TCS revolutionizes clinical trial monitoring and data analysis with AR/VR-driven immersive analytics

Introduction

Technological advancements have been disrupting sectors worldwide, including healthcare and drug development. Digital analytics have been revolutionizing clinical trials by examining extensive datasets, enabling early detection of trends and patterns, data inconsistencies, and outliers. Leveraging big data enhances real-time data analysis, boosting monitoring and speeding up trials. SaaS-based platforms with AI have streamlined research processes, aiding stakeholders like clinical and medical monitors in ensuring patient safety and data integrity. However, reliance on 2D visualizations limits data analysis capabilities. Advancements in augmented reality and virtual reality offer opportunities for immersive 3D data visualization.

This paper presents the development of an AR/VR solution for visualizing multi-dimensional data in interactive 3D objects. Monitors can explore sites on a 3D globe, enhancing trend and anomaly detection. This technology improves monitors' efficiency and oversight capabilities for more proactive source data verification. It represents a step toward transforming outdated monitoring processes through extended reality technologies, enhancing clinical trial data quality and efficiency. Finally, we explore implications and future directions for applying AR/VR to improve trial quality, site training, recruitment, and telemedicine.

Augmented reality (AR) and virtual reality (VR)

Augmented reality and virtual reality have been revolutionizing digital interaction, especially in healthcare. AR overlays digital information onto the real world, while VR immerses users in simulated environments. The global AR/VR healthcare market, valued at USD 22.12 billion in 2024, is projected to reach USD 96.32 billion by 2029, growing at 34.2% CAGR during the forecasted period.

These technologies enhance medical training, surgery, diagnosis, and patient engagement. Surgeons use VR for 3D models to improve accuracy, while AR provides real-time patient data. Advances in wearables, 5G, and IoT have driven growth, despite high costs. AR/VR fosters interactive learning, remote collaboration, and better information retention, making healthcare more efficient and immersive.

AR in clinical trial monitoring and analytics

Augmented reality is transforming clinical trial monitoring by offering immersive 3D data visualizations, unlike traditional 2D dashboards. This allows monitors to dynamically filter, sort, and analyze data, enhancing pattern recognition and decision-making. Studies indicate improved information recall with 3D presentations, potentially boosting monitor engagement and oversight effectiveness.

A key advantage of AR is its ability to overlay data onto real-world environments via spatial mapping. Monitors can attach study data to specific sites or objects using AR headsets, merging virtual and physical spaces. Viewing study sites on a 3D globe provides geographical insights unavailable in traditional dashboards and supports remote monitoring by allowing off-site monitors to explore sites through data immersion. AR enables real-time collaborative data review, allowing monitors in different locations to analyze shared data in virtual meetings for faster issue identification and decision-making.

Future research should focus on intuitive interface designs and usability testing to optimize these tools for trial oversight.

In subject monitoring, AR helps doctors assess patient health history, vitals, and conditions through 3D models. It supports training by enabling healthcare professionals practice procedures on 3D models, reducing costs and enhancing learning. AR improves subject adherence to trial protocols with interactive reminders and instructions via smartphones or AR glasses, offering visual cues for medication or tasks. It also ensures accurate data capture by guiding subjects through self-administered procedures with real-time feedback.

AR transforms clinical trial monitoring and subject oversight by enhancing data visualization, collaboration, training, remote monitoring, and subject engagement. Its intuitive, and interactive tabletop visualizations and analytics contribute to more efficient and effective clinical trials.

Methodology

To conceptualize immersive 3D data visualization for clinical trial monitoring, one can leverage open-source frameworks for interactive 3D rendering and AR/VR integration. This approach involves constructing dynamic 3D objects like globes, graphs and charts to represent clinical trial data, enabling real-time interaction within AR and VR environments.

