Leveraging Virtual Reality For Enhanced Industrial Training In Defence

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Abstract

As we see, the world has wriggled into the new floruit & digitalization is a critical part of it. While talking on the digital world, limelight can be tossed mat the part of Virtual Reality (VR). It can be observed VR usability can be seen in almost every sector of the economy. This research will focus on one of the vital fragments of the economy that is impact on operational training using VR technology in military. High-fidelity simulations are essential for military industrial training to enhance safety, operational efficiency, and skill development. VR has evolved as a vital technology in the domain, contributing experts & learners in various ways like; it's worthwhile and can help in various unhazardous sessions too. This mentioned research explores the implementation of VR-based industrial training in the military fragment, focusing its usage on enhancing technical skills, research, decision-making, and operational issues. The research evaluates VR technology in various areas, including emergency response training, equipment maintenance and battle scenarios. By studying & analyzing various case studies evidence & research, the study highlights the advantages of VR, such as increased engagement & motivation in sessions also improved knowledge retention amongst the users. Additionally, it mentions challenges & their solutions. The findings accentuate the potential of VR to mutate military industrial training, ultimately leading to ameliorate preparedness and coherence in defense operations.

Keywords

Virtual Reality, Industrial Training, Military Training, Digitalization, Training enhancement.

1. Introduction

Virtual reality (VR) has significantly transformed the landscape of military operations, particularly in combat preparedness and strategic planning. Soldiers can practice and train in a safe and realistic way with the help of the immersive and interactive environment. Because today's wars are more complex and unpredictable, it is important for people in the military to be flexible and well prepared. Even though traditional drills and outdoor practice are helpful, they are expensive, can be dangerous, and they involve many challenges in organization. Using VR, soldiers can practice for difficult missions in an environment that is safe and affordable. In these virtual circumstances, soldiers train their abilities such as quick thinking, moving strategically, and cooperating in combat, without facing real harm or paying for big physical structures. Liu et al., (2018)

1.1 Significance of study

This study has significant value because it highlights the impact of Virtual Reality (VR) to modernize military industrial training. As the demand for safer, more economical, and more impactful ways of learning is balanced against the demand for high-quality training, it demonstrates how capability gaps in existing military training can be mitigated as it concerns establishing key military training requirements, specifically in high-risk combat situations and highly technical military operations. It describes how VR can encourage better decision-making and strategic thinking, emissary demonstrate increased skill retention, efficacy training, and a higher level of psychological readiness for military operations without putting personnel at actual risk. VR simulates real-world experiences using adaptive learning capabilities and immersive technology to increase situational awareness. In this way, VR will enhance knowledge retention, skill retention, active engagement, the importance of practicing in the adult learning model, psychological resilience, readiness, and an understanding of the complexity of actual world operations. In addition, the research captures the aspects of scalability and access necessary to provide training using VR technologies to military occupational specializations in different geographic locations. As the defense environment continues to evolve, this research generates valuable findings illustrating the importance of VR and how emerging digital technologies influence operation effectiveness and improve mission readiness and training.

1.2 Objective

• The objectives of conducting this research include:

• To demonstrate the value of VR in military training.

• To assess effectiveness & efficiency of training via VR.

• To demonstrate scalability & access.

• To identify limitations & solutions.

2. Literature Review

1. Liu et al., (2018) reveals intriguing insights into the future of military applications of VR. It highlights the development of holographic virtual command and control systems, projected for use by 2025, which will allow fighters to maximize battlefield information sharing and control ships through visual and tactile sensors. This advancement suggests a significant shift in how military operations may be conducted, potentially reducing physical risk while enhancing strategic capabilities. The emphasis on VR in military command indicates a trend towards more immersive and data-rich decision-making environments in future warfare scenarios.

