Augmented reality for improved communication of construction and maintenance plans in nuclear power plants

SORENSEN Soren S.[1]

1. The Oslo School of Architecture and Design, Institute of Architecture, Oslo, Norway. (E-mail: sss@aho.no)

Abstract: The purpose of implementing Augmented Reality, AR, in the planning, construction and maintenance of Nuclear Power Plants is to secure strict control, precise and correct constructions, exact execution of assignments and heightened safety at all levels. Communication of construction plans to ensure precise and correct assembly of structural elements is essential in all building projects. This is especially crucial in the construction of nuclear plants and installation of new components. The current ways in which construction plans are communicated, blueprints, 3D digital models and written descriptions all embody the need for significant levels of abstraction and interpretation, and are thus both difficult to understand and can lead to misinterpretations. A simulation system with full scale three dimensional models experienced in the physical setting where operations are to take place would bring operators closer to the real life assignments. Augmented Reality is a visualization technology that provides this motivation.

Keyword: augmented reality; simulation; visualization; training of operators; maintenance

1 Introduction

Construction and maintenance of nuclear facilities require strict control and exact implementation. Guidelines are made, based on approved technical standards, [1] to ensure this and to specify how tasks are to be executed down to the smallest detail. Communication of construction plans to ensure precise and correct assembly of structural elements is essential in all building projects and especially crucial in the construction of nuclear plants, installation of new components and for other procedures. As described by IAEA "The policy at the plant for the use of operating procedures by the operators should be clearly established and communicated. Operating procedures should be categorized according to the manner in which they are applied. Operating procedures that are applied continuously in a step by step manner, procedures that are used as references to confirm the correctness of actions and procedures for informational use should be clearly indicated through the method of categorization of procedures." [2]

The current ways in which construction plans and guidelines for maintenance are communicated are blueprint drawings, two-dimensional representations as plans and sections, 3D digital models and written descriptions. All embody both the need for significant levels of abstraction and interpretation, and are thus both difficult to understand and can lead to misinterpretations. Construction workers and operators are usually not trained in reading two-dimensional representations and mistakes done due to this can lead to fatal results.

Simulations in three dimensions that are closer to the physical real are easier to understand, can prevent misinterpretations and possible safety hazards and can result in more efficient procedures. Virtual Reality, VR, has proven to enhance the understanding of complex structures and has been implemented for planning, simulation of procedures and training of operators. [3] VR systems have distinct advantages, [4] but the users are removed from the actual site of study and, in desktop solutions, one still relates to computer screens with the limitations these pose.

A simulation system with full scale models placed in the physical setting where operations takes place would bring operators and construction crews closer to the tasks at hand. Augmented Reality [5], AR, is a visualization technology that provides this.

2 Augmented reality

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Augmented Reality is a further development of VR, where the system combines digital information and the real world. In theory this encompass all information that can be converted to a state which can be sensed or perceived, like touch, smell, sound and visual. In this paper, as well as in my research [6], I will limit the field to visual perception of 3D graphics, but in part also include aural simulation.

An AR system generates a composite view with a real time combination of digital models and the physical real life setting in which the user is located. Intrinsic in the term Augmented Reality lies that it is an enhancement of a specific environment. This requires the simulation to be experienced not as a scale model or in a remote location, but in full scale directly related to the actual site. Applying the technology removed from the intended site implies a different definition according to Milgram [7]. Nevertheless I choose to use the term AR in a broader sense in order to include variations for practical reasons.

There are several principles for AR systems, with the main difference in the system for positioning of user and models and for the registering of orientation and field of view. Examples are systems based on camera recognition of graphical markers [8], ultrasound, WiFi or GPS in combination with inertial sensors like gyroscopes. [9] Common for all is a dedicated computer with the application and database, a progressive camera for video feed and a viewing device, often a head mounted display.

The functional principle of AR is that the exact position and orientation of the user is registered. Three dimensional digital models with geometry and rendering are retrieved from the database and positioned according to their geo-location. Models can be static, animated or dynamic. Live images of the site and the digital model are processed in real time by the software. The system composite these and present the combined view on the viewing device. Users experience the view as a blend of digital and real images with correctly scaled models directly related to the environment in real time.

In the section on the use of AR I will base my elaboration on a technical solution with basic level of mobility described under section 2.1.

2.1 AR Binoculars

A major issue in implementing a working AR system is the level of accuracy of the position and orientation trackers used to register the user's location and direction of view, to correctly composite digital models and the view of the real world surroundings. Inaccuracies lead to unstable results and incorrect locations and discrepancies are amplified the greater the distance between user and digital model, making outdoor systems especially vulnerable.

Institute for Energy Technology, IFE, in Norway in collaboration with Graduate School of Energy Science, Kyoto University, Japan, and the Oslo School of Architecture and Design, Norway, have managed to develop an AR system with sufficiently accurate geo-tracking that is easily deployable for both indoor and outdoor use; the AR binoculars; as seen in Fig. 1.

