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Design Recommendations for Integrating AR in VR Environments Within Defence Research

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ABSTRACT

This paper utilises the methodology and discoveries of a recent Defence project as a pilot study to contemplate the potential implementation of augmented reality (AR) within a virtual reality (VR) environment in a Defence context. By doing so, it sheds light on the possible applications, advantages, obstacles, and prospects of such an integrated system. Additionally, it evaluates specific methodological and design recommendations to extend the effectiveness and inclusivity of the military training experience. These recommendations consider various factors, including interoperability, authenticity, environment fidelity, human-centred interface design, and the user experience. This contribution is significant in the broader discourse surrounding utilising immersive technologies in the Defence industry, as it provides valuable guidance for researchers, developers, and military professionals.

Keywords: Virtual reality, Augmented reality, Defence, Immersive technology

INTRODUCTION

Technological advancements have led to the continued development of immersive technologies such as VR, AR, Extended Reality (XR), and Mixed Reality (MR). The Defence sector explore the use VR and AR technologies for training, simulation, maintenance, and mission strategising (e.g., Harris et al., 2023; Henderson & Feiner, 2010). There is growing interest in understanding the potential for using these immersive technologies in operational domains. Each technology has advantages and limitations that require careful consideration. VR offers immersive virtual environments, while AR overlays situational information in real-world environments. XR includes all combined real and virtual environments, while MR combines real and virtual worlds to create hybrid environments. Advancements aim to combine VR's situational immersion with AR's real-time, contextual advantages, but may only partially replicate VR's immersive experience (Carmigniani et al., 2011). By combining these technologies, Defence applications could be enhanced, including comprehensive training scenarios, improved mission strategising and situational awareness (Xiong et al., 2021; Munzer et al., 2019; Livingston et al., 2011). Using multiple immersive technologies while mitigating limitations opens new opportunities for innovation.

As technology advances, examining how AR and VR can be optimally utilised is essential. Research needs to continue to understand their impacts and provide evidence-based recommendations. The fusion of AR and VR enables innovative applications to enhance operational efficiency and training outcomes in a Defence context. However, whilst incorporating AR into a VR environment for Defence operations and training shows promise it requires careful consideration of methodological and design aspects. Successful implementation requires analysing challenges and opportunities and understanding fundamental design factors for an efficient, user-friendly, and secure system (Quarles et al., 2009). Realising the benefits of AR-VR fusion requires balancing research optimism and pragmatic considerations on integration and application.

Overview of VR

VR in Defence contexts aims to create an immersive simulated battlefield where soldiers feel fully present and can interact realistically (Sherman & Craig, 2018). Key aspects are all-encompassing visuals resembling the combat environment, a sense of physical situation, unrestricted navigation, and weapon control. This enables soldiers to rehearse drills and gain tactical experience by actively engaging with responsive virtual zones. Rather than fully replicating real-world senses, the goal is to establish sufficient presence and interactivity for meaningful training. Enclosed head-mounted displays, tracking systems, interfaces, and tailored audio and visual feedback help create the VR battlefield. The opportunity to rehearse simulated missions in VR can provide valuable tactical experience, improving Defence readiness. Essentially, VR in military settings involves interactive computer-generated combat simulations that submerge soldiers in artificial three-dimensional battlegrounds with multisensory feedback tailored to their tactical viewpoint (Berkowitz, 1995; Cruz-Neira et al., 1992). It generates a sense of presence and "being on the battlefield" (Cipresso et al., 2018; Sherman & Craig, 2018; Witmer & Singer, 1998) and enables interactive tactics through bodily movements and weapon interfaces (Sherman & Craig, 2018; Steuer, 1992), replacing real-world combat stimuli with their virtual counterparts (Slater & Wilbur, 1997).

The distinguishing characteristics of military VR compared to other research platforms include the combination of immersive multimodal feedback, the perception of being present in combat, and the ability to interact. These unique features allow VR to surpass visual representations and elicit responses similar to real combat situations, even when soldiers know it is a simulation (Cummings & Bailenson, 2015). This suspension of disbelief plays a crucial role in various applications, such as tactical training, psychological resilience building, and strategy formulation. Contemporary military VR systems strive to completely immerse soldiers in synthetic battlefields by replacing natural sensory inputs with tailored multimodal digital illusions that cater to tactical requirements (Abrash, 2014; Sherman & Craig, 2018). This sensory isolation distinguishes military VR from augmented realities, integrating virtual battle overlays with unmediated views of actual terrains (Milgram & Kishino, 1994).

