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Opportunities and challenges of high-level visualization technology in process operations and safety

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Abstract

The rapid development in high-level visualization technology in recent years has created tremendous opportunities for enhancing all facets of industry. Augmented reality (AR), mixed reality (MR), and virtual reality (VR) can be harnessed to support efforts in various stages of a life cycle of a facility. For example, AR technology can be utilized in the fabrication stage as well as in the validation and operation stages of the life cycle. MR can support efforts during fabrication, operation, and decommissioning stages. VR can be used in various dimensions of all stages of the life cycle.
This paper will review the forefront of technology of high-level visualization and will discuss the opportunities and challenges associated with this technology with respect to its implementation in the process operations and safety arena.

Keywords: Augmented reality, Mixed Reality, Virtual Reality, Process operations, Process safety

Introduction

Exponential increase in computational powers in recent years opened doors for evolvement of high-level visualization and its utilization in workforces. The term Extended Reality (XR) refers to a continuum presented in Figure 1. The continuum is composed of three segments of visualization technologies titled Augmented Reality, Mixed Reality, and Virtual Reality.

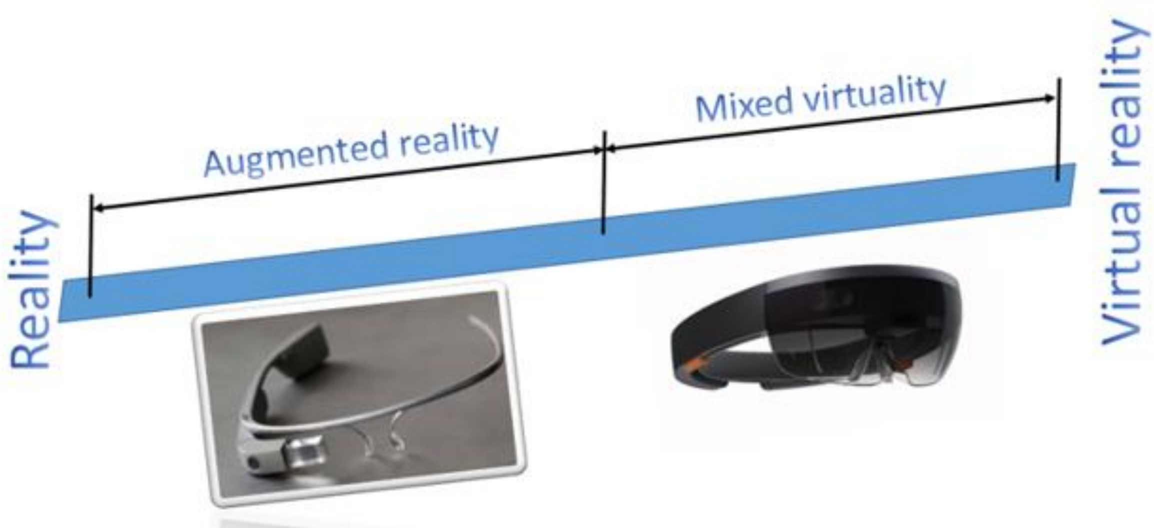

Figure 1. Reality-Virtuality continuum.

Augmented Reality (AR) is a platform that augments the real environment with digital data, allowing the user to seamlessly interact with these data and images. Cars, where GPS information is projected to the vehicle's windshield are facilitating AR technology.AR can be facilitated on mobile devices such as smartphones and tablets and on other computing platforms.

Mixed Realty (MR) are platforms that are anchoring 3D passive or dynamic holograms in the perceptual real environment. Once anchored, we forget that they are holograms and related to them as they are part of the environment. As with AR, MR can be facilitated on mobile devices such as smartphones and tablets. However, MR Head Mounted Devices (HMDs) provide enhanced control in locating holograms in the user's field of view and generate stronger sense of immersion. New generation of MR HMDs—such as Microsoft Hololense (Hololense 2, 2019) and Magic Leap (Magic Leap, 2019)— can operate as portable, standalone units. This facilitates functions that are more complicated when the HMD systems are connected to an external computing platforms such as laptops and desktops. Virtual objects may be anchored to real-world objects, allowing the user to interact with combined virtual/real objects.

Virtual Reality (VR) is a complete synthetically generated environment, where the user is isolated from reality and is immersed in a computer-generated realm. VR is the most used synthetic reality platform. The following sections further describe the technologies above and their use in the industrial arena.

