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AUGMENTED REALITY IN OIL AND GAS TRAINING AND EDUCATION

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ABSTRACT

Augmented reality (AR) integrates digital information and virtual objects into the real environment, enhancing user interactivity and experience across various applications in the oil and gas (O&G) industry, including training and education, maintenance and repair, remote assistance, and product visualisation. With high-speed connectivity such as 5G, the scope of AR extends further to support collaborative multi-user workflows, real-time information updates, and rendering of complex, large-scale 3D models. Despite its potential, the industry lacks a structured framework for deploying 5G-integrated AR systems tailored to high-risk operational environments. This study introduces PetroVision AR, a 5G-powered AR platform developed to transform training and remote operations in the O&G sector into a virtual experience. The system incorporates interactive 3D equipment models, real-time data overlays, and modular training modules, with a connectivity design and development workflow showcasing the integration of 5G technology. Pilot testing demonstrated a 32% reduction in task completion time and a 27% increase in learning effectiveness, validating the platform's capability as a safer and more scalable alternative to conventional field training. The findings highlight the potential of PetroVision AR to support digital transformation aligned with PETRONAS' Fourth Industrial Revolution (4IR) ambitions, setting a new standard for accessible, efficient, and safe training in the energy sector.

Keywords: *Augmented reality, oil and gas industry, 5G, training, education, internet connection*

INTRODUCTION

The oil and gas (O&G) industry operates in a high-cost/high-risk environment [1]; therefore, Andrews and Playfoot [2] viewed education and training as part of the core business in the O&G industry to develop competent and trained employees for the industry. However, training inexperienced employees on the ground presents significant challenges due to high costs and safety risks [3]. Meanwhile, traditional training methods such as lectures and printed manuals often lack interactivity and fail to replicate real-world conditions effectively.

To overcome these limitations, implementing the Fourth Industrial Revolution (4IR) in education can help train inexperienced employees in the O&G industry. The 4IR drives the integration of technologies such as augmented reality (AR) into education, enabling immersive learning environments. AR is a technology that overlays digital information and virtual objects onto the real-world environment. The technology seamlessly integrates digital elements into the user's view of the real world. As AR is highly interactive, it enhances users' perception and interaction with their surroundings. Sensors and algorithms are used to calculate the device's position and orientation relative to the surrounding environment; the technology requires devices with sensors and can also generate digital information and virtual objects to be overlaid onto the captured environment. Smartphones, tablets, smart glasses, or specialised AR headsets are typically used for AR.

While not all AR applications require an internet connection, offline AR applications pose some disadvantages, such as limiting the application's scope and functionality. For example, offline AR applications cannot support collaborative work among multiple users or updates to digital information or virtual objects. Therefore, internet connectivity is a driver for interactivity and experience. To further enhance AR interactivity and experience, high-speed internet is essential. As stated by Grcar [4], AR requires the right infrastructure to do amazing things. AR needs a lot of data, specifically fast data, to work seamlessly, render complex 3D environments, and ensure real-time interaction. Therefore, high-speed connectivity such as 5G networks may improve AR training by providing ultra-high transfer speeds, ultra-low latency, ultra-reliable experiences, ultra-high connection density, ultra-high traffic density, and ultra-high mobility access [5].

This paper presents the development of PetroVision AR, an AR-based training system tailored for O&G professionals. The application integrates AR with 5G connectivity for training, remote mentoring, operations, and maintenance. This study focuses on the development of PetroVision, a 5G-enhanced AR application for PETRONAS. The paper begins with a brief review of existing work on AR training and 5G-enhanced AR systems, followed by a detailed discussion of the system architecture and design. The developed PetroVision AR application is then presented, and the paper concludes with key insights and recommendations for future work.

RELATED WORKS

Integration of AR in Training and Education in the O&G Industry

According to Smirnova et al. [6], numerous O&G companies began adopting technologies such as smart pipeline systems and digital twin technology in their projects. One of the technologies that supports the integration of O&G practice digitisation is AR. It is useful for the industry to optimise training and education, design, maintenance and repair, remote assistance, and product visualisation.