Overview of AR

AR overlays digital information and interactions into the real world to enhance users' perceptions and experiences. AR supplements reality by integrating abstract data into real-world contexts in real time (Azuma, 1997). AR systems combine real and virtual elements, operate interactively in real time, and align the virtual with the real (Carmigniani et al., 2011). While virtual reality replaces reality with a simulated environment, AR selectively augments real-world aspects with contextual overlays. This makes AR helpful in improving situational awareness and informing decisions during real-world tasks (Van Krevelen & Poelman, 2010). AR virtual overlays are positioned within a three-dimensional coordinate system mapped to the physical environment and user viewpoint, anchoring the overlays to real spaces. Relevant information and interactions supplement the user's natural environment and activities, preserving situational awareness (Bimber & Raskar, 2005). AR systems track the precise viewpoint and positions of real objects and surfaces, allowing for accurate, location-aware rendering of overlays from the user's perspective as they move and interact. Additionally, modern AR leverages technologies like optical head-mounted displays, outward-facing cameras, inertial sensors, depth sensors, image tracking, GPS, wireless networking, and mobile platforms, enabling lightweight and portable AR systems that map and supplement real-world environments and activities (Carmigniani et al., 2011).

AR-VR: Simulating AR Capabilities into VR Environments

Integrated AR-VR platforms offer a significant advantage in facilitating seamless interaction between real and virtual assets for Defence training. By capitalising on their innate sensorimotor skills and instincts, trainees can actively participate in the environment by interacting with tangible and digital components (Slater & Sanchez-Vives, 2016). Such a high level of embodied interactivity brings enhanced flexibility and realism in AR-VR training, surpassing the limitations of purely virtual or augmented simulations (Hill et al., 2003). To achieve this, AR-VR systems should ensure precise alignment of virtual augmentations with the physical environment and the user's perspective, accomplished through robust registration and tracking methods. Even minor discrepancies in alignment can disrupt the immersive experience (Rokhsaritalemi et al., 2020). Additionally, the system must effectively manage occlusion and seamlessly respond to user actions and real-world elements in real time to maintain a sense of plausibility (Grubert et al., 2017). Advancements in inside-out tracking, sensor fusion, edge computing, and display technologies are instrumental in addressing these challenges (Huang et al., 2017). Through progressing these areas, Defence trainees can freely navigate hybrid environments such as AR-VR, using instinctual interactions between virtual and physical elements to achieve a realistic training experience.

However, effective design and integration are critical for AR-VR training. AR-VR integration balances both technologies' strengths for more authentic and responsive simulated environments. The promise is developing more transferable military skills than VR simulation alone (Darken & Peterson, 2002). AR overlays provide missing contextual cues in VR, enhancing information and presence (Dey et al., 2018). AR also enables seamless switching between VR simulation and live surroundings to improve awareness (Davis et al., 2015). VR provides simulated military training environments but lacks physical fidelity compared to real-world practice (Darken & Peterson, 2002). AR overlays digital information onto real environments to maintain physical awareness Integrating AR into VR headsets blends simulated elements with real physical props and environments. This hybrid AR-VR approach aims to mimic real-world conditions more accurately than VR alone (Zhu et al., 2017). In essence, AR-VR headsets overlay digital AR information onto a VR environment. This fusion offers benefits over VR isolation while retaining VR's control and safety. The potential is developing more transferable military skills than VR simulation alone (Georgiou & Kyza, 2018). However, effective design and integration are critical for hybrid AR-VR training. AR-VR integration balances both technologies' strengths for more authentic and aware simulated environments. However, realisation depends on overcoming key technical challenges. Further research should clarify the optimal fusion and applications of hybrid AR-VR for Defence training.

To achieve effective training in AR-VR, it is essential to prioritise user experience and interface design beyond technical considerations. This involves giving primary importance to human needs to prevent overwhelming users and ensure skill transfer. For optimising AR-VR training, information visualisation, attention guidance, and collaborative interfaces require further exploration. For instance, using multimodal cues in AR could improve information acquisition, compared to relying solely on a single modality (Rebetez et al., 2016). The variation in visual-spatial abilities among individuals can affect the performance of AR. By providing options such as switchable viewpoints, the diverse needs of users can be accommodated (Chen & Tsai, 2012). AR-VR training can be improved by customising interfaces and experiences to meet cognitive and psychomotor demands. Furthermore, integrating physical and virtual elements in personalised blended environments presents opportunities for improvement.