Fig.1 HRH King Harald testing AR Binoculars

Contrary to what the name could imply, this is not a telescopic device, but a complete AR system with integrated position- and orientation-registration, a camera for live video feed and a display for experiencing the augmented reality. The binoculars are connected to a laptop running the dedicated software and mounted on a tripod stand. By restricting movement to orientation, and incorporating a robust precision tracker, the problem of viewing distant objects accurately is resolved. The device is mobile, but not intended for completely free movement. It requires no additional rigging of positioning systems and can easily incorporate control devices for interactivity. The user's experience can be recorded for later viewing or shared by transferring the composite view to external screens. The high fidelity of the system is due to the fact that both the position and orientation is tracked with high accuracy. The position is tracked using a differential GPS, which has an accuracy of better than 10 cm both horizontally and vertically, and in addition is the orientation (yaw and pitch angle) measured with 16 bits optical absolute rotary encoders. The camera can be a standard COTS camera (for instance a Sony HDR-HC7 with DV output) or a progressive camera (for instance a Flea from Point Grey). The display is a customized HMD or a standard sunlight readable COTS monitor. Information on exact geo-location of viewer, digital models and orientation is recorded to secure the end result and make simulations verifiable.

The development of the AR binoculars has been supported by the Norwegian Research Council in a verification project and is currently commercialized by the Norwegian company AR-Lab Norway AS. [10]

3 Real world applications

Virtual Reality simulations has for several years been acknowledged as valuable tools during the design process. An advantage of VR is that it can be set up independent of an unprepared construction site or removed from hazardous environments and that models are easily exchangeable. Except for immersive systems, it has the disadvantage of being screen based and therefore object to interpretation. Neither does it relate to the surroundings other than those included as part of the digital model. Since desktop systems are two dimensional representations users also lack depth cues one experience in reality. Navigation is done by means of control devices and travel through virtual environments as walk-like movement or as transitions between defined points in a discrete, instantaneous manner or continuous with visual momentum. A problem here is the lack of bodily cues for motion, which can lead to incorrect understanding of movement and orientation as well as contribute to simulator sickness [11].

Augmented Reality, when presented, is immediately recognized as a tool for studying concept models, design alternatives and for confirmation of design. In this context the system can be used to visualize alternative solutions for entire plants or cooling towers to decision makers and authorities in their real environment. Parts of structures or assemblage of components can be digitally modeled and studied as built from all sides to perform validation of the design. The digital models used are the same as in VR; a combination of the two systems through the process is thereby viable. AR simulations are related directly to the real world and in principle only the objects needed to be studied are modeled. Contrary to VR, AR simulations are experienced with the user's bodily presence both in the environment and in movement.

Immediate limitations to AR are the same as the strength of the system, it has to be experienced at the intended site. A looser definition of AR still opens to set up an AR system at a remote or more convenient place.

An extended value of the AR system is achieved by implementing it in the actual phase of construction and furthermore for training and maintenance of structures and installations.

3.1 Augmented reality and construction

An early stage where one can benefit from AR is during the political discussions on the expansion of an existing plant, construction of new cooling towers or the establishing of new facilities. These are all large structures often dominating the landscape, resulting in comprehensive discussions when presented to the public. Proposed building structures are often presented as illustrations or photomontage; techniques opening for subjective presentation, manipulation and interpretation. Experience from large scale architectural projects show that AR visualizations of planned structures in their intended environment to politicians can ensure informed decisions. An example is the use of AR by building authorities and the responsible politician for the validation of large architectural proposals part of the urban transformation of Bjorvika in Oslo, Norway, as seen in Figs. 2-4.

Fig.2 AR Binoculars on-site in Bjorvika

Four solutions were presented as a final part of approving concept, architect and contractor. The simulation showed that all proposals were in breach with the guidelines, resulting in refusal and opening for an architectural competition. By implementing AR at this stage one could avoid a prolonged process of approval, exceeding budgets and undesired results.

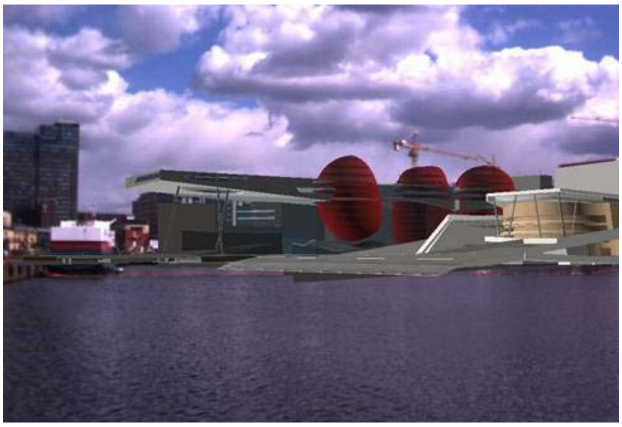

Fig.3 Example of AR visualization, Bjorvika.

Fig.4 Example of AR visualization, Bjorvika.

Prior to the actual construction phase, AR can be used to enhance the understanding of construction workers of the tasks ahead. By visualizing stages of the construction progress, either as milestones or animated, an overview is established, opening for more efficient handling of assignments.