2. Dhar, A., (2019) presents specific applications of VR across different sectors. In medical training, VR simulators are used for regional anaesthesia, offering a safe and adaptable environment for practice. Industrial

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training, particularly in the mining sector, utilizes VR to provide risk-free drilling scenario training. Other areas covered include Advanced Cardiac Life Support (ACLS) training, disaster response training for firefighters, dance instruction, and military training. Each application demonstrates VR's capacity to offer immersive, interactive, and safe learning environments. One of the most interesting insights from this document is the potential of VR to bridge the gap between theoretical knowledge and practical experience across various fields. The ability to simulate high-stress, high-risk scenarios without real-world consequences opens up new possibilities for training in fields like medicine, disaster response, and military operations. Additionally, the document reveals how VR is not limited to technical skills but can also be leveraged for soft skills development, potentially revolutionizing interpersonal and cultural competency training.

3. **Boyce et al., (2022)** synthesizes prior work comparing terrain visualization modalities—tablet, augmented sand table, and HoloLens—and examines their impact on mission planning performance in military training. It highlights foundational findings by Boyce et al. (2019) that while a topographical sand table reduced cognitive load versus flat displays, it didn't improve accuracy or response times. The current study integrated the Microsoft HoloLens into the Battlefield Visualization and Interaction (BVI) system and observed that, contrary to expectations, the immersive 3D displays worsened performance, usability, accuracy, and increased cognitive load. The authors suggest this may result from headset discomfort and insufficient user familiarity with the device. They stress the importance of accounting for training effects and technology ergonomics when evaluating immersive tools. The review underscores that increased visual fidelity alone does not guarantee improved training outcomes and calls for further research on user proficiency and hardware design.

4. Zahabi & Razak, (2020) synthesizes research on adaptive VR training across diverse domains. It systematically reviews studies that tailor training based on real-time kinematic/physiological input, trainee profiles, and performance metrics. The authors propose an adaptation framework comprising performance measures, adaptive logic, and controllable variables such as difficulty level and feedback timing. The review underscores reinforcement learning and real-time monitoring for dynamic adjustment yet notes the need for longitudinal studies comparing adaptive versus non-adaptive VR. It highlights mixed evidence on whether continuous adaptation yields tangible learning gains. Finally, the framework serves as a foundational model for designing and evaluating future adaptive VR training systems.

5. Harris et al. (2023) applies established fidelity and validity frameworks to compare three simulation modalities—live fire, VR, and 2D video—for military shoot/don't-shoot decision-making. It highlights that 2D video offers minimal cognitive challenge, while VR and live fire deliver comparable performance in accuracy and response time. Utilizing metrics like d-prime and β, the paper shows VR's decision-making outcomes align closely with live-fire conditions. However, presence ratings and subtle performance differences suggest distinct cognitive and psychological demands between modalities. The authors argue that simulation choice must be driven by specific training objectives, as each offers unique strengths. This work sets a precedent for rigorous comparison of simulation technologies in military decision training before wide adoption.

6. B C, (2024) performs profound research on the topic of Virtual Reality (VR) usage in military training. The article begins by an abstract where the promise of VR as a means of offering immersion in learning is mentioned. These environments emulate real world conditions and increase the preparedness and decision-making abilities of the soldiers. Introduction gives importance to the vital role played by VR in military training to offer physical risk-free experiential learning environments. The given study includes the exclusive

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data about the opportunities of VR to revolutionize the military training. It points out how VR can help save the development cycle and money spent on the making of weapons which is extremely high- as the development of Hammer F-22 and JSF fighter has demonstrated. The paper also says how VR may alleviate the inexperienced support personnel since they would be able to train in VR on equipment, e.g., personal boats in the marine corps. These applications demonstrate how VR can revolutionize the way the military trains its troops turning it into a more efficient, less expensive and inability to keep abreast of the dynamics of modern war.

7. Dalal, (2024) emphasizes the foundational development of VR and AR technologies, tracing their evolution from early systems like Sutherland's HMD to current immersive platforms. Key theoretical definitions from Azuma, Burdea, and Gigante help distinguish between VR as a fully virtual environment and AR as a digital overlay on the physical world. The study explores the integration of hardware and software components essential for realistic user experiences. Dalal also highlights major benefits such as enhanced visualization and interaction, while acknowledging limitations like motion sickness and high costs. A user survey reveals a gap between awareness and practical usage of AR/VR in India. The paper concludes that future advancements will be driven by merging VR/AR with AI and IoT.