As AR-VR methods continue to advance, it is imperative to prioritise human-centred design to realise the potential of hybrid training fully. This involves combining technical advancements with thoughtful consideration of human perception, cognition, and team dynamics. Adopting this approach has the potential to transform military learning and preparedness through the integration of AR-VR platforms. A human-centred design approach is vital to achieving practical AR-VR training, considering human factors and personalising the training experience. Further research on optimising hybrid environments to meet human needs has the potential to revolutionise Defence learning through the implementation of AR-VR. Let me know if you need any more clarity or conciseness.

Integrated AR-VR platforms offer the potential for enhanced and more natural interoperability between humans and technology in the context of Defence training and the operational environment. However, fully realising this potential necessitates optimising crucial factors such as registration accuracy, occlusion handling, and real-time responsiveness. As technology advances, hybrid simulations can transcend the mere display of digital augmentations and usher in shared embodied environments, where the boundaries between the virtual and real worlds fade away from the trainee's perspective. This signifies the next stage of evolution in the capabilities of MR training. In summary, the integration of AR within VR holds the potential for facilitating more authentic experiences, although it encounters obstacles. To achieve more efficient Defence capabilities while upholding safety and respect in training and operations, a well-balanced approach that drives technology forward with a focus on human-centred perspectives is crucial. The exploration and advancement of this trajectory through ongoing research and development can unveil vast opportunities for hybrid reality.

AR-VR Pilot Study

This pilot study presents a summary of research conducted by Trimetis, BMT, and Middlesex University on behalf of the Defence Science and Technology Laboratory (Dstl). The primary objective of this research was to showcase the potential of emerging human-machine interfaces (HMIs) in enhancing cognitive performance for military personnel using prototypes within an AR-VR experimental testbed. The experiments undertaken aimed to address two key research questions:

Research Question 1: What is the impact of an AR HMI (interface augmented in the virtual environment) compared to a non-AR HMI (interface through a virtual handheld device) on the performance of individuals and teams and their cognitive workload during cognitive tasks?

Research Question 2: By developing a measure of cognitive optimisation (CO) based on performance and workload, how does an AR HMI support CO compare to a non-AR interface?

In this study, the term "*cognitive optimisation*" (CO) refers to attaining cognitive performance that is maximised within a given situation's constraints and contextual factors. It emphasises the optimal utilisation of cognitive resources for task performance rather than striving for unattainable perfection based on exhaustive analysis and logical reasoning.

Methodological Approach

The experimental setup consisted of a realistic situation where an Armoured Fighting Vehicle (AFV) patrolled through a town resembling the typical layout encountered in UK operations. The AFV is manned by a driver, gunner, uncrewed aerial vehicle (UAV) operator, signals intelligence operative, and at least two infantry soldiers. In this scenario, the AFV is unexpectedly attacked by hostile targets. The crew and the vehicle retreat to a secure location, retaliate, and subsequently devise a plan for a counterattack. Unfortunately, the gunner sustains injuries, and the other soldiers ensure their safety before initiating a CASEVAC.

All participants are exposed to both experimental conditions, namely the AR HMI and the non-AR HMI conditions, within the synthetic VR environment. Experiment 1 (individual performance) comprised 18 participants, including civilians and military personnel. Experiment 2 (team performance) involved 18 military personnel working collaboratively in teams of 3. In both counter-balanced conditions, participants completed a series of experimental phases where task-specific information was either delivered through an augmented view (AR condition) or on a virtual tablet (non-AR condition). The primary focus of the experiment was on two measures: cognitive workload, which refers to the measurable or perceived mental effort exerted by individuals in response to a cognitive task, and cognitive performance, which relates to the performance on a cognitive task as observed through appropriate indicators. The subjective workload experienced by participants was assessed at critical points within each phase using the Instantaneous Self-Assessment method (ISA; Jordan & Brennen, 1992). Additionally, the NASA TLX (Task Load Index, Hart & Staveland, 1988) was used to measure workload at the end of each condition.

