Augmented Reality Applications Assisting Maintenance Activities in Extreme Environments: HCI Issues

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Abstract. Maintenance of complex technology artifacts in hazardous environments can be a risky and demanding procedure. Operators need to be both efficient and meticulous in their activities in order to ensure the quality of their maintenance activities and the effectiveness of the limited time spent in the hazardous environment. Thus, an intuitive AR informative system could improve the operators' efficiency during their presence in the hazardous environment. What are the Human-Computer Interaction implications that arise in such applications?

Keywords: augmented reality, extreme environments, personal safety system, human-computer interaction, assistive information systems, exploitation.

1 Motivation

The European Organization for Nuclear Research (CERN) is broadly known across the Globe for its unique physics projects probing the fundamental structure of the universe. In order to deal with such unique objectives and nuclear physics matters, the world largest and most complex scientific instruments are being utilized in day-to-day demanding assignments. These instruments include the Large Hadron Collider (LHC) and the four discrete detector that are lying in the trajectory of LHC. In a typical experiment, the LHC accelerates two beams of protons or heavy ions traveling in opposite directions in extremely high speed. These opposite travelling beams collide at the four detector locations, including the ATLAS[1] detector. This detector is a complex construction which is about 45 meters long, more than 25 meters high, and about 7,000 tons heavy. The operational efficiency of ATLAS and the rest physics detectors is degraded due to the aforementioned collisions of protons, thus maintenance and upgrade activities have to take place periodically at all sites in order to restore and evolve the operational ability of the complex electronics and information systems that are exposed in the beam. These maintenance activities are

[1] The ATLAS experiment, http://atlas.ch/

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very complicated operations executed by highly trained and experienced technicians, and can last from one month, to that long as two years. During the maintenance or upgrade operations, the operators are exposed to radiations that has been developed while the accelerator was operating and experiments were executed in the detectors caverns.

The radiations of a radioactive environment are the followings: α (alpha), β (beta) and γ (gamma). This radiation can be very harmful for the operators' health, but unfortunately, it has not yet been discovered a wearable layer that can protect human being (and consequently operators) from gamma radiation. Thus, from a practitioner point of view, the only feasible way for operators to ensure their protection is to monitor the cumulative radiation that each operator absorbs, so that he will stop exposing his self in the hazardous environment once a safety limit has been reached. However, this approach limits the operational timeframe of each user while in the detectors caverns. The aforementioned limitation in conjunction with the enormous number of complex steps that a maintenance routine consist of, emerges the increasing need for a Safety System that will be able to assist operators during their maintenance activities or (possibly) emergent evacuation incidences.

Which would be the operators' requirements for such a system and which are the human-computer interaction implications? A functional characteristic of such a system is that the final artifact should be a lightweight, wearable device that will be easy to start or stop intervening in the maintenance activities. Furthermore, the appropriate information should be displayed in a way so that it does not distract the users from their challenging workload and does not involve the use of their hands, as they need them for the difficult maneuvers in the scaffoldings and the actual activities.

Augmented Reality (AR) applications with Head Mounted Displays (HMDs) could provide operators with the sufficient informative content in order to aid them in their step-by-step maintenance process and assist them in an emergency evacuation plan.

The EDUSAFE[2] project in which the author is involved, has an objective to develop an AR assistive system for maintenance operators in extreme environments. This system aims to improve the operator's performance, by providing maintenance and radiation information and (if feasible) to function as an assisting tool for navigation during an emergent cavern evacuation. While we are at the face of designing the platform, questions arise regarding human-computer interaction in extreme environments.

2 Human-Computer Interaction Issues

The system under development in the project could be classified in the family of mobile and collaborative augmented reality applications, since it will be a wearable device used in known but hazardous environment and will also help in the visual communication of the operator with his supervisor at the safe control room. Because

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[2] Education in Advanced VR/AR Safety Systems for Maintenance in Extreme Environment, `http://edusafe.web.cern.ch/edusafe/site.php`

of the environment problematic and the current technology limitations, there are numerous HCI issues to be studied in the view of this project.

2.1 Visual Display Technique

Since the specific application is targeting difficult operations in extreme environments, the operators should be able to work and interact with the system with free hands. Therefore, the proposed display device is on the category of Head Mounted Displays (HMDs). Furthermore, the utilized technique could not be a video see-through device, as functionally wise it is not easy to force the operators to rely their lives on a screen without having direct visual contact with the environment. Thus, the most suitable AR technique for demanding operations in extreme or hazardous environments would be the Optical See-through which utilize a pair of AR glasses with advanced optics so that graphics content can be projected on them and thus, the surrounding reality will be augmented. Currently, for this technique there is a technical limitation that could mitigate the user acceptance of such application; the displaying area is significantly smaller than the human viewing area. For instance, there could be a radioactive hotspot that is in the viewing area of the operator, but the radiation information cannot get augmented on it because it is out of the HMD displaying range.