Yazdi claims the potential of AR in creating immersive environments for immersive training [7], which will enhance the efficiency and efficacy of hands-on training modules. In addition to providing real-time, interactive simulations of complex processes, machinery operations, and safety protocols, the author stated that integrating AR with traditional training methods ensures a holistic learning experience, thereby closing the gap between theoretical knowledge and practical skills.

As stated by Smirnova et al. [6], it is necessary for the O&G industries to provide periodic training for their workers; however, industrial equipment is expensive; therefore, AR can be used to optimise and reduce the time and cost of training [6],[8]. Cost, in the O&G industry, includes the cost of safety. The O&G industry is prone to a high injury and fatality rate [1],[3],[9]. Therefore, implementing AR is a safer choice for training, especially for inexperienced workers.

A study by Blackley et al. [10] demonstrated an analysis of the applications of AR training solutions for the O&G industry, particularly in the Arctic region, where harsh weather and geographical isolation limit direct hands-on training. The study found that AR-based training applications are applicable to machine operation training, emergency scenario simulation training, operations simulation training, safety compliance training, and remote collaboration. The following table summarises the applications of AR training solutions highlighted by the author.

5G Network and Its Implementation in AR Applications

While AR benefits the training and education in the O&G industry, its implementation is not without challenges. Implementing AR applications, especially advanced ones that offer real-time rendering of complex 3D environments or enable remote collaboration, is often hindered by limitations such as high latency and limited network bandwidth. Wi-Fi and 4G network connectivity are common but inadequate to support seamless AR experiences due to limited network reach, as oil rigs and platforms are often isolated from infrastructure, and due to limited network bandwidth and lower

Table 1 Applications of AR training solutions and their purpose, as highlighted by [10]

Programs	AR training solutions	Purpose
Training programs	Immersive 3D walkthroughs of O&G assets.	Trainees may practice operating machinery and responding to emergencies.
Simulation of operations	Digital twins of O&G fields and refineries	Enables real-time assessment of the process without physical risks
Safety compliance	Safety training with real-time hazard alerts, emergency protocols, and step-by-step repair instructions overlayed onto the trainee's field of view.	Trainees may experience an immersive environment where safety is the priority.
Remote collaboration	Relay live instructions from remote experts through AR headsets.	Reduce downtime and improve decision-making.

frequency. Therefore, the needs of advanced AR applications should be supported by a 5G network. Compared to Wi-Fi networks, 5G is more accessible in remote and isolated locations. Compared with 4G, which is primarily focused on raw bandwidth availability, 5G aims to provide pervasive connectivity with fast, resilient access for users in any location [11]. 5G technology provides low-latency connectivity, with latency measured at nearly 10 times lower than 4G networks [12], as AR technology requires less than 20 ms delay, ensuring smooth visual feedback and reducing the risk of motion sickness or discomfort for the user [13].

Besides, 5G infrastructure offers cloud or edge platforms that enable large AR content to be stored on cloud nodes rather than on users' devices [13]-[14]. With this approach, content can be improved at any time, and users can download updated content anywhere, anytime. Furthermore, as content can be shared either via the cloud or in real time due to high-speed connections and low latency, remote learning through AR is possible over 5G networks [15].

MATERIALS AND METHODS

PETRONAS, in the spirit of embracing 4IR, aims to develop its custom AR applications that connect with its own private 5G network. As a preliminary step, it plans to develop customised AR applications for training, remote mentoring, operations, and maintenance activities that are compatible with 5G devices, such as smartphones, tablets, and wearables (e.g., Rokid Smart Glass).