Augmented Reality

Exhaustive review of literature, with respect to the utility of AR, identifys tremendous merit for AR technology, manufacturing, and maintenance (Palmarini et al., 2018)). Fiorentino et al. (2014) found the adding real-time information to operators' view has significant positive impact on the operators' perception of their environment. Scope AR (2018) points out that when operators used

AR, efforts for identifying proper maintenance steps dropped by more than 50% and the error rate dropped by more then 80%.

Schlueter (2018) explored the merit of using simplified visual-based AR content. This system would enable a remote specialist to create detailed AR content in real-time, and immediately deliver customized instructions to an on-site technician. His work also demonstrated that expert-assisted field maintenance can significantly reduce maintenance costs and errors.

Current challenges with AR are rooted in (1) the state of computational perception; (2) AR systems have limited computational power; (3) model-based recognition capabilities are very limited; and, (4) limited capacity of integration of artificial intelligence/machine learning to reduce cognitive load and dependency in third entity (remote expert).

Mixed Reality

In this section we refer to MR systems that are standalone HMDs systems, which allow interaction based on gaze, gestures, and vocal commands. MR utilizes two functions in order to implement the visualized MR:

(1) **Mapping the environment**: Once the MR platform mapped the environment it ‘anchors’ holograms in this environment and maintains its location fixed in the environment, independently of user’s movement. MR platforms are preprogrammed to scan the environment and map them.
(2) **Recognizing shapes in the environment**: Recognizing objects and either representing them as holograms or implementing additional virtual holograms, that can be manipulated with respect to the physical objects, open the MR space for facilitating virtual, or remotely assisted operations.

Figure 2 presents a user operating a Microsoft Hololense MR system. Figure 3 presents the ‘Recognition’ feature of MR utilized to facilitated virtual guidance for assembly process.

Figure 2. Participant interacts with a Hololense system.