Another HCI issue regarding the use of AR HMDs is the user fatigue and eye strain that narrows the effective operating timeframe of the user. There is a study claiming that monocular or stereo binocular displays (each eye sees its own image) can cause significantly less discomfort, both in eyestrain and fatigue, than non-stereo binocular displays [15].

2.2 Tracking and (Auto)Calibration

Computer vision algorithms efficiency in such industrial environments that are full of shiny objects and have similar patterns and layouts can be extremely challenging without preparing first the environment with any kind of markers or sensors. On the other hand, this kind of functionality in a safety system could bother users with additional and in some times annoying extra actions. Thus in the view of the project that the author participates, the HCI impact of different computer vision techniques will be measured and will be develop the most suitable one for industrial and extreme environments.

2.3 Depth Perception

One difficult registration problem is the accurate depth perception. Stereoscopic displays could help, but additional problems including accommodation-vengeance conflicts or low resolution and dim displays cause objects to appear further away than their real position [16]. Some depth perception problems can be reduced by rendering objects with correct occlusion. [17] Furthermore, it has been stated that consistent registration plays a vital role in users' depth perception, and this could be achieved by accurately determining the eyepoint location as the eye rotates. An analysis of various eyepoint locations to use while rendering an image concluded that the eye's center of rotation yields the best position accuracy. However, the center of the pupil entrance yields higher angular accuracy [18].

2.4 Augmented Object and User Eyes Position

Since it is difficult to ensure a firm installation and a continuous correct position of the HMD towards the user's eyes, it is difficult to ensure the constant accurate pose of the augmented information with regards to the target objects and the current vision range of the user. Thus, specific eye tracking algorithms and devices will be implemented during the project so that the position of the augmented content is always recalibrated in the vision range of the user based on the current position of his eyes. Furthermore, the augmented content may not fit in the real environment because of difference in the actual distance of operator and augmented point. This issue could also get handled with specific eye tracking techniques in order to understand the user's current focus based on the eyes convergence.

2.5 Overload and Over-Reliance from Content and UI

Since the system is positioned as an assistive system for use in extreme environments, the augmented content as well as the user interface should compose a user experience that will be intuitive and helpful for the users. Thus, decisions regarding the kind and the amount of the provided information and the suitable representation of it have to be taken so that the user interface of the system in extreme environments will be smooth. Furthermore, there are important issues regarding the user interaction with the system that have to be handled as in an extreme environment the alternatives are fairly narrow. For instance, no touch interaction can occur as operators need to utilize specific gloves that are not touch equipment friendly. Tangible interfaces, speech recognition or even physical button utilization could be the optimal for such applications in extreme environments.

2.6 Connections and Communication

In our project, the system technical architecture involves a number of connections and interfaces between the modules (wired and wireless). From HCI point of view, there are numerous concerns about the usability and efficiency of such a system. We need to build an assistive system that will be compact and lightweight without complex wires and heavy units and at the same time it will not compromise in the system efficiency due to unwanted wireless transmission delays. Delay causes more registration errors than all other issues combined. For close range tasks (as the maintenance procedures), a rule of thumb is that one millisecond of delay causes one millimeter of error [19]. More importantly, delay can reduce task performance significantly [15].

3 Other Applications

In order to identify similar applications and exploitation potential of such a system in other industries, we need first to define the term “extreme environment” which is difficult. For the purpose of this paper, we will consider an environment as extreme when the operations in that field might induce mental or physical load or if the environment encapsulates hazards. Hazardous could be considered an environment that potentially can threat the surrounding biota and consequently could harm the human being if it is exposed in this environment beyond a specific amount of time without any protection layers. Given the presence of radiation at CERN detectors caverns, this working environment could be considered as hazardous. Other extreme environments include space, nuclear power plants, disaster scene, underwater, mining and so on.

Applications for such environments have already been developed or explored in the past trying to provide added value in the corresponding operations. The use of AR systems for nuclear power plant maintenance has been investigated in terms of navigation and environmental dose rates visualization [8]. The impact of gravity environments while using a head-mounted AR system has also been investigated [7]. An AR navigation system to aid fire brigade officers during a fire incident has been developed and tested in terms of usability [5]. Another work can be found in marine applications where an AR system for professional divers was developed in order to increase their capability to detect, perceive, and understand elements in underwater environments [6]. Although aircraft and train maintenance are not considered as operations in typical extreme environments, the fact that very complex work has to be performed in very short timeframes with high impact on potential failure, could let us treat them as extreme conditions due to mental overload. In this view, a framework applicable for the industrial maintenance and repair tasks was presented. The system was tested with various controlled settings [10]. Similarly, an AR system prototype for aircraft maintenance was developed to train and support maintenance operators [11]. Such AR systems have been proven to be useful through evaluations in the in-vitro condition. On the other hand, there are also systems designed and tested for real use-case scenarios. For instance, an AR system for military mechanics working in an armored personnel carrier has been developed. In this application, the space for tracking equipment was significantly limited [12, 13]. EDUSAFE application will be more in this category.

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