As shown in figure 1, augmented reality display 3D overlays onto the real-world camera view via mobile devices or AR/VR headsets, requiring motion tracking, environmental mapping, and lighting estimation for seamless integration. For VR, entity-component architecture supports rapid scene construction, linking 3D assets for immersive data exploration. Specialized components can visualize bar charts, pie charts, and scatter plots, enabling interactive clinical trial analysis.

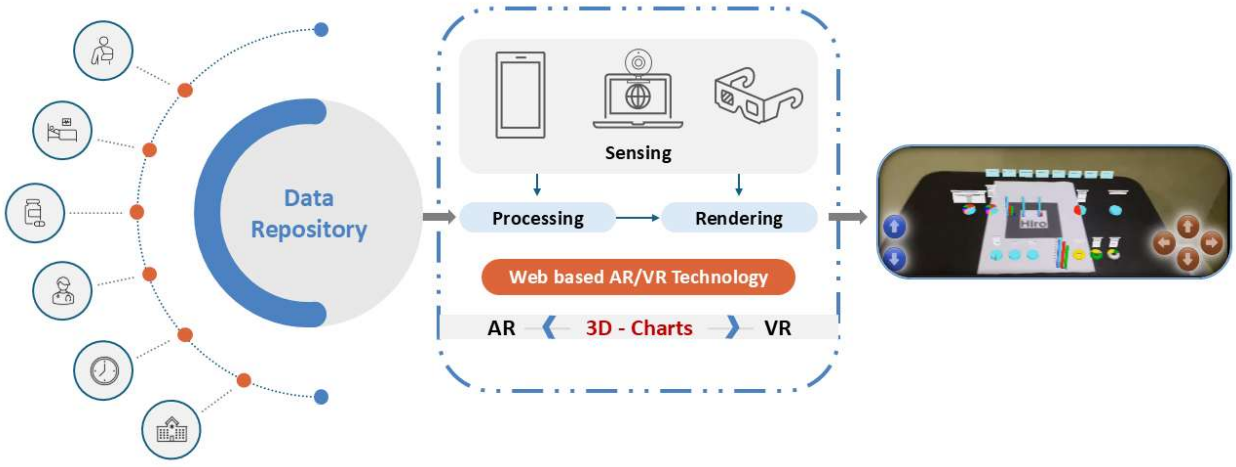


Figure 1. AR/VR clinical trial visualization schematic diagram

A visualization layer can be imagined as a key component designed to efficiently parse clinical trial data and generate the necessary 3D charts and objects. This approach enables the swift development of an interactive AR/VR environment that is optimized for visual clinical data exploration. Such an immersive methodology enhances oversight of clinical trials by providing a technically robust platform for data visualization and interaction. The ability of medical reviewers and clinical operations team to interact, drill-down, roll-up in immersive cross domain datapoints coupled with AI/ML insights in tabletop paradigm, help in proactive oversight and making faster decisions this ultimately help faster drug to market and patient safety.

Scenario

Traditional approach

In a large-scale clinical trial, monitoring patient safety and site performance involves analyzing multiple risk factors, protocol deviations, adverse events, and missing data. Traditionally, monitors rely on 2D dashboards and spreadsheets. They manually drill down through different pages across multiple domains, such as data management, clinical operations, and pharmacovigilance, to assess risk signals. Identifying high-risk sites requires multiple clicks, filtering, and cross-referencing data across siloed systems.

Enhanced approach (3D AR/VR-based risk monitoring)

With AR/VR-powered 3D visualization, clinical monitors can interactively explore risk signals in a unified environment. A 3D site risk map dynamically highlights trial sites based on composite risk scores, integrating multiple parameters such as patient dropout rates, protocol deviations, and adverse event reporting delays all in a single interactive view. Instead of navigating multiple pages, a monitor can instantly identify high-risk sites using color-coded risk heatmaps on a 3D globe.

