IMMERSIVE, INTEROPERABLE AND INTUITIVE MIXED REALITY FOR SERVICE IN INDUSTRIAL PLANTS

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ABSTRACT
The authors propose an innovative Mixed Reality solution representing an immersive intuitive and interoperable environment to support service in industrial plants. These methodologies are related to concepts of Industry 4.0. Solutions based on a mix of VR and AR (Virtual and Augmented Reality) with special attention to the maintenance of industrial machines; indeed the authors propose an overview of this approach and other synergistic techniques. Moreover, alternative instruments are presented and their specific advantages and disadvantages are described.
Particularly, the approach is based on the SPIDER, an advanced interoperable interactive CAVE developed by the authors which supports cooperative work of several users involved in training, troubleshooting and supervision are proposed.
Last but not least, an overview of projects using same techniques in other fields, such as construction, risk assessment, Virtual Prototyping and Simulation Based Design is presented.

Keywords: Augmented Reality, Virtual Reality, Mixed Reality, Industrial Plants, Maintenance & Operation, Plant, Service, Interoperable Simulation

1 INTRODUCTION
The use of Virtual and Augmented Reality is pending as explosive technology since several years; it is still very fresh in our memory the promise never accomplished of Google Glasses as well as the Oculus Rift new version that was downsized after acquisition by Samsung and promotion of low cost smartphone head mounted displays (Chafkin 2015; Scudellari 2016); despite these limited achievement respect commercial expectations for 2015 and 2016, it is evident the big growth of VR & AR (Virtual & Augmented Reality) applications and their potential (Wagner 2016). The very interesting aspects about the advance in this area is the possibility to recombine different technology, reduce costs, increase capabilities and ramp up reliability in order to create solutions able to be usable in a wide spectrum of applications (Bruzzone et al., 2016a).

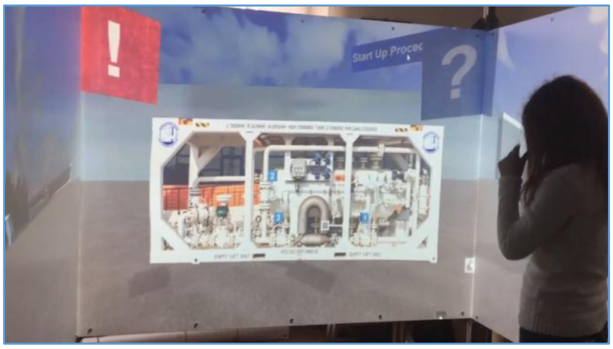

Fig.1 –Guided Procedures and Troubleshooting Processes of an Industrial Skid within MR SPIDER

Considering these aspects, the potential for industry is great and especially in training and education, service, maintenance, remote tutoring and troubleshooting; (Spanu, 2016). For instance a peculiar application could be related to safety training and emergency planning/simulation in chemical plants involving batch and semi-batch reactors processing reactive chemicals and relevant storage of flammable liquid and gases (Fabiano et al. 2015; Palazzi et al. 2017). This paper proposes researches derived from industrial projects that have been extend over a specific CAVE (Cave Automatic Virtual Environment)where it is possible to combine AR & VR to develop new Mixed Reality (MR) solutions for Service of Plants and Skids.

2 SIMULATION, AR & VR FOR INDUSTRIAL MAINTENANCE
The authors have been extensively involved in application of M&S and VR to maintenance in industrial Plants; in facts in recent years a specific project named SISOM (SImulation SOlution based on virtual and augmented reality for Maintenance) allowed to develop new solutions and to demonstrate the potential of modern VR (Virtual Reality) and AR (Augmented Reality) for industrial maintenance (Bruzzone, 2016a). In this field several solutions and technologies are available such as Laptop, Head Mounted Display, Glasses, CAVE, Smartphone.

Fig.2 – Cooperating Environment: Local Review on CAVE,Virtual Distributed Service between Site & Office

Fig.3 – Guided Start Up Procedure by Mixed Reality within the Interactive Interoperable Immersive CAVE

