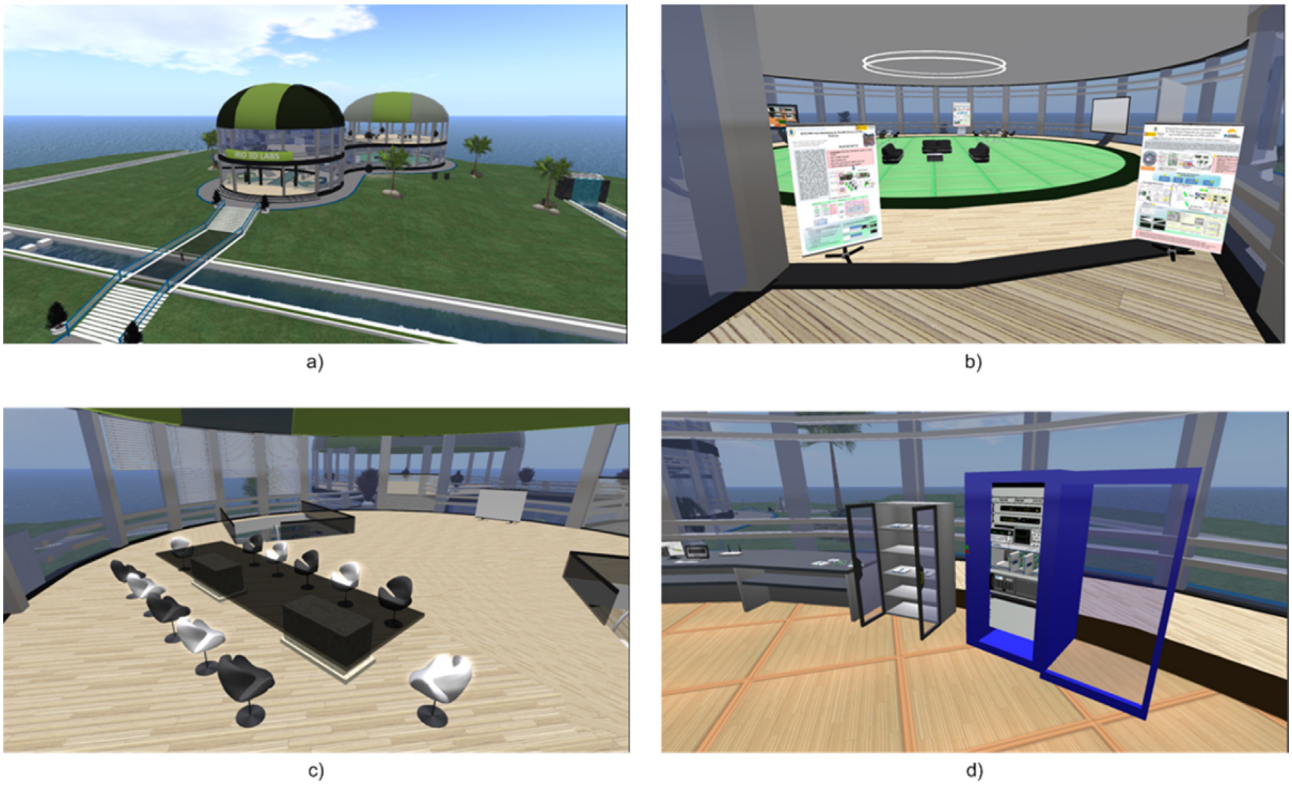

Fig. 1. Facilities of iRIO-VirtualLab: (a) Laboratory Building, (b) Exposition Room, (c) Meeting Room, and (d) Technical Room.

configure the IOC the designer must be familiar with the operation of EPICS, the syntax of the IOC configuration files, and its relationship with the selected hardware configuration. In the current stage, in which the technologies that are to be used to design future diagnostics and control systems are being specified, there is a need for tools which enable users and developers to familiarize themselves with the proposed technologies. This is the case for the FlexRIO and EPICS technologies. These tools must also overcome the geographical dispersion of developers and enable them to access the real hardware making up the system.

iRIO-3DLab is a multi-user 3D Virtual World developed on OpenSimulator [4] aimed at providing advanced instrumentation systems users with an understanding of acquisition system architecture, as well as its procedures for assembly, connection, start-up, shut-down, etc. Additionally, it enables them to carry out a set of predefined tests to establish different configurations and test their effects on a real system in operation, as well as drive inputs and measure outputs remotely.