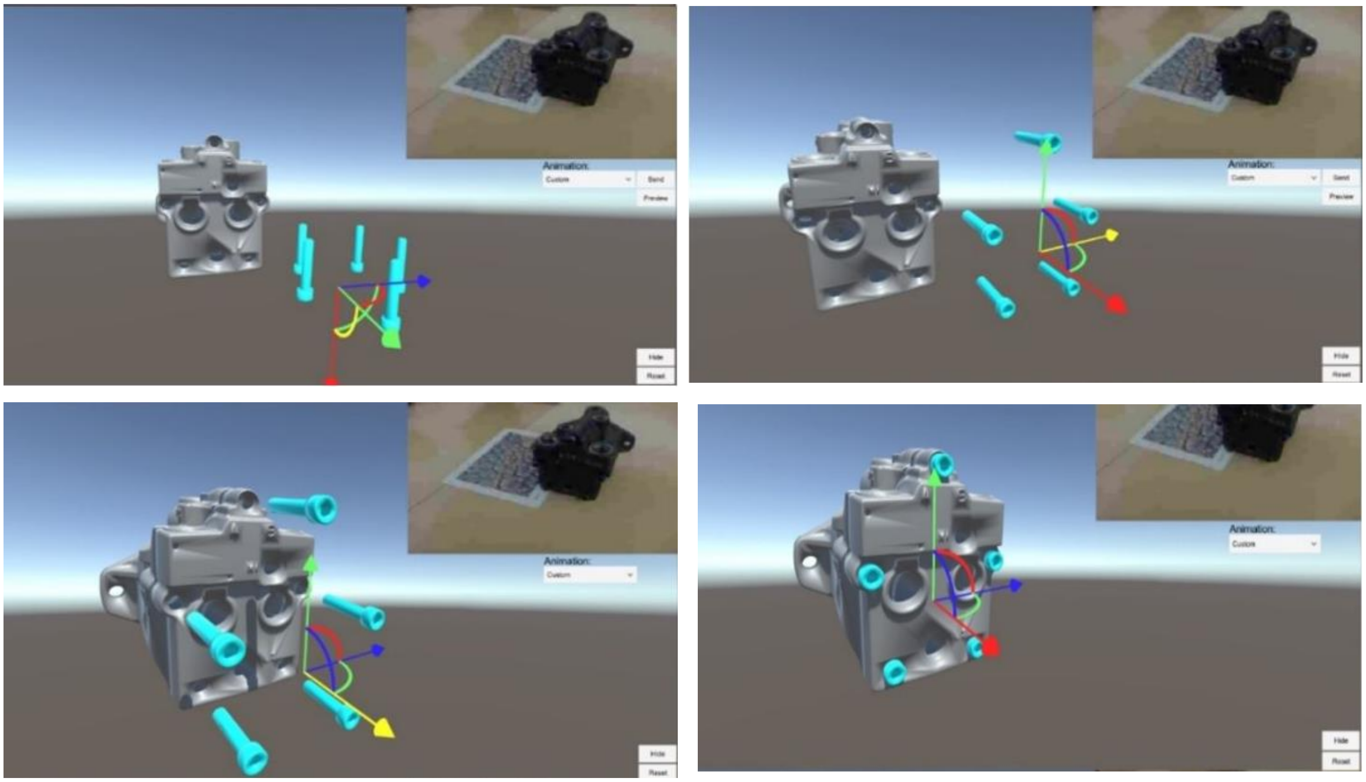

Figure 3[1]. Utilizing an MR platform for guided assembly.

While MR systems seem to have tremendous potential in industrial applications, their adoption is not as common.

Virtual Reality

VR is the most common synthetically generated environment in use. VR offers a multitude of facets that can be harnessed for various industrial applications. Due to its nature, VR disengages the user from his/her real environment and thus, by definition, excludes reality-connected applications from its scope.

VR systems span from room size VR facilities to HMD-based systems. Room size VR systems (Figure 4) allows multiple users to attend the environment simultaneously. HMD-based VR require developing specific applications that connect multiple users in the VR environment (VRE). The authors and their team developed a 3D, full-scale, highly interactive VR application titled Collaborative-VR (CVR) to allow multiple users to work in the virtual reality environment and build systems in the VRE (Figure 5a and 5b) (Slezak, Keren, et. al, 2018). A simplified overview of the CVR application is provided in figure 6. The system consists of a server in the cloud that receives an updated object state from one CVR client application and sends it to the rest of the

[1] Courtesy Jonathan Schlueter, Iowa State University.

clients to synchronize the virtual environment. The data flow is represented by bi-directional arrows, showing that the server cloud and client applications send and receive data. By continuously sending and receiving data from the server cloud, the system establishes real-time communication between users, bypassing the single-user limitation of VR and achieving a synchronized virtual environment. The only limitation for affective use is the quality of internet connection among the users.

Figure 4. Room-size VR system – The C6 at the Virtual Reality Application Center at ISU.

Figure 5. Multiple users with HMDs interact in the same VRE through the CVR system.

VR systems can be used for experiencing system designs in concept exploration stage and pre-fabrication phases. For example, Figure 6 presents a snapshot of a user exploring a bridge currently under construction between the states of Iowa and Illinois. The bridge was adopted into the author's VR systems, and the applications allowed for review of the design in full scale mode.

Multiple interactive features implemented afforded those constructing the bridge opportunities for enhancing exploration in VR, leading to many subsequent changes and initiated cost-saving methods.