Performance measures showed variability and included binary (yes/no) responses, correct/incorrect responses, reaction times, and a correctness score for the provided response. To establish a consistent performance score during the relevant phases of the experiment, a score that accounted for all essential performance measures was generated. It is recognised that different methodologies can produce a performance score, each of which may yield different results. In this study, the research team adopted an approach to determine a performance score that best represents the research inquiries related to cognitive optimization.

AR-VR Results, Discussion and Recommendations

Results from the pilot study revealed some insight into the intricate relationship between technology and human perceptual capabilities. The pilot study highlighted a decline in performance as visual threats within the AR condition increase, which underscore challenges in interface design rooted in the inherent limitations of visual perception. As suggested by Wickens' (2002), the risk of cognitive overload due to competing information streams in AR necessitates a cautious management of occlusion and visual clutter (Grabowski et al., 2018). This was evident as performance deteriorated with the escalation of visual threats, pointing to the potential risks of overwhelming the human visual processing capabilities (Swan & Gabbard, 2005).

Given AR's potential to augment visual perception, it is critical to consider a multimodal design approach to mitigate the effects of increased cognitive workload. The integration of cross-modal capabilities has been shown to enhance the effectiveness of AR by distributing sensory input loads among various modalities (Piumsomboon et al., 2013; Lee et al., 2012). For instance, the use of haptic pulse guidance and combined spatial audio can direct attention more efficiently and improve task performance, underscoring the benefits of incorporating multiple modalities to alleviate visual overload. Furthermore, the development of infantry-appropriate AR solutions necessitates a rigid alignment between real and virtual environments to avoid disrupting immersion (Harris et al., 2023). Minor misalignments can have adverse effects on user performance, highlighting the importance of advanced technologies like predictive tracking and artificial intelligence in maintaining real-virtual coherence. This alignment is especially crucial in volatile infantry contexts where discrepancies could have dire consequences.

The study also revealed challenges in presenting comprehensive battlefield data without obscuring real-world views with excessive occlusion (Tang et al., 2003). A human-centred design approach, which prioritises understanding and fulfilling infantry needs within their operational context, is paramount for the successful implementation of AR systems (Sanders & Stappers, 2008). Viewing infantry personnel as collaborative partners rather than mere subjects fosters the development of tailored solutions that enhance rather than detract from operational capabilities.

Feedback from study participants revealed preferences for non-AR HMIs during tasks requiring situational monitoring, such as ambush and route change scenarios, due to the easier identification of threats and less cognitive load from not having to shift attention between multiple screens or directions. This suggests that certain screen layouts and presentation methods can aid situational awareness and reduce the cognitive demands associated with monitoring complex environments. The implications of switch costs, or the cognitive and temporal burdens associated with alternating attention between tasks, were also explored in relation to AR and non-AR HMIs. Research indicates that minimising switch costs can improve decision-making speed and accuracy by reducing the cognitive load on the individual (Philipp, Gade & Koch, 2007). In team settings, however, the expected benefits of distributed situational monitoring in AR were not fully realized, potentially due to low levels of information sharing and team cohesion. This highlights the necessity for future AR systems to foster a shared awareness of the team workspace and roles within virtual environments (Gutwin & Greenberg, 2004).

CONCLUSION

The findings from the pilot study highlight the potential use of AR visuals, when anchored to real-world objects and locations, to enhance performance and facilitate the transfer of competencies from VR military simulations. The observed enhancements in tasks such as threat identification underscore the perceptual advantages offered by AR technology. To fully harness AR's capabilities a human-centred approach to interface design is essential. Key challenges include managing visual occlusion, clutter, ensuring precise alignment, and balancing perceptual resources to prevent cognitive overload. It is crucial to engage in participatory design processes to deeply understand the specific needs and operational workflows of infantry personnel, enabling the development of customised and modular AR interfaces that cater to the diverse requirements of Defence users across various roles and operational environments. The commitment to sustained, iterative prototyping and testing with representative users in realistic conditions is vital for identifying usability challenges and refining augmentation strategies. Moreover, ongoing interdisciplinary research spanning technical and cognitive domains will be instrumental in furthering AR's capabilities to revolutionise military training and operational effectiveness. The integration of AR into VR training represents a significant advancement with promising implications, yet its success hinges on a design philosophy that prioritises human factors, ensuring AR's benefits are fully realised while minimising cognitive drawbacks. The journey towards effectively integrating these advanced technologies into Defence forces continues, with each step forward bringing closer the realisation of their transformative potential.

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