Beyond site-level insights, 3D patient models provide a comprehensive view of individual patient health, consolidating vitals, demographics, lab results, and risk factors into a single immersive interface. These models allow monitors to visually track anomalies in biometrics, medication responses, and disease progression over time. Clicking on a site or patient model brings up layered risk factors, including data trends, patient histories, and site performance, enabling faster and more informed decision-making without relying on fragmented 2D reports.

Example: A clinical monitor sees site B glowing red on a 3D globe, instantly revealing that patient dropout rates and protocol deviations exceed safe limits. Immediate action can be taken to prevent trial disruption.

Results

2D traditional dashboard

Typical dashboard screens of clinical and operational review application. The metrics are segregated by categories and typical drop-down and graph-based filters. Figures 2 to 5 shows sample screens representing a traditional dashboard layout.

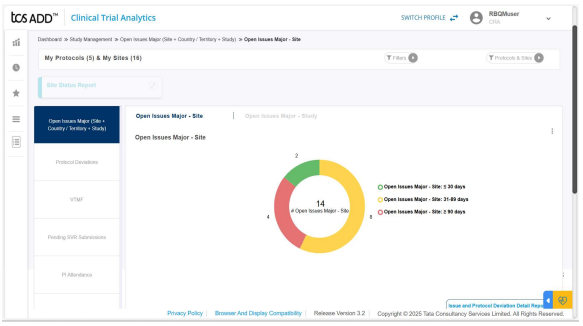
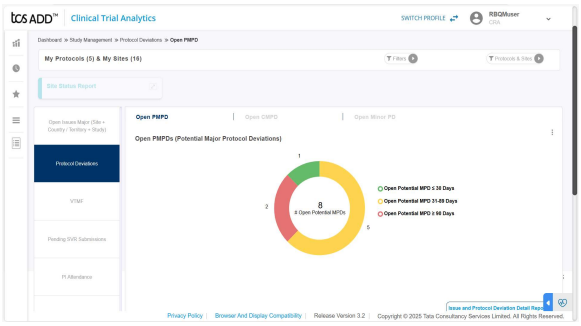


Figure 2



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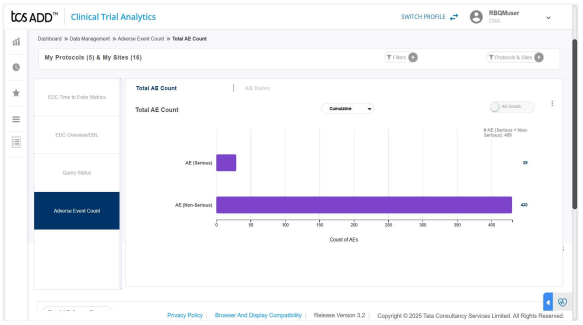


Figure 4

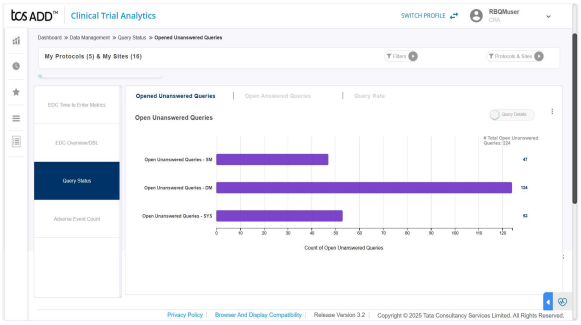


Figure 5

Triggering immersive experience

In next-gen analytics, scanning a QR code available on the dashboard screens, seamlessly transforms to immersive tabletop analytics as shown in figure 6.