As well as most people, even trained construction workers can have problems reading drawings and the translation of information from paper to the three dimensional reality opens to mistakes. AR used to visualize correct placement and mounting of structural parts during construction will prevent misinterpretations from reading blueprints alone. Simultaneous use of the system and the actual maneuvering of parts like columns, trusses or large components, viewed like an overlay in three dimensions, add additional security for correct execution. An implementation of GPS-controlled positioning of building components during the actual mounting in combination with AR will further diminish the possibilities for mistakes.
AR- simulations can be dynamic and animating the assembly in AR on site secures proper sequence and order of the assemblage. This utilization and the use of AR to verify correct construction after each stage will add significant levels to the quality control.

3.2 Augmented reality and training of operators

Training of operators to achieve awareness of radiation [12] through the use of VR-simulations has proven efficient. Research indicates VR-based training to be superior to training using map-based radiation overviews and effectively teaches procedural steps [13].

Static or animated visualization of three dimensional representations of radiation distribution can be run in AR based on the same principles as in VR simulators. AR simulation of radiation in a controlled setting, during downtime or even in a digital mock-up presents participants to a closer to real life training than in a VR system. Participants move physically in the actual work environment, thus achieving experience of distance and orientation directly related to the site. Scenarios can be generic or normal radiation levels for training everyday situations and simulated leakage situations for training in crisis handling.

Real time visualization of radiation distribution during walkdowns can expose the workers to radiation, but enhance the awareness and serve as a tool to minimize exposure. To keep the radiation exposure as low as reasonably achievable, ALARA, measuring points mapping the radiation level with real time feed to an AR visualization will give a direct view of the area in question. Operators can plan their route "just in time" before assignments and be given guidance during their work to avoid unnecessary exposure.

3.3 Augmented reality and maintenance

A great potential for heightened safety, reduced downtime and overall savings lie in the use of AR prior to maintenance assignments. Used by service and maintenance crew to visualize alternatives of transportation, through simulations with animated models, will help securing the proper order of transporting high risk components. Besides aiding in "finding the right path" it will enhance the control of size and maneuverability when executing in real life. By adding geo-located virtual sound of engines or objects moving positioned related to these, so called spatial sound, one add a new element to support orientation in the simulation. Implementation of controls for interaction with the model during simulations, as in VR training facilities, one opens to full scale training in complex procedures at the actual site where the work is to be executed. Simulations like these demand a complete and exact model of existing structures, installations and parts for occlusion or collision avoidance.

An example of simulator systems that can be translated to AR is the Refueling Machine Simulator based on Virtual Reality, RMS-VR, at the Leningrad Nuclear Power Plant. [14] It has been developed in order to improve safety by providing complete training for operators of the refueling process. Through simulations operators perform a full range of physical interactions between the refueling machine, the fuel module, the core and the coolant in order to train the complex co-ordination of the work and the understanding of the consequences of mal-operations.

AR has been tested during maintenance and found to add levels of information and heightened control of operations. This is done by adding virtual tags to components giving additional information on functions and use and by direct link to the control room for updates. By combinations of VR and AR simulations, supervisors can guide operators through assignments. This is done by operators experiencing an AR simulation at the site of work, while the supervisor follows the progress with the operator represented by an avatar in a VR setup.

Finally the previous described applications of Augmented Reality can ultimately be applied for Outage planning and Decommissioning. [15] Especially real time measuring and visualization in AR of radiation distribution and changes directly related to the structures in question can prove invaluable.

4 Conclusion

Communicating proposed building structures of large scale like nuclear power plants or cooling towers to politicians, authorities and the public often lead to extensive debate. Traditional representations of planned structures are open to interpretations, easily manipulated, hard to verify and therefore readily countered, leading to prolonged debates and possible delays. Augmented Reality used to visualize proposed buildings and urban changes to authorities and politicians has proven valuable for validation of such proposals, giving a basis for informed decisions.

Precise and correct construction of nuclear power plants is essential. Blueprints and traditional means of communicating construction plans embody levels of abstraction that can lead to misunderstandings and consequently incorrect execution and construction.
Augmented Reality is recognized as a tool for studying concept models, design alternatives and for confirmation of design. AR is furthermore a valuable tool during the construction process visualizing correct positioning of building components in three dimensions at their exact physical position.
AR can be used throughout the process of construction, from initial stages of design to the verification of built structures.

Training operators by the means of AR is a consequent continuation of simulations done in VR. Advantages are that operators are training in the physical setting of their future undertaking of assignments, relating directly to the constraints of the site. Simulation of radiation distribution in three dimensions experienced in a real life setting by moving physically will heighten the awareness of the operators. Real time measuring and visualization will enhance safety and keep the radiation exposure as low as reasonably achievable.

AR used during maintenance has been tested and found viable. A great potential for heightened safety, reduced downtime and overall savings lie in the use of simulations prior to maintenance assignments. The principles and solutions implemented in existing VR simulators can be adopted and developed into on-site simulators where operators relate to the physical constraints of the actual workplace.

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