In this regard, the iRIO-3DLab platform has shown itself to be a very useful resource for accelerating the learning curve. Just like any virtual world, its strength lies in its ability to create an Immersive Learning Environment (ILE) with a high sense of realism that is accessible via the Internet [5]. A 3D virtual world is an environment in which users are virtualized by avatars through which they can interact with objects in the virtual world or each other using synchronous communication tools. These spaces considerably improve the capacity for spatial representation and manipulation procedures, and strengthen practical learning, which promotes greater involvement, collaboration and creativity [6]. It is therefore not surprising that this type of technology has already been used in the fusion field for teaching and training in the management of equipment and execution of procedures [7], as well as for testing instruments and material at the development stage in order to evaluate the suitability of their design prior to final manufacture [8].

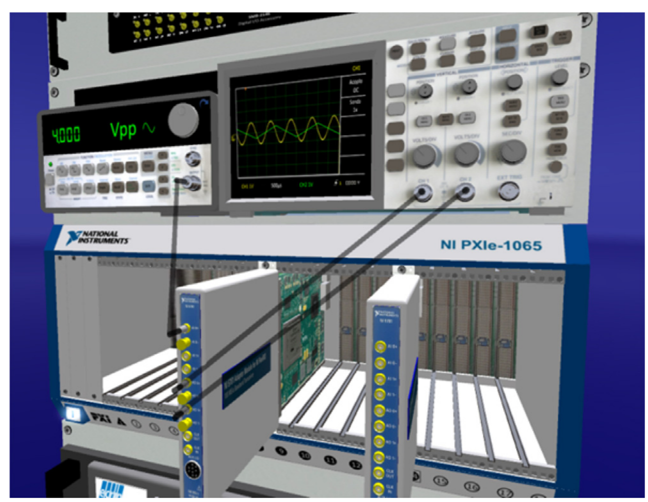

Fig. 2. Example of a virtual hardware configuration for a PXIe system using FlexRIO.

2. iRIO-3DLab operation and functionalities

The main component of iRIO-3DLab consists of the virtual world. As shown in Fig. 1 a), the virtual world comprises a building in which we can find several rooms assigned to different uses. In particular, as Fig. 1 b) shows, these include the exposition room were textual documentation and multimedia about the latest developments carried out on FlexRIO-based intelligent acquisition systems can be found. There is a meeting room, shown in Fig. 1 c), in which collaborative tasks can be conducted using available synchronous