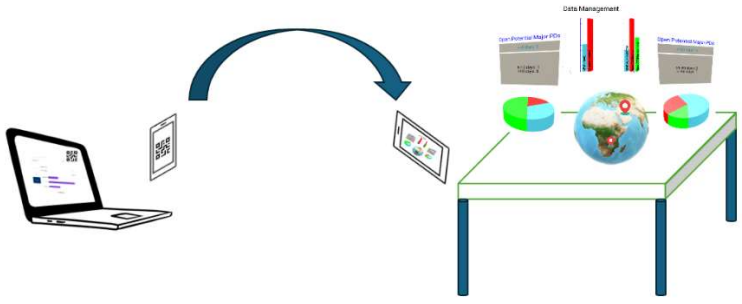


Figure 6 - Tabletop view diagram

Augmented reality

In the current approach, scanning a marker triggers an AR experience displaying objects, text, videos or charts directly in any web browser supported device. Figure 7 - 12 are some sample AR screens.

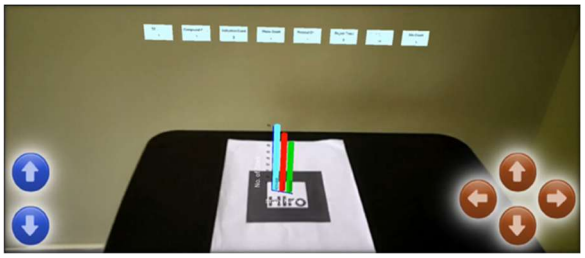
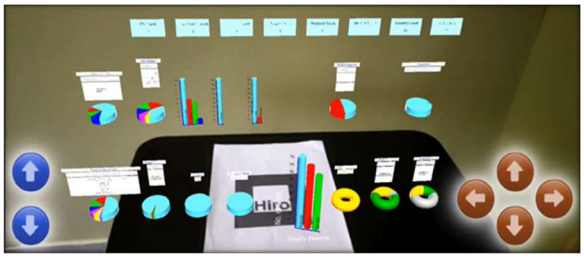


Figure 7



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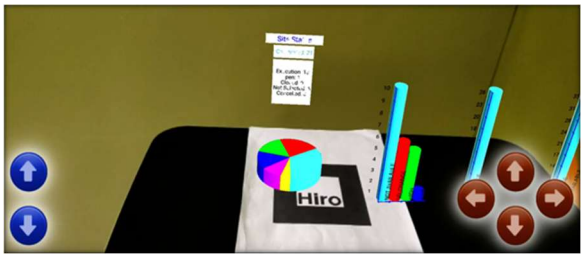

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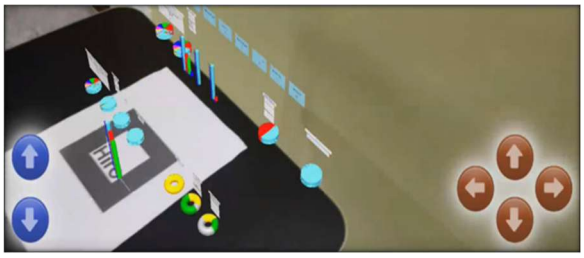


Figure 10

Figure 11

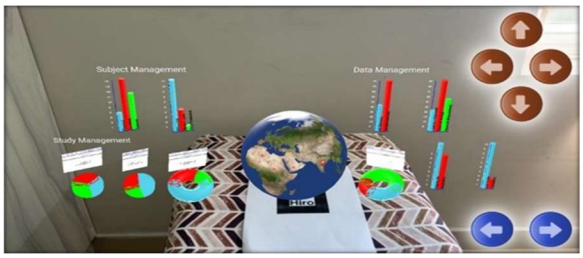


Figure 12

AR screens

Virtual reality

Virtual reality creates a 3D environment where users can explore and interact with charts to better understand clinical trial data, trends, and risks. Navigation controls allow movement within the virtual space. Figures 13 – 18 are some sample VR screens.