In facts in SISOM and other projects the authors evaluated the specific potential and shortfalls of different solutions in order to identify best configurations for specific applications. In facts it is very important to find evidence of their strongholds to properly develop immersive virtual ambient that could be reliable and suitable for industrial applications (Bruzzone et al., 2016a). During SISOM project the Simulation Team, with special cooperation among members from Genoa and Cosenza developed solutions able to run over multi-plaforms: in this way it was possible to operate from very light and compact platform by based on tablets, smart phones, HDV and virtual glasses, as well as from more immersive and interactive framework such as CAVE presented in figure 1. It resulted that the CAVE approach could be very interesting in case the use involve cooperative work among more people that could easily enter in it and interact directly with the virtual world and among their selves in an intuitive way. This solution is obviously more expensive, but it is pretty good in case of remote supervision for troubleshooting and industrial service and in facts this mode allows participation of multiple users maintaining at the same time an high level of interactivity. In this paper it is summarized this approach as well as the capabilities of these technologies and instruments along with opportunities provided by integration of the new solutions in Industry 4.0 which foresee connection of IoT (Internet of Things), Data Farms and Smart Devices in the field of support of industrial maintenance are presented.

3 INDUSTRY 4.0 & MIXED REALITY SERVICE

It's evident that adopting Industry 4.0 assumptions to create innovative solutions for Industrial Service based on Mixed Reality and Simulation is a guarantee to support supervision and assistance to personnel in case of problems and during of execution of complex procedures. Hence these new services are expected to allow a sensible reduction on the number of interventions of high-qualified personnel on site; this will turn to be possible by resolving significant amount of critical problems operating from offices and providing support in cooperative way utilizing opportunities provided by VR and AR.

Obviously this approach allows to improve drastically safety and efficiency of operations with heavy savings.
Furthermore the skilled people in charge of commissioning and on-site service are usually pretty rare. So this approach multiples their availability providing them the opportunity to work from the main office; this reduces their traveling around the world and makes it possible to serve customers in higher numbers as well as plant facilities that lay on not accessible locations.

4 TECHNOLOGIES AND APPLICATIONS

Improving availability and reliability of industrial plants as well as safety by using solutions based on VR and AR is one of most promising applications in this field (Tatić et al. 2017). In facts many R&D projects have been developed in this area and specific networks and consortiums have been created in Europe to address these issues (Quero et al. 2012; Pérez-Ara et al. 2013).
One of the ways VR and AR could assist mentioned activities is to guarantee "telepresence", which allows to move virtually high qualified personnel in the place where presence of its knowledge and professional capacity is required, in the same time it's possible to provide training different from the traditional face to face (Alzahrani et al. 2014; Zhang et al. 2014; Safir et al. 2015). In fact last years there were performed researches in this field (Peña-Rios et al. 2016), one of them is dedicated to airplane maintenance (Gonzalez-Franco et al. 2017). There are several interesting applications of cooperation and remote assistance in industrial field utilizing VR based on CAVE, for example virtual environments which could be connected to share data (Bruzzone et al., 2011b; Dai 2012).
VR and AR have been applied also in mining industry, with scope to increase productivity and safety of miners and operators, which control machines used in extraction and transportation of raw materials, using HMD (Head Mounted Display) with scope of training and orientation inside mine (Benes & Kodym 2014). Some applications have been developed also in the field of construction, which is still influenced by risks caused by lack of training of personnel (Le et al. 2015, Perlman et al. 2014).

Fig.4 – Interactive with CAVE Walls while applying a procedure on Driver Rack through Mixed Reality

By the way, another improvement of productivity and safety in this field could be achieved by remote training based on above mentioned concepts.
Immersive VR demonstrated its potential also as instrument of instruction for operators and students, creating non physical training classes, that could be worldwide distributed and could provide quite comparable results respect face-to-face lessons' (Bower et al. 2016).
In this sense there are still concerns about the capability to operate by VR in remote classes with equivalent results, therefore it is evident that technology evolution is expected to overpass some of this shortfalls, while cost and time saving will force to further extend these applications (Seidel & Chatelier 2013).

5 MIXED REALITY CHARACTERISTICS

Mixed Reality (MR) deals with the capability to create Virtual Environments where Augmented information and interfaces could be used to multiply usability, visibility, efficiency and many other indicators (Lindgren et al. 2016).
Indeed to improve usability of MR to multiple applications and by multiple users, it is very useful to guarantee compatibility of different technologies in proposed solutions: devices, MR and their connection; in some specific cases Virtual Environments are generated to allow several users to act individually and in collaboration through their Avatar representation Avatars (Biocca & Levy 2013).
Another important aspect which must be taken into account is related to immersion capability of the MR solution; indeed this aspect guarantees a quite complete engagement of the users, changing them from passive watchers of movies/animation to active participants of interactive activities within the virtual world (Sherman & Craig 2003).
In facts within VR applications, the user must interact with world, becoming "actively immersed" (Nakatsu & Tosa 2000).
In facts this status creates user's temporal estrangement from the world outside of the Virtual Environment even if virtual world is not perfectly real or even realistic and caused mainly by deep involvement of the user (Pimentel & Teixeira 1993).

