VIRTUAL REALITY APPLIED TO INDUSTRIAL PROCESSES

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Abstract. The present paper shows the development of a virtual reality application through the creation of environments that allows supervision, monitoring and control of industrial processes. It has the possibility to simulate or work with live-time information, linked to existing process modules of the most important physics variables such as level, pressure, flow and temperature. The results of the application are presented to validate the project, using the functions of supervision, monitoring and control, the scopes reached in emulation, as well as the contrast between the emulation option and real interplaying with industrial processes.

1 Introduction

The constant changing of society and the technological revolution that world is living, leads to appear improvements of the techniques and methods implemented in skills training process in order to be applied in working or educational activities. The inclusion of Information and Communications Technologies (ICT's) like smart boards, videoconferences, virtual platforms, and others have allowed a speedy advance of education, creating in present generations a high dependence to digital products and services, in order to complete daily activities. Although, inside educational institutes and some industries, state-of-the-art laboratories are implemented with the objective of incrementing operators' expertise during the training process. The fact of working with high-cost equipment, makes that all elements must be manipulated carefully and considering safety standards. Similarly, for teaching purposes, it is very difficult to establish a module which includes all characteristics involved in a real industrial process. Thus, this circumstances does not allow people who uses the instruments to exploit and improve the skills and capabilities in an integral way. For that reason, the use of virtual and technological tools is essential, aiming to increase the possibilities available within training process inside industrial environments. [1,2]

In automation's field, the control pyramid [3] becomes in the central point of analysis and taking as main involved instrumentation, which acquires great importance because it is the attendant that manages every single level of the pyramid, from field components to the manage resource system implementation. Industrial processes needs constant maintenance, calibrations and adjustments of components of the system, where the

instrumentalist is responsible for carrying out these procedures. The monitoring of this processes through acquisition data and its posterior visualization through a human machine interface (HMI), allows to keep under control the actions that are made in different stages of the system; graphics and two dimension (2D) trends, let people know the behavior of the process and at the same time it is necessary additional elements to achieve and present the results [4,5].

Focusing on process instrumentation, some companies have been specializing in the development of tools to complement vocational training from the point of view of process analysis, structures modeling, components designing, systems simulation, and others. Nowadays, the possibility to carry out industrial tasks such as development of architectural plans is bigger, and now they can be complemented with other global use tools like electrical diagrams, pipes diagrams and tree dimensions (3D) modeling [6]. In the same way, there are tools intending to analyze and develop applications, from basic tasks, *e.g.*, math operation to the implementation of intelligent controllers for industrial plants. These tools contributes optimizing the execution time of those tasks, but the big disadvantage they present is two dimensions environment display. This fact limitates the implementation of improved techniques for tasks manipulation training, supervision and process control. Therefore, a new environment that allows to obtain the performance parameters of systems is needed, as well as alarms' status and many other alerts directly involved with process' operation.

The awakening of Virtual Reality (VR) has led researchers to find many uses and applications for virtual environments (VE). Among them we find videogames with a high immersion grade that makes users feel unique sensations [7,8]. All of that does not finish there, due to applications in medicine's branch now are posed, especially in the way of rehabilitation [9,10], e.g., for people with brain damage or children who has born with some kind of retardation. Another applications are virtual tours to identification institutions or hard to reach places, and more recently, this tendency is joining to educational field as projects development managers or even contributing with learning process [11-13].

For all the above, in this project the developing of a VR Application is presented. It starts with pipes and instrumentation diagrams (P&ID) that are the basis of understanding for any industrial plants. Prior to digitalization's process, with help of graphic and industrial design tools, the project is looking for the achievement of two principal objectives. [14,15] The first one allows the *monitoring* of didactic modules placed in the laboratory of industrial processes, where physics variables, *e.g.*, level, pressure, flow and temperature are analyzed. The application enable users a live and direct interaction with modules as well as exchanging data in order to implement monitoring, supervision or any kind of control in each process without external elements. In the second part, the *emulation* of a bigger and greater complexity industrial process is developed. It has the purpose of interacting with processes that resembles to real industrial plants, where more variables are controlled as also a large data flow is processed at the same time.