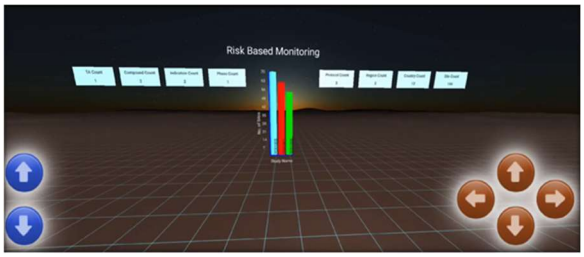
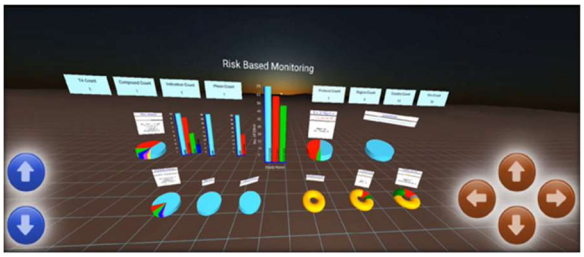


Figure 13



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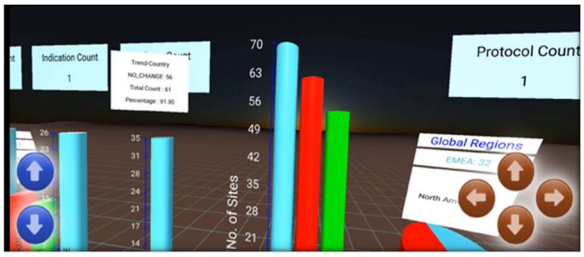

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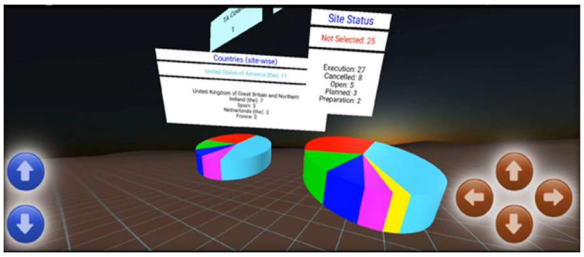

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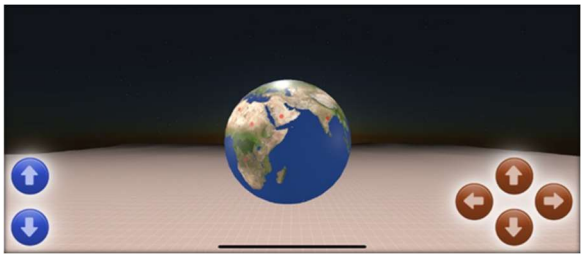

Figure 17

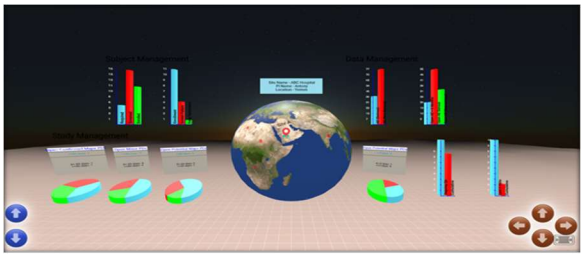

Figure 18

VR screens

Conclusion

This work shows the potential of AR and VR technologies to transform clinical trial monitoring with immersive 3D data visualization. By enabling interactive real-time analytics through web-based AR/VR environments, this solution aims to improve monitors' efficiency and satisfaction over traditional methods. Further research is needed to optimize these technologies for trial settings and evaluate their impact on data quality, patient safety, and cost-effectiveness. Visualization interfaces should be refined based on user feedback. Connectivity, security, privacy, and collaboration capabilities also need enhancement for enterprise deployment.

Future scope

The immersive analytics capabilities will be enhanced to visualize complex multidimensional data, including 3D models to provide a deeper understanding. This will generate real-time insights and include collaborative features for efficient distributed trial monitoring. It will integrate with existing clinical trial management systems and support diverse devices and interfaces for flexible use. Opportunities extend beyond clinical trials to drug discovery, medical education, patient engagement, and precision medicine. The solution's commercial potential includes licensing to healthcare and life sciences organizations focused on trial efficiency.

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