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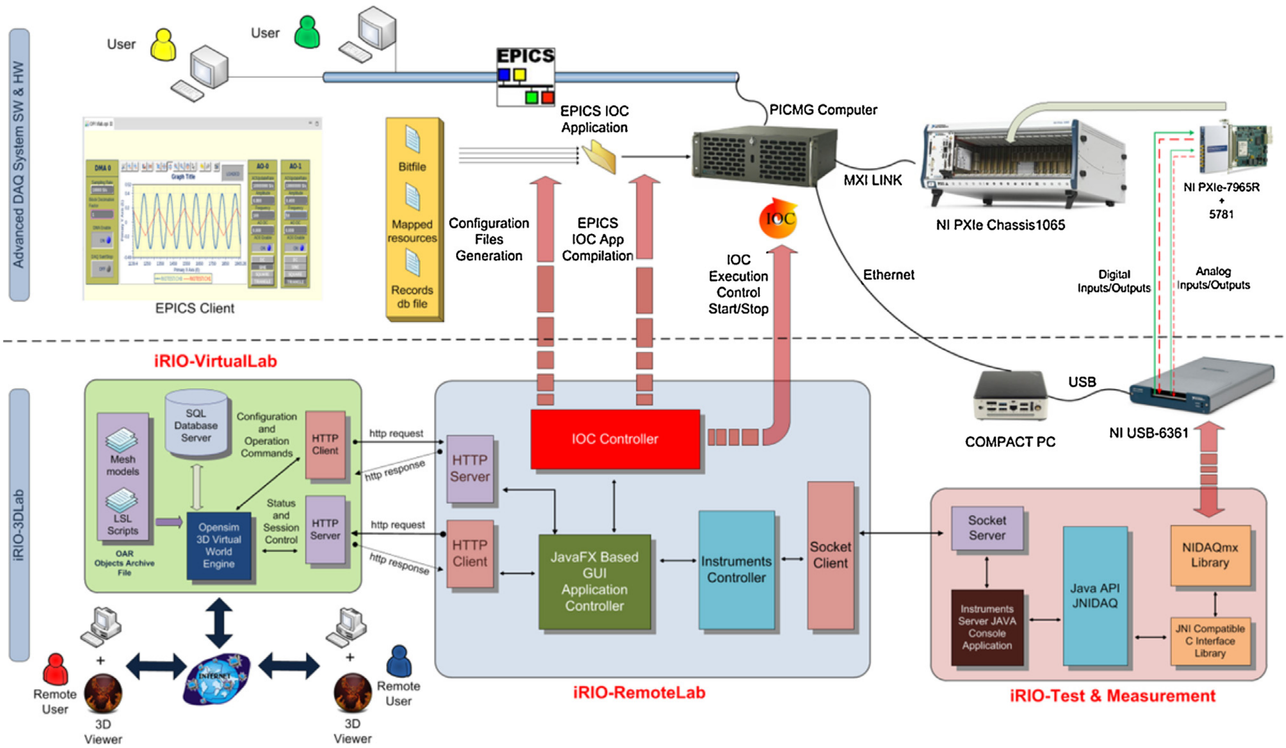

Fig. 3. iRIO-3DLab architecture.

communication tools (voice and text). Lastly, the main core of the facilities is the technical room, shown in Fig. 1 d), which has four virtual cubicles containing all of the equipment available in the real cubicle, including the chassis where cards can be connected, a PICMG-compliant computer and a variety of laboratory instrumentation. Next to it there is a cabinet holding the FlexRIO cards and the adapter modules available for connection.

The virtual system needs to be managed just like the real system, by following the same procedures and in the established order. If the correct sequence is not followed, the system will give a warning and explain the correct mode of operation. The current system version enables actions such as: selecting FlexRIO cards and the adapter modules; obtaining information about equipment characteristics; connecting and disconnecting cards on the chassis; selecting the pre-processing algorithm and hardware resources to be programmed in the FPGA from determined configurations; and starting up and shutting down the chassis, computer or general power supply to the cubicle. All of these actions carried out in the virtual world are replicated in the real system that is being controlled remotely. For this purpose, for each action a command is sent to the application responsible for configuring the IOC Application in the appropriate way. Finally, after compilation and start-up of the IOC, the resources of the real device are published by means of the corresponding Process Variable (PV), being accessible through the EPICS Network.

The system also enables remote tests to be performed using two virtual instruments: a function generator and an oscilloscope. Connections can be made between these instruments and the inputs and outputs of the adapter modules.

The operations carried out using these virtual instruments are translated into orders sent to real instrumentation, implemented by an NI USB-6361 device, controlled remotely from the virtual world. In this way it is possible to work with FlexRIO cards by driving the inputs with the desired signals and measuring the waveforms at the outputs, as shown in Fig. 2.

3. System architecture

Fig. 3 shows the global system architecture. On the lower part we can see the elements that make up the iRIO-3DLab platform: iRIO-VirtualLab, iRIO-RemoteLab and iRIO-Test & Measurement. On the upper part we can see standard software and hardware components which make up the EPICS Linux-based system, which is the system that will be controlled and configured remotely. The figure also shows the interactions among them.