This paper is divided into seven Sections, including Introduction. The second Section presents a general description of the problem, its justification and proposed solution. In the third Section environments' virtualization are illustrated. The tasks of monitoring and emulation are established in this part. The system's interaction with didactic modules is in fourth Section. The fifth Section reviews the developing of the emulation

for the greater and complex process. The results of tests and its effects after the implementation in the system are analyzed in sixth Section, and finally in the seventh Section, all conclusions of the project are presented.

2 Problem Formulation

The automation pyramid helps to understand industrial process' structure, showing basically hardware and software components of systems, where communication buses allows a continuous data flow through the other levels of the pyramid. It is important to know the performance of each element part of the system, for this reason, an SCADA that belongs to the second level of the pyramid, takes on a major roll being the link between a process and users. As it can be seen on Fig. 1, devices in charge of giving information about status of a single part or the entire system are not only screens, where the dynamics of the process are shown in historical trends, but also some of the devices presents a kind of visual information by themselves. Those information, is within SCADA level of the automation pyramid.

The implementation of an application that bases on VR to present in a graphical way the behavior of a process, from the point of view of physics, *i.e.*, animations of proper characteristics of system's elements, to the possibility to find HMI's with the entire information of processes, without using additional elements. It optimizes monitoring, supervision and control tasks and attracts attention of people which works with industrial plants. By last, the application helps operators to improve their skills, because in addition of training modules they now are able to emulate the process and see a very high approximation of how it works in real world. These processes are involved generally in systems of MIMO type, where a high working complexity level, space availability inside plants and design characteristics, are more advanced as usual.
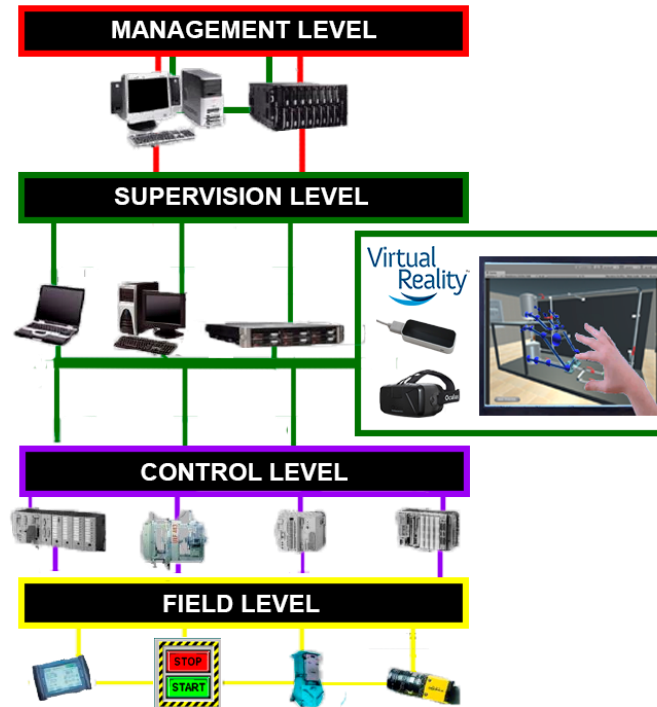
Fig. 1: Characterization of the Automation Pyramid using VR in Supervision level.

3   Environment Virtualization

A VR application should integrate some aspects that mixing each other, allows users a complete immersion into VE. For that reason, is important that every single component part of VE, present animation and functionality characteristics in order to achieve the best immersion and performance of the system. The proposed VE is shown in Fig. 2.

Fig. 2: VR Application developed in Unity

The base of the VR application are plants of some industrial processes. Those plants where digitized and introduced into VE using P&ID diagrams.

The technique chosen for industrial plants' digitization are based on the interaction with several specialized programs that enable the creation of equipment and instrumentation in 3D, as it seen in Fig. 3. Obtaining a representation of a real process is the main objective of virtualization, with the intention to apply on it animations and control variables involved in each plant.
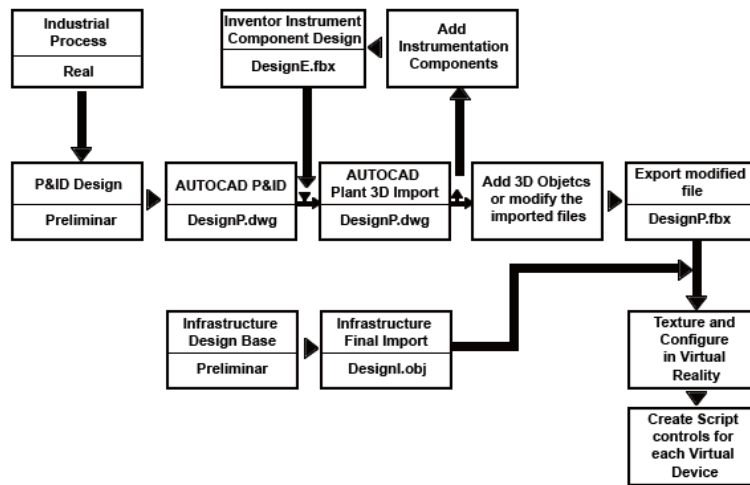
Fig. 3: P&ID diagram conversion into a 3D model.