8. **Fawkes & Burden, (2025)** explores the impact of the Metaverse on military operations, including procurement, maintenance, training, planning, and combat. It traces the history of military use of virtual reality and augmented reality technologies, noting that while the military was an early adopter, it now risks falling behind due to the rapid democratization of these technologies in the consumer market. One of the most intriguing aspects of this document is its exploration of how the Metaverse could fundamentally change military operations and warfare. It suggests that the Metaverse presents both new opportunities and challenges for future conflicts, potentially creating an entirely new domain for warfare alongside traditional physical and cyber domains. It also raises thought-provoking questions about the nature of combat in virtual environments and how this might interact with or influence real-world conflicts. The inclusion of topics like social virtual worlds and their potential use for intelligence and influence operations hints at the complex interplay between virtual and physical realms in modern warfare and geopolitics.

3. Uses of Virtual Reality for Industrial Training in Different Sector

3.1 Exploring the Depths of Virtual Reality (VR)

Virtual Reality (VR) is a complex computer technology that helps users interact with computer spaces as if they were real. Rather than using a screen, VR plunges users into a virtual world that has three dimensions. You can use this virtual environment to make it look exactly like the real world or to invent any environment for purposes like entertainment, schooling, or exploring. The key idea behind virtual reality (VR) is to make a person's brain think that what they experience is actual and realistic. Such devices as HMDs are used to achieve this, showing the user high-resolution pictures all around them, which adapt to their movements instantly and add to the feeling of being in the virtual world. Slater, M., & V., M. (2016)

Fig 1. Head-mounted display

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Source: https://techterms.com/img/xl/hmd_1502.jpg

Virtual reality (VR) is well known for its interactivity. Usually, films are only viewed by the audience, so VR allows users to explore, find things, and operate virtual gadgets. Motion tracking is done by sensors and devices such as hand controllers, haptic gloves, or full-body suits help players control the game. To increase the feeling of being in a VR world, spatial audio is often used, making sounds change depending on the user's direction. Some advanced systems add haptic feedback which uses vibrations or pressure to stimulate the sense of touch. Virtual reality, at its most basic, acts as a strong link between what we do physically and what we do online, providing exciting and transformative experiences that surpass the norm in screen-based media and are used in many fields, including entertainment, healthcare, education and others. Shell et al., (2022)

3.2 Industrial Training via VR in Military Training:

In the constantly evolving realm of military operations the need for proper and effective training methods has become more important. Those serving in the military should be able to work with modern weapons, move according to strategic plans and handle complicated technology. Experts in this field are built through traditional activities like physical workouts, live shooting and field simulations. However, these procedures are affected by the high cost of running them, worries about safety and a shortage of important resources, along with not being able to replicate real battlefield conditions. As virtual reality (VR) technology advances swiftly, armed forces around the globe are adopting VR-driven industrial training as a transformative approach. In VR, personnel can safely experience different situations, increase their skills and plan strategies that are more difficult or unsafe in real-life exercises. With VR training, people can practice and improve their specialized skills, be ready for different situations and make better tactical choices using virtual programs that closely resemble real-life scenarios. Mahmoudi-Dehaki & Nasr-Esfahani, (2024)

Fig 2. Defence training via VR simulation

Source: https://www.wareable.com/wp-content/uploads/sites/6/2024/migration-4/7023-original-820x461.jpg