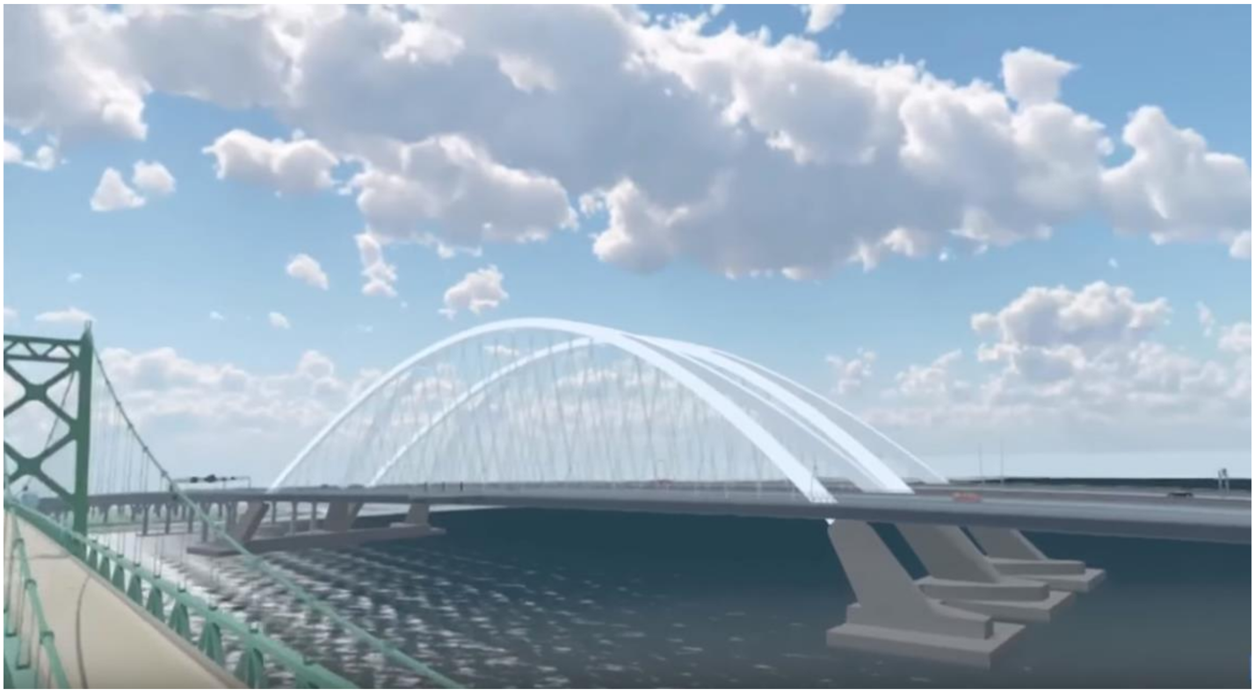

Figure 6. Review of bridge design in VR.

VR systems can be used for simple learning and training needs, and with proper development of a VR application can be harnessed for introducing users/trainees to more complex systems. Figure 7a shows a user with an HMD-based VR platform observing a full-scale internal combustion engine. Figure 7b demonstrates the user separating and interacting with the engine parts. The nefits of this application is that it helps the user create a proper mental model of the system. Furthermore, engine parts can be accompanied by audio files and animation to further enhance the introduction of the content.

Figure 7a. User observes full-scale virtual internal combustion engine.

Figure 7b. User interacts with parts of virtual internal combustion engine.

One further remarkable aspects of simulated virtual reality environments is that participants tend to respond realistically to virtual situations even when the visual fidelity is low, and the representation of the physical reality is significantly reduced. . Three concepts have been reported as strong generators of immersive simulations:

- **Place illusion**: the strong sensation of being present in the space generated by the virtual reality environment, even though participants know they are not there (Held & Durlach, 1992; Sheridan, 1992; Barfield & Weghorst, 1993; Slater & Wilbur, 1997)
- **Plausibility**: the component of presence that is the illusion that the perceived events in the virtual environment are really happening (Bergstorm e al, 2017). In comparison to Place Illusion, which is a static characteristic, Plausibility is more concerned with the dynamics of events and the situation portrayed. de la Pena and colleagues (2010) provided an animated example to convey the sensation of Plausibility:

  > *"...suppose that you are (in physical reality) parking your car illegally. Just as you pull up to the curb, you notice a police officer standing by the street corner. Your heart misses a beat and you are just about to pull away rapidly when you notice that there is no police officer at all but a dummy stationed there. The police dummy is a failure in plausibility—for a moment the dummy was for you what it appeared to be, a real police officer. Then the plausibility, the sensation that something is real, that it is actually what it is represented to be...*" (p. 294)

- **Virtual body ownership**: utilization of multisensory correlations to provide people the illusion that alien objects are part of their body (Botvinick & Cohen, 1998).

The features above are effective in any of the applications described earlier. However, these features become an extreme asset when training users to respond to emergency situations. For example, the authors are using full scale VR system to research firefighters' situational awareness and decision making (Bayouth & Keren, 2019; Keren, Franke, Bayouth, 2013; Keren, Bayouth, Franke et. al, 2013; Bayouth, Keren, Franke, 2013), and for inoculating space workforce to stress associated with emergencies in space (Finseth, Keren, et al, 2016; Finseth, Keren, et al, 2018).

Summary

While enhanced visualization is yet in development stages, manufacturing and process industries can utilize AR/MR/VR application for enhancing operations and workforce development in a multitude of facets. Current challenges are as follows:

(1) developing models and applications for AR/MR/VR (the VR arena) require extensive efforts and expertise. As the virtual reality arena evolves, applications with user-friendly authoring systems will attract common users to develop and work with VR systems.

(2) VR systems demand strong computational resources. As the VR arena evolves and computation power continues to grow, mobile AR and MR systems must be capable to support operators in real-time.
(3) Systems designed with the VR arena in mind will allow operators to further delve into the manufacturing and industrial running processes. Implementation of visualization sensors (not pursued yet) will further enhance operators' mental models of the state of systems and support of mental models in emergencies.

The VR arena is in its infant stages but show great potential in supporting various aspects of process industry operation in the various life cycle stages.

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