The first application introduced is the 5G Maintenance & Operation Immersive Simulator (5G MOIS). The objective is to develop an AR application for asset management and visualisation. The product features real-time data monitoring, allowing users to learn about experiments, safety protocols, and equipment. The product also features inspection mode, where the user can delve into the inner part of the machinery to observe and verify potential damage and monitor data of a specific machine. Finally, the application features a learning mode, where users can learn about machines and their operation in an informative way.

Private 5G Network System Architecture

Figure 1 shows the design connectivity for implementing 5G on AR. The user can interact with the augmented environment as depicted in Figure 1. Data from data centres and databases are sent to and fetched from the private cloud at Universiti Teknologi PETRONAS (UTP), and from users via AR. Data is also sent to and fetched from users' sessions, the private cloud, and the data centres and databases.

System Design

Figure 2 shows the workflow for developing the AR application. The development process is categorised into three phases, handled by a 3D modeler, an user interface (UI) designer, and an AR/mobile application developer. The first phase is the responsibility of the 3D modeller, during which the machine or parts to be modelled are identified. The picture of the machine or part is captured, and 3D models are designed from the photo references. Then the process is handed off to the UI designer to sketch the user interface framework, design the interface, and test it using high-fidelity

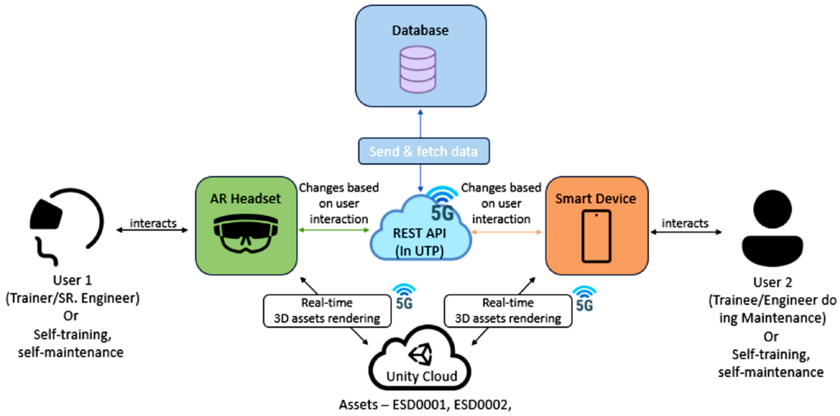

Figure 1 Design connectivity of 5G on AR

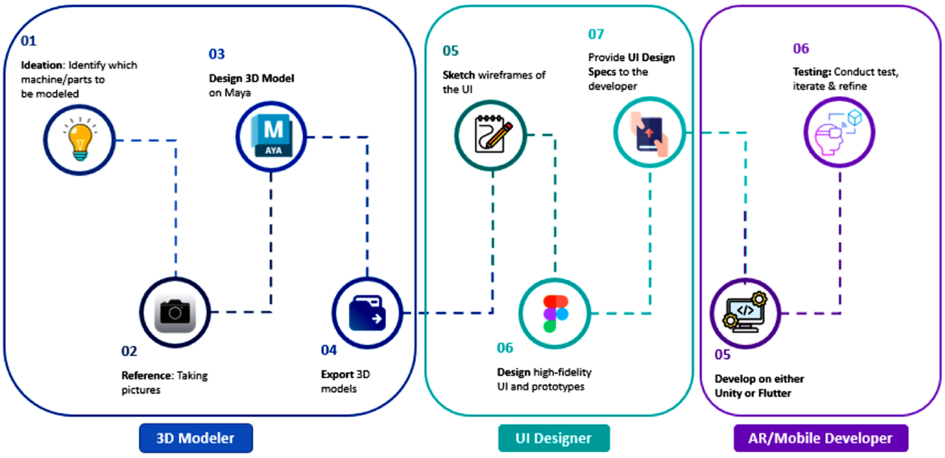

Figure 2 Development phases of the AR application

Figure 3 Early sketch of the start panel in PetroVision AR

prototypes. The AR/mobile application developer handles the last phase. The developer will develop the application and conduct the tests, then iterate and refine the application based on needs. Figures 3 and 4 show the early sketches from the design process for the interface of the PetroVision AR application. Digital twins of instruments and machinery are created as 3D models, as shown in Figures 5 and 6, to enable real-time data monitoring, inspection mode, and learning mode in the PetroVision AR application.