As already mentioned, the interaction is a fundamental aspect of correct expression of MR, and it is guaranteed by sensors of different kind such as positioning sensors for eyes, fingers or muscles, otherwise motion capture, quick response graphics, touch devices, voice recognition systems and joysticks (Bowman & Hodges 1999).

6 THE CAVE: COLLABORATIVE & IMMERSIVE ENVIRONMENT

While it is already stated the importance to operate over multiple solutions, in this paper it is focused the attention on the use of frameworks able to guarantee multiple user engagement and collaboration. In industrial plants, during troubleshooting this is a quite important aspect dealing with the connection between the people on site and that one the office as proposed in figure 2. The collaborative environment between industrial site and central service center office should rely on an distributed virtual environment that could benefit of web simulation services and interoperable simulation (Bednarz et al. 2015). Vice versa the local collaboration in the main service office and in other overseas supervision sites it should rely on solutions able to simplify interpersonal relationship while interacting with the virtual world; due to these reasons the authors propose to adopt innovative new generation CAVEs able to interoperate with Simulation and MR.
CAVE systems have been introduced since long time; first appearance are dating since in the beginning of 90s by Illinois University researchers and it is not surprising that even in that case they were focused on providing the capability to visualize a virtual environment for cooperative use (Cruz-Neira et al. 1992). CAVE have been used in many different fields, from military training to medicine to visualize parts of a body giving so an opportunity to prepare for operation in shared environment (Hale et al. 2014). In addition to these fields there are CAVE used in Universities and Industries as virtual show rooms, or in Museum for the reproduction of natural or past environment. In fact, some applications of CAVE are specifically related to entertainment sector (Jacobson & Hwang 2002).
In facts, a CAVEs contains usually a limited space where virtual world is reproduced, but it allow the users to enter and eventually, by most modern solutions, to interact with it (Hale et al. 2014; Bruzzone et al. 2016a).
Therefore traditional CAVE have a cubic shape, with images, creating visual part of virtual environment, shown of its sides; screens could be done using different types of material, for example white plastic or mirrors (Hereld et al. 2000). Images could be created using classic direct view otherwise rear projection, which reduce drastically number of components inside CAVE, hence improving its virtual immersion, however this solution is not so comfortable in exploitation and requires bigger external volume and space occupancy of the whole equipment (Hale et al. 2014).

Fig.5 – Reviewing Virtual Handbook while interacting dynamically with the Plant Simulator

In facts the authors developed a special CAVE, named SPIDER (Simulation Practical Immersive Dynamic Environment for Reengineering) designed especially to provide top performance at very low costs with high versatility an interoperability levels.
SPIDER utilize direct view created by Super Short Throw Projectors which are capable to project image on 2 meters width screens from distances around 30cm with particular angles which allows to reduce significantly shadows (Bruzzone et al. 2016c). Much more expensive and large solutions require usually curved screens, up to completely spherical surface (Kenyon et al. 2014).
In any case the CAVE could be effectively integrated with many other I/O devices, for example in SPIDER it could be placed a motion capture system as well as motion platform. In facts it is possible to install a CAVE over a large platform as it is widely done for commercial flight simulators (Muhanna 2015).