Virtual reality (VR)-driven military training covers a wide array of areas, including firearms instruction, aircraft piloting, vehicle operation, combat tactics, and technical maintenance. It is necessary to understand technical things and work with them, but this is often prevented by unavailable or difficult-to-access high-priced hardware. It fills these shortcomings by using flexible simulations that can be done again and again to make learning safer and more successful. Trainees use realistic 3D graphics, motion control and haptic sensors to practice and learn by feel. Virtual reality (VR) also supports strategic decision-making under pressure by simulating unpredictable combat scenarios that require rapid judgment and teamwork. Practicing in short steps, getting instant feedback and using customized learning paths helps users become more competent before using their new skills in real life. VR is employed in the military for aviation, naval docking and maintenance work, so soldiers can handle difficult tasks using virtual objects. With fewer resources used, it cuts costs and helps athletes build toughness by dealing with stress. VR is changing military-industrial training by offering safer, smarter and more efficient education for defense teams to handle the range of needs in today's warfare. B C, (2024)

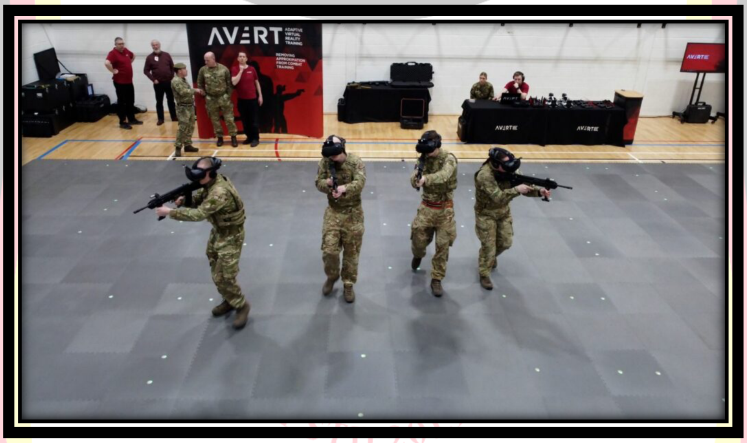
Fig 3. Equipment Training via VR

Source: https://sp-ao.shortpixel.ai/client/to_webp,q_glossy,ret_img,w_1200/https://wear-studio.com/wp-content/uploads/2020/08/equipment-military-training-in-vr.jpeg

3.3 VR usage in Battlefield

Beyond training, virtual reality (VR) plays a crucial role in operational planning and enhancing situational understanding is used to make three-dimensional models of the battlefield, so military experts can study the terrain, predict upcoming risks and plan tactics before taking action. Soldiers become more situational-aware in the field by making use of AR combined with VR in receiving real-time reports of enemy locations, targets, and environmental conditions. It promotes quicker reactions, better coordination and improved skills in dealing with changing fights. VR technology is useful for helping veterans recover and develop strong mental skills. SIT program conducted in virtual reality puts soldiers through tough situations to enhance their mental strength for combat. Those veterans with PTSD can find help in VR therapy that provides them with a safe way to deal with their emotions. Even if new advancements in VR help, such as using AI simulations and better haptic feedback, some issues, such as technical errors, safety, and costs, still remain. With VR, the military is able to train soldiers better, lower their chances of harm and improve their skills in facing today's challenges during war. Steven et al., (2023)

Fig 4. Soldiers engage in a fully immersive free-roam VR combat training session using VR technology.



Source: https://avrt.training/wp-content/uploads/2024/01/IMG-20240124-WA0002-1024x576.jpg

3.4 Research & Development via VR in Military Training:

Using VR, the military can train soldiers in a secure, affordable, and engaging way that helps them become ready for operations. In the last twenty years, the military has stepped up its Research and Development in VR, and academies all over the world have started using sophisticated training simulations to train their staff. Military leaders use virtual reality (VR) for training because it allows them to maximize results and reduce the risks and expenses involved in preparing soldiers for today's challenging battles. Field exercises, working with live devices, and classroom lessons have some negatives like being more dangerous, needing lots of preparation, and not closely resembling real situations. VR training enables personnel to take part in combat simulations, visit virtual areas, collaborate with both friends and enemies, and practice their strategies in a safe way they can repeat as needed. Girardi & De Oliveira, (2021)