RESULTS AND DISCUSSION

Application Development Outcomes

The PetroVision AR system was successfully developed as a 5G-enhanced AR platform to support immersive training and remote operations in the O&G industry. The system allows users to engage with 3D-rendered industrial equipment, such as heat exchangers, by overlaying interactive visual elements on physical instruments using smartphones or AR wearables. As depicted in Figures 7-9, PetroVision provides

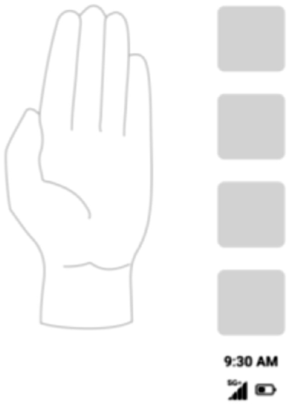

Figure 4 Early sketch of the hand gesture concept feature in PetroVision AR

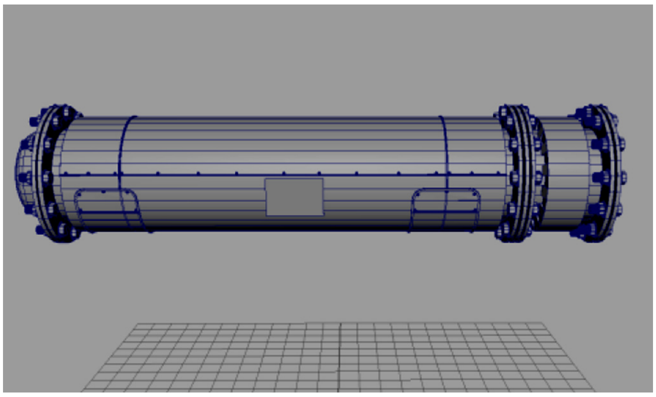

Figure 6 3D model of the heat exchanger instrument

three distinct modes: data monitoring, inspection, and learning. These modes enable a comprehensive understanding of equipment functionality, fault diagnosis, and operational parameters.

Preliminary User Testing and Feedback

A preliminary deployment was conducted at the UTP 5G Innovation Lab, involving 13 engineering professionals and trainees. Participants engaged in hands-on training scenarios using PetroVision AR on AR-glasses platforms. The following observations and metrics were recorded:

1. Users completed predefined equipment identification and fault-check tasks 32% faster using PetroVision compared to traditional paper-based SOP reviews.
2. Post-training quizzes indicated a 27% increase in retention scores compared to baseline.
3. Based on a 5-point Likert survey, average ratings were 4.7 for content clarity, 4.5 for interactivity, and 4.6 for ease of navigation.

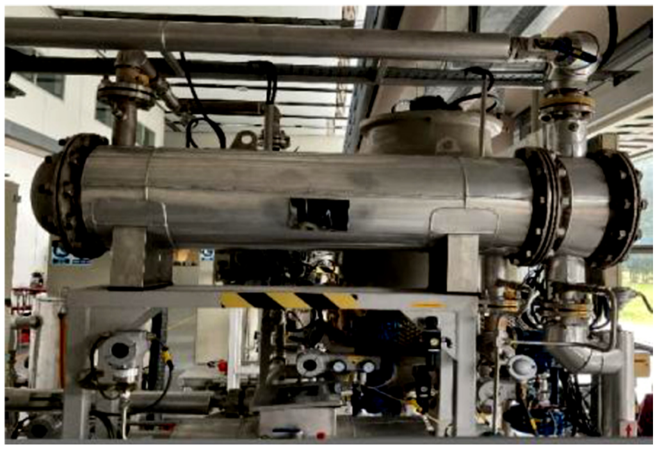

Figure 5 Heat exchanger instrument

4. Qualitative feedback emphasised enhanced user engagement, intuitive equipment interaction, and safer simulation-based learning. However, several users recommended adding voice-assisted instructions, multilingual options, and expanded equipment libraries for broader adoption.