6 SPIDER: INNOVATIVE CAVE

Simulation Team has used its SPIDER for several projects including SISOM in order to test the related versatility and performance; from this point of view, the SPIDER represent a innovative compact and movable solution which allows to evaluate different combinations of real equipment and immersive virtual environment (Bruzzone et al. 2016b). The SPIDER is a compact innovative interoperable and scalable thanks to its design based on modules suitable to be installed in a standard High Cube Container, in fact main SPIDER dimensions are 2m x 2m x 2.6m to fit in these kind of box and shelters.
SPIDER is designed to work in a federation of simulators with other interoperable simulators by most advanced standards. Another interesting SPIDER feature is represented by his touch screen technology: indeed the SPIDER screen surfaces are interacting with user using direct touch captured by laser scanners and/or by tracking electronic pencils. The interactivity on the multiple big screens (2m width each and up to 4 horizontally plus up to two more for top and/or bottom) is extremely intuitive due to the fact that users could touch elements in the MR corresponding to simulation objects; in this way it becomes possible to assign tasks, to give orders, to use them or just to require specific information easily within complex environment. All these functions turn to be immediately available to CAVE guests just by a direct touch by their fingers or by special electronic pens. These aspects guarantees an high level involvement for users and it could be further combined with other elements such as, for example, sounds, visual effects, vibrations, accelerations and touches. SPIDER solution has been used in R&D applications in fields of defense, marine, transportation and logistics (Bruzzone et al. 2016b). In the last case the BBBUS Simulator (Box Bull Bus Simulator) developed in collaboration with Central Labs of the University of Cagliari for training purposes has demonstrated its capacity to assist training, also procedures, using the same VR as other simulators of cranes (Bruzzone et al. 2011a). In facts, SPIDER is a CAVE which emphasizes interactivity and interoperability characteristics by being compatible with many HLA Simulators (Bruzzone et al. 2016c). In addition, this system could be integrated with several biometric devices (e.g.cardiofrequenzimeter, oculometer, muscle tone meter) to measure human experience as well as with devices such as other motion platforms o motion capture systems (Gonzalez et al. 2016).
In the same time a lot of devices could be connected to the system, for example various I/O systems (audio, motion) which are capable to make user experience inside SPIDER deeply immersive, allowing efficient supervision and analysis to bigger amount of persons, which dealing with dynamic virtual presence in VR activating different functions and subsystems.
Even more, the interoperability of the SPIDER guarantees the possibility to connect this environment to simulators of different kind using federation, which allows to represent different parts of machines (electric, mechanic, hydraulic and control parts).
This proposed solutions is very effective in terms of allowing the Subject Matter Expert (SME) to supervise operations remotely, in fact SME become available to control remotely distributed systems without leaving office, hence optimizing availability of limited high qualified human resources. In this way it becomes possible not only to supervise and/or control even geographically distributed systems, but also to provide training both in office or on field sites through internet in centralized way. In fact the applications of SPIDER represent an interesting example of new generation CAVEs able to provide new efficient ways of collaboration over the web and on site.
In fact in case of supervision by groups of 4 or 5 persons, the SPIDER allows to all of them to remain inside the CAVE and, at the same time, to move them and interact with machines and operators that are on the real plant on the field by reading data from various sensors, receiving video and audio feeds from remote cameras, etc. It is important to state the use of simulation models allow to combine this synthetic environment with functionalities of plants, skids and machines, to make possible to carry out virtual experimentations as well as to test in advance

procedures (Whisker et al. 2003); vice versa the use of interoperable simulation based on HLA Standard keeps open the possibility to federate the SPIDER also with real equipment to act as an element of a much complex simulation or emulation (Liu & Theodoropoulos 2014). Feedback could be provided using MR, by combining VR and AR; for example a remote assistants could send data through his tablet to the CAVE where experts review the situation and provide suggestions and directions back to him by using AR. For instance it could be possible to superimpose images from the tablet's camera and indications from SME (Subject Matter Experts), such as markers on control panel with description of sequence of procedures to be done, received from the remote assistant (See figures 3-5). Another potential application is related to the possibility to demonstrate on screen the procedures and operations; for instance the virtual models of a skid could be augmented with explanations of required actions and images related to this specific case and overlapped within the cave and on the field tables in a synchronized way based on data obtained from camera. In fact this approach, now it could be possible to address multiple problems in different areas, such as service, maintenance, safety, E&T. Combined use of VR and AR for remote assistance has already demonstrated interesting results and its efficiency in industry, at the same time the potential for training was experienced in SISOM Project (Bruzzone et al. 2016b); in these case experiments have been conducted by involving students and researchers in reference to industrial case studies in different sites.

8 CONCLUSIONS

Nowadays evolution of AR & VR allows to produce new MR solutions with high potential, for these reasons the authors are further developing the capabilities of their SPIDER to address maintenance in Industrial Plants. In this way it is possible to develop new support systems for service and maintenance that enable new distributed collaborative work procedures. This approach is efficient in cases of training of operators and remote control and support. The authors are currently conducting experiences with different user groups to collect important data and to define guidelines for introducing the new MR solutions in industry. In facts several experiments and examinations have been already conducted as well as comparison among many different possible approaches. In this way the MR approach maximizes the impact of multiple innovative M&S techniques into the Industry 4.0 concepts.

In facts, it is as important to extend analysis and theoretical studies by development and experimentation of new conceptual models, simulation architectures and software solutions to evaluate their real benefits on the field. This approach allows to refine the design and to identify new concepts and new solutions utilizing M&S, AR & VR. In facts, based on current researches and experiments it validated and quantified the capability to assist operators both on site and remotely through the SPIDER as example of innovative MR solution.

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