The computer-based advanced instrumentation system, on which the platform is installed, consists of the following hardware and software configuration based on products available in the devices catalog:

- NI-PXIe-1065 model PXI chassis.
- PXI-6682/PXIe-6683 timing module that supports standard IEEE-1588.
- Acquisition devices based on FPGA FlexRIO NI-PXIe-7965R and NI-PXIe-7966R.
- Adapter modules NI5781, NI6581, NI-5752, NI-5761.
- External controller (PICMG 1.3) connected to the chassis by means of the PCIe link with NI-PXIe-PCIe8371.
- Red Hat Enterprise Linux v.6.5.
- EPICS environment v.3.15.1.
- EPICS Device Support for FlexRIO devices based on asynDriver software technology developed by UPM.

3.1. iRIO-VirtualLab

This is the application that implements the virtual world. It was developed using version 0.8 of Opensim. The virtual world server runs on a separate computer from the PICMG, with both computers connected over an Ethernet network. Users access this server via the Internet by using a 3D Viewer which must be installed on their computer. There are several free versions of these viewers, such as Firestorm and Singularity [9], which are compatible with Opensim.

Apart from the development of 3D models (mesh models) and LSL language scripts that make up the objects forming the virtual world, an HTTP server and client have been implemented for this application to communicate with iRIO-RemoteLab. The latter is the application responsible for transferring the actions carried out by the user in the virtual world to the real cubicle.

3.2. iRIO-RemoteLab

This application is responsible for controlling the acquisition device and acting on it according to the actions carried out. This is an application developed in JavaFX which runs on the Java 8 virtual machine installed on the PICMG Computer. This enables access to the EPICS tools in order to configure, compile and run an IOC. The IOC configuration is carried out by defining data structures referred to as *records*. Once the IOC is executed, these records are instantiated as PVs, which allow access to the FlexRIO physical inputs and outputs, through the EPICS device support [3]. Likewise, the resources used to send samples to the processor and the processing algorithms that will be implemented in the FlexRIO card's FPGA are recorded in two files: the bitstream file needed to configure the FPGA and a header file including the mapping of the resources used by the EPICS device support based on asynDriver. In a conventional system the data acquisition system designer is responsible for creating these files, and for their definitive location on the directory tree included in the IOC application. However, in this case the application has an IOC Controller module responsible for generating these files and sending them to the virtual world so that the syntax needed to configure the IOC application in the required manner is presented to the user. This module also compiles and runs the IOC, such that the resources are published at the end of the process, as in any other system, by means of PVs accessible via an EPICS Client.

3.3. iRIO-Test & Measurement

This application was developed in Java and runs on a compact PC with an NI USB-6361 data acquisition card. In order to allow development using only non-proprietary tools, this card is controlled using National Instruments' standard DAQmx libraries, which are available free of charge. For this purpose, a C library has been developed which is compatible with Java Native Interface (JNI) and the corresponding Java API called JNIDAQ. This application is connected to the Remote Laboratory by means of a client-server structure in such a way that it receives orders carried out in the virtual world, processes them and returns the results to be presented on the virtual instruments.

4. Conclusions and outlook

The iRIO-3DLab platform is a novel solution in this field that can contribute to improving the provision of training required in this field for users involved in the design of complex instrumentation systems such as ITER I&C systems [10]. Work in this field needs to continue in order to increase system performance and to achieve a configuration which is much more versatile, personalized and integrated with the other development tools.

Furthermore, the proposed solution serves as a starting point in the development of new generation remote participation tools based on advanced user interfaces. For this purpose, the advantages provided by virtual world technology, in relation to the immersion capacity and its benefits, must be considered along with the requirements demanded for this type of application for large physics experiments [11]. In this regard, the main challenges to be faced in upcoming work are to strengthen communication security and to include mechanisms for the management of large information volumes.

Acknowledgments

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