The virtualization's process starts with references of the desired system, in this case, every industrial process has its proper P&ID diagram. Through this diagrams and using several CAD programs, the conversion from 2D to 3D is carried out, as it is seen in Fig. 4.
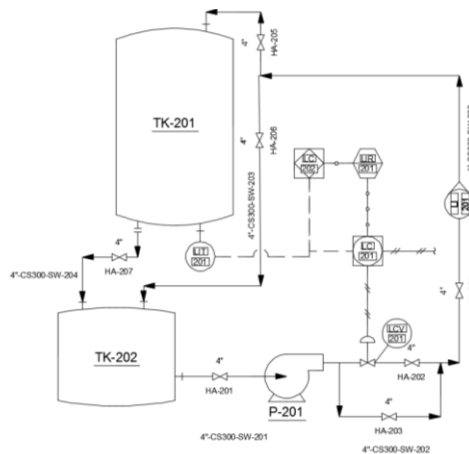
(a)   Level P&ID Diagram.
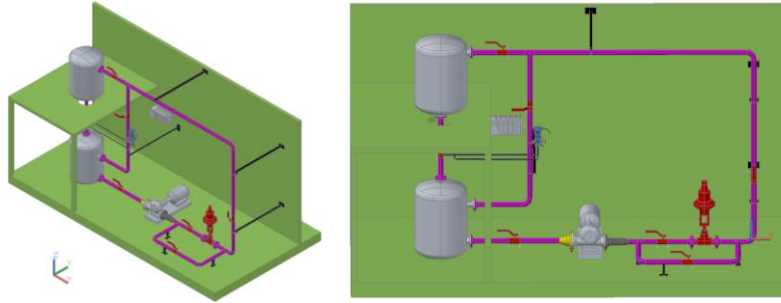
(b)   Industrial plant 3D prospects designed with AutoCAD Plant 3D.

Fig. 4: Results obtained after P&ID diagram to 3D model transformation's process.

A digitized industrial process should make user feel comfortable and familiarized with VE in the highest grade possible. For this reason, is necessary to use additional software which complements the transformation and at the same time adds a bigger immersion and credibility of the functionalities of the VR application for operators. In this case, there are some CAD software tools, *e.g.*, Inventor, Solidworks, Blender, and others, which help developers to add a high level of details in instruments' virtualization as it seen in Fig. 5. Those modifications does not represent a big change in the part of functionality, but referring to the experience given to operators, it is a really big advance, due to the reference of real world stuff in the VE.
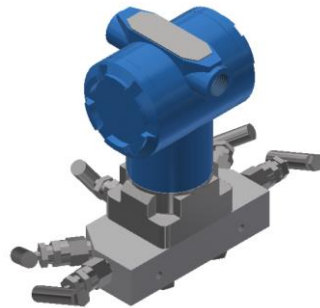

Fig. 5: Instrumentation modeling using Inventor.

An aspect considered to complement user's immersion in VE, was the creation of buildings where industrial plants were supposed to be located. Depending of industrial process, they can be located in different areas, *e.g.*, laboratories for training process modules or even an industrial plant for a big and complex process; all of this to add more reality to the VE and make it approaching the most to real world. As it seen in Fig. 6, for this part of VE development, it was necessary to use software, *e.g.*, SweetHome 3D, SketchUP, Polyboard, and others, to create buildings according necessities of people who is going to use the application.

(a)   Plan of building created in 2D.

(b) Upper view of the building created using SweetHome 3D.

Fig. 6: Final building structure used in application.