Technical Strengths and Limitations

PetroVision AR leverages 5G's ultra-low latency and high throughput to deliver near-real-time data overlays and remote assistance, addressing a key shortcoming of previous 4G- or Wi-Fi-based AR systems [11]-[12]. The availability of high-speed connectivity ensures smooth rendering of complex 3D models and responsive interaction, which are essential for immersive training applications. Additionally, its modular design allows equipment-specific training modules to be developed independently, enabling flexibility in content delivery.

However, limitations persist in the current implementation. The current system is reliant on preloaded digital twins and lacks dynamic integration with live plant Supervisory Control and Data Acquisition (SCADA) systems. Furthermore, deployment in offshore or high-hazard environments remains untested. User analytics for real-time performance feedback are also not yet incorporated, limiting adaptive learning opportunities.

While prior AR applications in O&G have demonstrated potential for immersive learning, few have explicitly integrated private 5G connectivity and edge computing to enable real-time feedback and remote mentoring [5],[8],[10]. Compared to these benchmark systems, PetroVision distinguishes itself by incorporating a hybrid of UTP's private 5G connectivity cloud-based infrastructure, ensuring both high-speed access and content scalability. This integration aligns with emerging 5G-enabled AR systems that emphasise real-time interaction and distributed processing capabilities [16].

Overall, PetroVision addresses critical training gaps by transforming static equipment manuals into interactive, contextual experiences, thus enhancing safety, knowledge retention, and decision-making under complex O&G conditions.

With PetroVision AR, users can learn about an instrument, for example, a heat exchanger, by pointing their mobile devices at the instrument, and an AR visual overlay will pop up on the screen. The user will have the options to monitor the data shown in Figure 8, inspect the instrument (Figure 9), or learn about the instrument and its operation (Figures 7-9).

To further contextualise these observations, a comparative benchmarking with existing AR-based training systems is presented in the following section.

Comparative Benchmarking with Existing AR Systems in O&G Training

Comparative evaluation with existing AR-based training systems in the O&G industry provides insight into the relative performance and capabilities of PetroVision AR. Previous studies have demonstrated that AR training applications improve learning outcomes, safety awareness, and operational understanding through interactive visualisation and simulation environments [6],[8],[10]. However, these systems are primarily