The ability to train virtually without any actual risks makes VR useful for the military. Soldiers improve their reflexes, practice dangerous strategies, and become mentally strong by practicing in virtual environments that cause stress without actual danger. Because of this system, people can practice and improve their skills as they go. By setting up VR for different military roles like medics, drone pilots, infantry and special forces, training stays relevant and personalized. Besides simulating wars, VR is also used in the military for planning missions, training in cybersecurity and teaching emergency medicine. The use of technologies like augmented reality, artificial intelligence and haptic feedback is helping to increase what VR-based training can do. New ways of delivering immersive experiences mean that virtual reality will soon transform how the military prepares by supplying safety, efficiency and flexibility in today's defense methods. Qiu et al., (2022)

4. Challenges in Military Training via VR:

Even though VR brings new approaches to the military training, there remain an array of issues regarding implementation to be solved if it's going to achieve its utmost efficacy and effectiveness. Some of them include discuss spaced-out in the following paragraphs.

1. Constraints of Technological Advancements Graphics and Computational Capability: The efficiency of military training using VR technology largely depends on its graphics and computational power. To realize sophisticated and identifiable VR simulations having complex scenes, physics-based interactions, and advanced AI behaviours, high-powered GPUs and CPUs are bound to be required. Development since past years has far improved VR graphics, so photorealistic images as the highest mode of training normally would not apply-and, thus, some extent of realism and the immersive aspect could be compromised. Poor texture quality or rendering at speed could make training less efficient and might cause a much wider gap between virtual and real-world experiences. Virtual Reality simulation executions must require robust personal computers with high-powered graphics processing units.

2. Capital requirement: Somewhat different reference goes to the digitalization concerning costs; in fact, more money is demanded for haptic feedback suits, additional advanced motion sensors, expensive software and hardware.

3. Kinetosis and fatigue: Long engagement with the VR environment may cause eye strain, nausea, and dizziness, reducing time for drills. The conflict between the visual perception and the balance performance opens a way to a so-called motion sickness or cybersickness in VR. That conflict may be reflected in the following: eye strain, dizziness and nausea, headaches and disorientation, balance problems, unnatural locomotion, neck and muscle strain, dryness and difficulty focusing, and repetitive motion stress from wearing heavy VR headsets for long periods. Besides physical fatigue, cognitive fatigue may also set in; information overload: Long and complicated simulations can overload learners and hence reduce their effectiveness. Mental exhaustion: Stress on soldiers caused by high-intensity virtual reality combat scenes can inhibit decision-making.

4. Lack of Tangibility in the Physical Dimension Insufficient feedback from haptics: Some haptic-feedback VR suits are still not quite there yet when it comes to an all-encompassing experience replicating the weight, force, and energy in combat scenarios. Environmental forces cannot be truly replicated: Some real-life forces, like wind resistance, weather, and gun recoil, cannot properly manifest through VR methods.

5. Data and cybersecurity data breaches and privacy intrusions: A basically hack of military VR systems could make data use disruption on training regimen quite presumably large. Ethical concerns: A serious ethical and security conundrum exists in the collection and storage of biometric data of personnel during VR training.

6. Flexibility and Pragmatic Considerations AI and NPC Limitations: The effectiveness of training within VR simulations could be deteriorated by adversarial Artificial Intelligence, which is incapable of mimicking the unforeseeable behaviours of real-world opponents.

7.Infrastructure and Network Requirements: High-Speed Internet and Connection Conditions: Reliable, high-bandwidth internet connections are a must for the facilitation of multiplayer virtual reality training, and such features may not be existential remote military installations. Hardware Maintenance: General maintenance and upgrades of the virtual reality equipment are required for systems to operate properly.

5. Solutions & Findings to the Mentioned Challenges:

1. **Constraints of Technological Advancements in Graphics and Computational Capability:**

- **Optimized Hardware and Software:** Military institutions should invest in high-performance GPUs and CPUs designed specifically for VR applications. Cloud computing and edge computing could be used to reduce the local system load.
- **Adaptive rendering approaches:** Using a technology involving only high-resolution rendering in the direct direction of vision, foveated rendering is one big step towards visual realism while saving processing power.
- **Soar with AI:** AI could be used to forecast the imminent motion of a user while prepping graphics or textures for faster efficiency and fluid real-time interactions.