One of the advantages that Unity 3D graphics engine presents, is an importing library and complements option inside application, for this reason better results are achieved due to the capacity of software to include elements which does not come originally with the program, for this case, industrial process plants and the building where they are located. Both of them were created previously with different software to complement VE.

Another important element implicated in industrial plants are control valves. They must be manipulated by operators following system's requirements, therefore, its behavior and characteristics in VR application have to be the closest to a real control valve. The import process of this kind of elements is like any other element with the difference that each control valve has its own characteristics that are going to affect the animation and as a consequence the proper performance in the application.

It is necessary to change the centroid and reference of each imported element related with animation in order to use them properly. All animations increase the immersion of users in the application due to the quantity of similarities with real industrial process plants included in the VE for learning or training process.
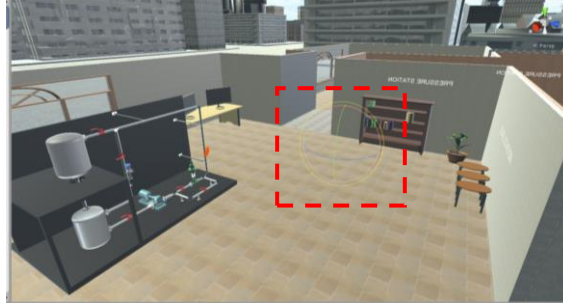
(a)   Original centroid of selected object.
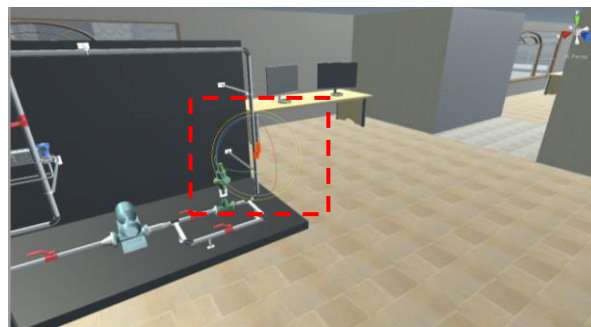
(b)   Centroid reference changes using an empty object.

Fig. 7: Changes applied in centroids and positional references of elements in Unity 3D.

4   Monitoring and Control of Industrial Processes

The VE has the same characteristics in functionality of an industrial process in real world, and for that, information is acquired and processed. These data is obtained from outputs of industrial transmitters collocated physically in processes or even from a process simulation software that generalizes the functionality of a complex industrial plant.

The link used for data exchanging between industrial processes or industrial process simulation software, both of them with VR application, is a database. It concentrates necessary variables used to modify the functionality of system on the one hand, and perform the implementation of monitoring and control on the other.

The database was created through a webserver with two specific objectives; the first one is receiving the information from real industrial processes and the second one is storage data needed to manipulate emulated industrial process. The centralization of information, allows greater control in data exchanging, and at the same time an important advantage appears from the point of view of supervision. The availability of the information of all industrial processes in a webserver, eliminates the fact where trainer monitors the operation of every single process in a manual way, and instead, do the same activity accessing to database remotely. For this activity is not necessary to run the VR application, because this is something that can be done by accessing database via internet, as it seen in Fig. 8.

Fig. 8: Communications established between components of VR application.

It is important to consider that experience given to users by VR application, has to be the most intuitive as possible, where processes displays real actions represented on models created with graphics engines. Hence, after data were acquired from data source as it seen in Fig. 9, animation and displaying scripts should be implemented in VE.

(a)   Database chart used for industrial process emulation.

(b)   Database chart used for industrial plants monitoring.

Fig. 9: Generated files through database using phpMyAdmin and Xampp.

Some characteristics offers by scripts in VE are associated to the functioning of each element part of the system, *i.e.*, displaying the main actions executed in a real process, *e.g.*, opening and closing valves, filling and emptying tanks, visualization of transmitters' outputs and related to this, the response of controllers applied in each process, and finally, to have a proper displaying of plants' status, it is necessary to create historical trends where critic variables are represented as same as in a local HMI inside the control room of an industrial facility.
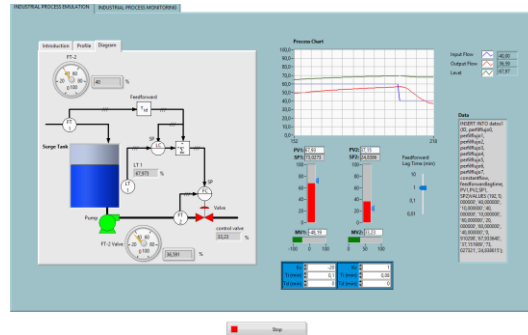
5   Industrial Plants Emulation

While it is true that interacting with industrial plant modules located in laboratories or training facilities generates skill's improvement in users and future operators of real processes, all of these elements are not always comparable to the real ones in real world. For that reason, an emulation of a complex industrial plant which approaches in complexity and realism, is implemented in order to complement the VR application.