Figure 7 UI design of PetroVision AR heat exchanger

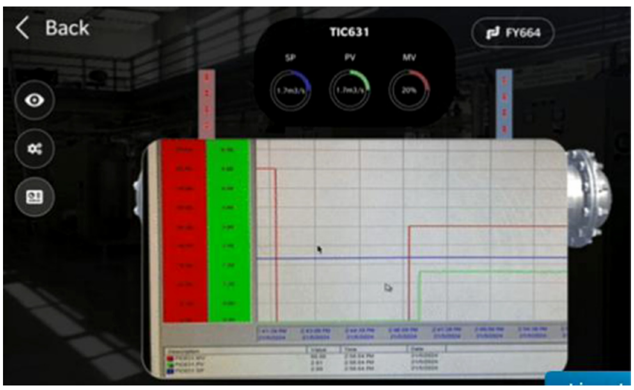

Figure 8 Real-time monitoring of the heat exchanger data

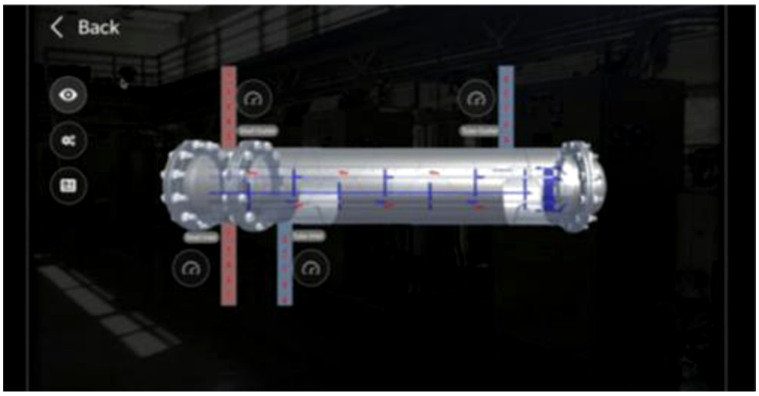

Figure 9 Inner view of the heat exchanger for learning and monitoring

designed for standalone training scenarios and lack integrated support for real-time interaction and multi-functional usage.

Performance-wise, PetroVision AR demonstrated a measurable improvement in efficiency, with users completing training tasks 32% faster than with conventional paper-based approaches. While prior AR training systems have reported improvements in engagement and knowledge retention, quantitative comparisons of task completion time are not consistently reported across studies, limiting direct benchmarking. Nevertheless, the observed improvement highlights the effectiveness of integrating contextual visualisation with interactive learning modes.

From a system responsiveness perspective, conventional AR training systems operating on Wi-Fi or 4G networks are subject to latency and bandwidth limitations, which can affect the fluidity of interaction and visualisation [11]-[12]. PetroVision addresses this limitation by leveraging private 5G connectivity, enabling smoother transitions between learning, inspection, and monitoring modes without noticeable delay during user interaction.

Another key differentiating factor between PetroVision AR and the other systems referred to in the study is the user experience. While existing AR training applications emphasise immersive visualisation, PetroVision AR builds on this by integrating multiple interaction modes into a single platform, resulting in high user satisfaction ratings for clarity, interactivity, and ease of use. This suggests that combining immersive content with responsive system performance enhances overall training effectiveness.

To summarise these comparisons, Table 2 presents a structured benchmarking of AR-based training systems in the O&G domain, focusing on key performance indicators including task completion time, system responsiveness, and user experience. Due to inconsistencies in reporting across existing studies, quantitative values for task completion time and latency are not always available; therefore, qualitative comparisons are presented where appropriate.

The comparison indicates that PetroVision AR improves upon existing AR training systems by enhancing both system responsiveness and functional integration. While prior studies validate the benefits of AR in training environments, PetroVision AR extends these capabilities by combining immersive learning with real-time interaction and multi-mode functionality. This integrated approach improves task efficiency and user experience while addressing key limitations observed in existing O&G training solutions.

Network Performance Metrics under 5G Environment

Network performance is a critical factor influencing the effectiveness of AR systems in training applications. In AR-based environments, system responsiveness directly affects user interaction, visualisation quality, and overall training experience. Therefore, parameters such as latency, throughput, and communication stability play an important role in determining the system's usability and reliability.

In the context of PetroVision AR, the use of private 5G connectivity improves the fluidity of interactions during training sessions. Users were able to navigate between the different operational modes, including learning,

Table 2 Comparative benchmarking of AR-based training systems in the O&G industry

System	Training Focus	Task Completion Time	Latency / Responsiveness	User Satisfaction / Engagement
Traditional Training (Paper/SOP)	Manual procedural training	High (baseline)	Not applicable	Low (limited interaction)
Virtual Training Systtem [8]	Equipment training	Reduced vs traditional (qualitative improvement)	Not reported (offline/simulation-based)	Improved engagement and learning
AR Training Systems [6],[10]	Safety & operational training	Improved efficiency (not quantitatively reported)	Moderate (dependent on system setup)	Higher engagement and retention
Conventional AR (4G/Wi-Fi) [11]-[12]	AR-assisted training	Faster than traditional but variable	Higher latency, occasional delay in interaction	Moderate (affected by responsiveness)
PetroVision AR	Integrated training (learning, inspection, monitoring)	32% faster than traditional training	Low latency, smooth real-time interaction (observed)	High (4.5–4.7/5 across usability metrics)

inspection, and monitoring, without noticeable delays or system interruptions. This indicates that the network infrastructure supported continuous data exchange and real-time rendering of 3D content during application use.