2. **The financial outlay is exceptionally big when going into VRs**: Scalable and modular VR systems could render a typical project this cost-effective, allowing for investment in phased equipment.
   - **Partnershipists:** engaged technological corporations and research institutions, in all appeared the best to actively share the learning pains while integrating the latest advancements into a system.
   - **Simulation-as-a-Service:** Renting VR training environments or resorting to cloud-based VR solutions may deliver high-end training simulations without imposing huge upfront investments.
3. **Motion sickness and fatigue:**
   - **Ergonomic construction and motion algorithms:** Smart, slender virtual reality headsets, and motion algorithms decreasing latency led to less fatigue.
   - **In the Training:** Systematic developed exposure in training to VR will get the users adjust to it with a minimal cybersickness complaint.
   - **Eye-tracking and adaptive displays:** Dynamic display adjustment of the frame rates and the focal point based on user feedback would minimize nausea and disorientation.
   - **Low cognitive load**: Break VR training into structured sessions facilitated by manageably sized objectives to avoid information overload associated with mental fatigue.
   - **Improving VR design:** Tolerable discomfort is lowered via high frame rate (risks 100 Hz) headsets with lower latency.
   - **Conducive movement tracking:** VR treadmills or let alone letting someone moving through real space would eliminate the sensory conflict altogether.
   - **Shortened training:** Allow for breaks periodically to avoid physical fatigue whilst allowing a better shot for memorization. And lastly, headsets that are lightweight in orientation.
4. **Lack of Tangibility in the Physical Realm:** Integrating advanced haptic feedback systems such as haptic gloves, vests, and exoskeletons can provide a more realistic sense of weight, resistance, and

physical exertion. Other sensory elements-like wind, temperature variations-can be added to further support.

- **Hybrid training:** VR simulations combined with real-life exercise keeping a fine balance between immersive training and two-way exposure in combat readiness.

5. **Data and Cyber Security:**
   - **End-to-End Encryption:** With military VR systems, strong encryption must be used in order to protect highly sensitive data.
   - **Secure Network Infrastructure:** Close-loop systems with direct dedicated military servers to avoid cyber intrusion; and last but not the least, strictly enforceable data policies.
   - Use of wide variety of major ai into training-advanced machine learning-based NPC behaviour becoming making training scenarios unpredictable and realistic.
   - **Space Terrain Mapping:** Geospatial data combined with other real-time scanning principles and technologies to actually recreate BFS and urban actions in training programs: scenario customization-as per the instructors, who are to modify training modules based on real-world crypto knowledge to actually make soldiers setup for missions: infrastructure and network requirements: with the ability offline an: VR manuals: create forces training modules that will resume cooperation with internet connections, thus allowing having training in remote areas: solutions local server: setting dedicated military servers to attain fully high-speed data without relaying with exterior networks: regular maintenance and upgrades: must have a task force to be in charge for system update and calibration so the VR hardware and software will be functioning as required and not outdated sadly after playing games.

This is assured that by providing innovative and strategic solutions, virtual reality can better amplify training of the military, while at the same time minimizing cost and providing greatly efficient and more vivid learning beneficiation.

6. Conclusion:

The above research can be concluded by mentioning the VR as a potential tool in the segment of industrial training in defiance. It hints at transfiguring its role in a successful training environment through various factors like safety, cost efficiency & effectiveness in learning. This makes it an effective tool for modern defence units because of its ease of use and scalability across geographical boundaries. Nonetheless, in achieving VR military training results, one must keep in mind its challenges: technology, human adaptability, and psychological factors. Further research, including virtual simulations of haptics, AI, and the combination of AR-VR, will offer a VR military training platform with greater capabilities. Hence, VR is one of the potent and modern training tools that may revolutionize military training for complicated and risky operations.

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