The use of NI LabVIEW is not mandatory, because there are several industrial process simulation software, and for that reason new integrations of software in the application are accepted. This option would give the user the opportunity to compare results obtained with every program and select the appropriate option to be used for emulation depending of characteristics of the process.

In this case, the dynamics of the process contained in Cascade and Feedfordward Surge Tank Level LabVIEW demo [20] is used for emulation, as it seen on Fig. 10. Some changes to demo's base code included in Control and Simulation Design toolbox were applied, in order to establish data communication with Unity 3D.
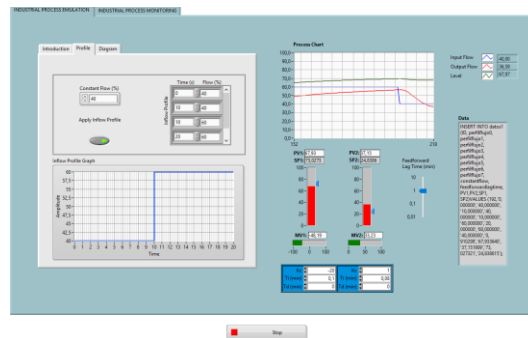
(a)   Controller process Inflow profile generation.

(b.1) Representation of industrial process in NI LabVIEW.

(b.2) Representation of industrial process in Unity 3D.

(b)   Comparison of the industrial process simulated using NI LabVIEW with its representation in VE.

Fig. 10: Demo used for the emulation of a complex process.

The communication between emulated process and Unity 3D is vital, and to complete this activity it is necessary to process inputs and outputs of system, liberating the source code of the demo selected in order to get that information. This information is going to be exchanged through database that storages this data and at the same time it is the information's source used by Unity 3D and the emulated process.

The selected process allows users to watch and control the behavior of the emulation from the process simulation software, as same as inside of final application where VR is applied.

6 Discussion and Experimental Results

The developed application is focus on manipulation of five recreated processes using VR. Four of them are Lab-Volt didactic modules where principal variables are controlled per each, *i.e.*, pressure, level, flow and temperature.

For representation purposes, as same as for data exchanging, the principal aspect that should be considered is transmitters' outputs nature. Didactic modules delivers a standard electric current through industrial transmitters that cannot be acquired directly from any task of analysis inside the application.

6.1 Results Presentation

The final disposition of elements in application is shown in Fig. 11, where each interactive component has its own animation, *i.e.*, valves moves as they do in real world and the value of current of real industrial transmitters are presented in the corresponding virtual transmitter. In addition, some important information, *e.g.*, P&ID diagram, electric current values and process' values are displayed in a screen placed in stations acting as a HMI. All of them are intended to help users to understand in the best way possible the operation of the industrial process they are interacting with.
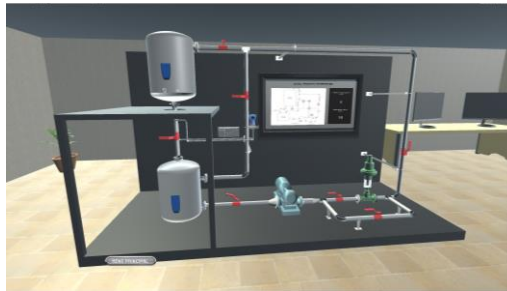
(a)   Virtual representation of level process station.
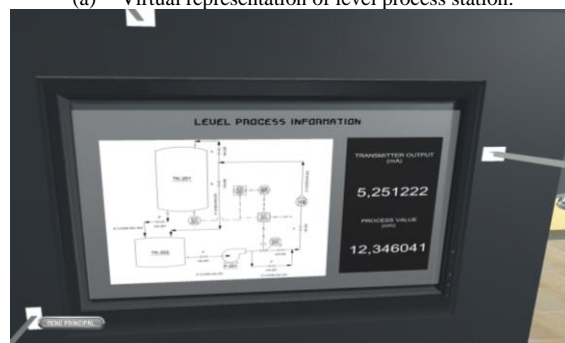
(b)   HMI displayed in screens placed in stations for plant monitoring.
Fig. 11. Application results after data interaction.