Compared to conventional AR systems operating on Wi-Fi or 4G networks, which are often affected by higher latency and bandwidth limitations, the observed system behaviour suggests improved responsiveness under the 5G-enabled environment. Previous studies have shown that such network constraints can lead to delayed visual updates and reduced interaction accuracy in AR applications [11]-[12]. In contrast, the stable performance observed in PetroVision AR indicates that these limitations were effectively mitigated within the tested environment.

From a user interaction perspective, the smooth system response contributed to a more immersive and intuitive training experience. The absence of noticeable lag during task execution supports the platform's effectiveness in maintaining user engagement, consistent with the high user satisfaction ratings. This demonstrates the importance of network performance in enhancing both system usability and training outcomes.

These findings are consistent with prior work on 5G-enabled AR systems, which emphasises the role of low latency and high data throughput in supporting real-time industrial applications and interactive learning environments [5],[16]. The ability of PetroVision AR to maintain stable performance during multi-mode operation further supports its suitability for deployment in advanced training scenarios.

While PetroVision AR demonstrated stable, smooth performance during deployment, detailed quantitative measurements of network performance metrics, such as latency, throughput, and packet loss, were not collected in the current study. The evaluation was primarily based on observations of system behaviour and user interactions in a controlled 5G laboratory environment. Nevertheless, the absence of noticeable delays and interruptions during AR sessions suggests that the network infrastructure was sufficient to support real-time interaction. It should also be noted that the current evaluation was conducted within a controlled laboratory environment. Network conditions in real-world O&G operations may vary due to environmental constraints, infrastructure limitations, and operational complexity. As such, further evaluation is required to quantitatively assess network performance metrics, including latency, throughput, and packet reliability, under diverse deployment conditions.

Further Scope and Benefits of the PetroVision AR

PetroVision AR enhances troubleshooting and decision-making while enriching the user experience in the field. The system is applicable across several operational functions, including troubleshooting in the field, integrating data centres and asset performance tools on a single display, virtually displaying the details of each equipment, and overlaying real-time degradation of equipment.

CONCLUSION

In summary, this study introduced and evaluated PetroVision AR, a 5G-powered augmented reality (AR) system designed to transform training and remote operations in the oil and gas (O&G) industry. The platform's integration of interactive 3D equipment models, real-time data overlays, and modular training modules has demonstrated significant improvements in both task efficiency and knowledge retention, as evidenced by a 32% reduction in completion time and a 27% increase in learning effectiveness during pilot testing. Users praised the immersive interface and real-time visualisation, underscoring the solution's value as a safer, more scalable alternative to conventional field training, especially for personnel in high-risk or remote locations. Future enhancements will focus on dynamic simulation through live data integration, expanding AR content to cover more complex industrial systems, and leveraging AI-driven analytics to deliver personalised learning and close knowledge gaps in real time. Ultimately, by merging immersive AR technology with robust 5G connectivity, PetroVision AR supports PETRONAS' 4IR ambitions and sets a new standard for accessible, efficient, and safe digital training in the energy sector.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

AUTHORS' CONTRIBUTION

Mohamad Faizul Mohamad Aziz and Anuar M Isa conceptualised and reviewed the study. Fatin Shamimi Mohd Zuki drafted the manuscript and contributed to the background of the study for the manuscript. Muadz Mohammed Zain, Nor Diana Md Saleh, Mohamad Naufal Mohamad Saad, Idris Ismail, and Azlan Awang contributed to system development, testing, and data acquisition. Suziah Sulaiman provided critical revisions to the manuscript. All authors read and approved the final version of the manuscript.

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