6.2 Experimentation

A test that shows if application is running appropriately in its monitoring stage was done by changing application input data, *i.e.*, output's values of selected transmitters in real world were modified in order to see a change in application's virtual transmitter. In this way, is proved that monitoring uses real information comes from processes as it should be.

As it seen in Fig. 12, the visualization of changes of real process is shown in transmitter, after modifying application's input data for level process plant, respecting to three different output values.

(a)   Results presentation of an output corresponding to 4mA.

(b)   Results presentation of an output corresponding to 7.5mA.

(c)   Results presentation of an output corresponding to 12.1mA.
Fig. 12. Transmitter changes to different current input values

Another animation resource used to help user's visualization, are sliders located in tanks. As is can be seen on Fig. 13, the sliders show actual tank's level of both tanks. These two tanks, are filled or emptied depending on the valves that users want to open, and in this way this specific part of immersion is increased.
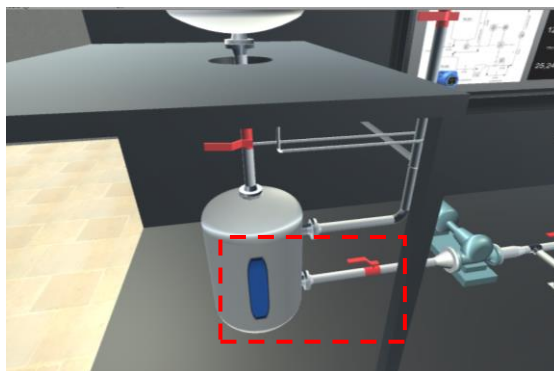
(a)   Tank's level representation with closed valve
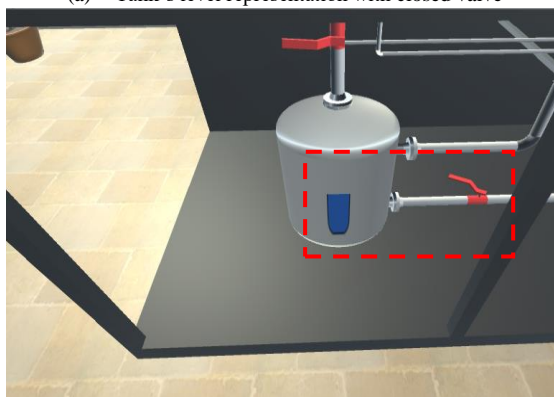
(b)   Tank's level representation with opened valve at 50%
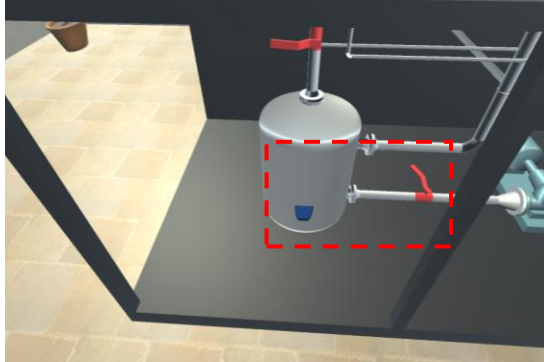
(a)   Tank's level representation with opened valve at 75%
Fig.13. Tank's level changes according to valves opening

7   Conclusions

The high grade of details added in 3D models of industrial process plants, increase the immersion of users in application. The advantage of this is the capability to start familiarizing with physical connections, instrumentation and equipment as they would be in real process. Therefore, focusing on application, from the point of view of operators' training in industrial plants, it turns into a tool for students who are learning in universities following the conventional educational process.

The use of a VR application cannot be compared with real didactic modules at all. The benefits received from a safe environment where operation tests of every element in the system can be done, represents a big advance because bad connections does not cause a risk situation for operators and the rest of staff in industrial plants. It guaranties the applicability of this project, and adding to that, the development of new VR applications is opened, where the use of VR would improves production levels and performance of operators in an industrial process.

Acknowledgment

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