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Research Article

Offline Augmented Reality for Rural Tourism Development: Empowering Cultural Preservation and Community Sustainability through ID-QUBE and ID-MAP Design

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ABSTRACT

This paper presents the development of two offline augmented reality (AR) systems—ID-QUBE and ID-MAP—to enhance rural tourism in areas with limited internet connectivity. ID-QUBE, a solar-powered portable AR server, and ID-MAP, an interactive digital poster, are designed to deliver cultural and tourism-related content to users offline. These systems provide scalable and sustainable solutions for immersive AR experiences, fostering cultural preservation, community empowerment, and economic development. The paper discusses system architecture, offline marker-based applications, and scalability in underserved areas, concluding with recommendations for further commercialization and innovation.

Keywords: Augmented Reality (AR), Offline Systems, Rural Tourism Development, Cultural Heritage Preservation

INTRODUCTION

The rapid evolution of Augmented Reality (AR) technology has revolutionized various industries, including tourism, by merging virtual elements with real-world environments. Despite its transformative potential, AR applications heavily depend on stable internet connectivity, a requirement that poses significant challenges for rural tourism in regions with limited digital infrastructure. This study addresses this gap by presenting offline AR systems—ID-QUBE and ID-MAP—that enable immersive cultural experiences without relying on internet access.

The challenges facing rural tourism stem largely from inadequate digital connectivity, which hampers the promotion of local attractions, cultural heritage, and tourism services. While digital tools hold immense potential to enhance tourism experiences, rural areas are often excluded due to their dependency on internet-based technologies [1]. This disparity limits the growth of rural tourism, adversely affecting the economic prospects of local communities. Additionally, traditional promotional methods, such as brochures and physical maps, lack the interactivity and engagement offered by digital solutions [2]. Thus, an innovative AR system capable of functioning without internet dependency is essential to bridge this gap and bring the benefits of digital interactivity to underserved regions.

Figure 1: The application of Augmented Reality through Interactive Posters and delivered via Wi-Fi in an offline connected manner.

This paper introduces two offline AR systems: ID-QUBE, a portable AR server, and ID-MAP, an interactive digital poster (figure 1). Both systems are powered by a sustainable solar-based energy source and feature an intuitive, user-friendly interface that can be easily managed and updated by local communities. These systems not only enhance tourist engagement but also contribute to the sustainable economic development of rural areas by making local tourism more accessible and interactive [3]. By addressing the digital divide, ID-QUBE and ID-MAP offer a scalable solution for promoting rural tourism and preserving cultural heritage in underserved regions.

LITERATURE REVIEW

The integration of Augmented Reality (AR) into tourism has advanced significantly over the past decade, offering new opportunities for immersive and interactive experiences. AR overlays digital content—such as images, videos, and 3D models—onto real-world settings, enhancing the visitor experience by providing additional context and interactivity [4]. While AR applications in urban tourism have been extensively explored due to robust digital infrastructure [5], its adoption in rural areas remains constrained by technological dependencies, particularly the need for stable internet connectivity [6].

The potential of AR to enrich cultural tourism is widely recognized. Wang et al. demonstrate that AR enhances cultural tourism by enabling visitors to engage with local heritage interactively, deepening their understanding and appreciation of cultural narratives [7]. This is particularly critical in rural areas, where cultural heritage often serves as the main attraction but may lack adequate resources for effective promotion. Traditional methods of conveying information, such as guidebooks or static displays, fail to engage tourists at the same level as AR-enabled experiences [8].

However, implementing AR in rural contexts presents unique challenges. Existing AR systems typically require high-speed internet access for content delivery, making them unsuitable for underserved regions with limited digital infrastructure [9], [10]. Recent studies emphasize the need for offline AR solutions that address these constraints. For example, Pietrzak et al. propose the development of local servers and portable devices to deliver AR content without reliance on internet connectivity, creating more inclusive tourism opportunities [11].

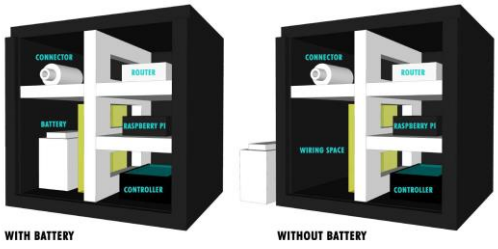
The offline AR systems—ID-QUBE and ID-MAP—proposed in this study align with these innovative approaches by providing solar-powered, user-friendly platforms for delivering AR experiences. These systems enable rural communities to showcase their tourism assets while preserving cultural heritage, offering a sustainable solution to the digital divide [12]. Furthermore, by incorporating local management capabilities, these systems empower communities to take an active role in their tourism development, fostering both cultural preservation and economic sustainability [13].

METHODOLOGY

This study developed two offline AR components—ID-QUBE, a portable AR server, and ID-MAP, an interactive digital poster—to address connectivity challenges in rural tourism through sustainable, user-friendly designs. The methodology encompasses system design, data collection, prototype implementation, user interaction testing, and system evaluation.

1. System Design and Development

The ID-QUBE and ID-MAP systems are offline AR tools designed to disseminate tourism and cultural information in rural areas. ID-QUBE is a cube-shaped AR server powered by solar energy, suitable for deployment in remote areas without stable electricity (figure 2).



Figures 2: 3D models of ID-QUBE, offering a detailed visualization of the portable AR server.

ID-MAP, an interactive digital poster, allows users to scan its images using a smartphone equipped with an AR application to access tourist and cultural information (figure 3).

Figure 3: Depiction of the ID-MAP digital interactive poster, showcasing the layout of homestays, tourist sites, and cultural locations that trigger AR content.

The systems communicate via a local wireless network, eliminating the need for internet access. Figure 4 outlines the interaction process, where data uploaded to ID-QUBE is retrieved by users through AR-enabled scanning, enabling augmented displays.

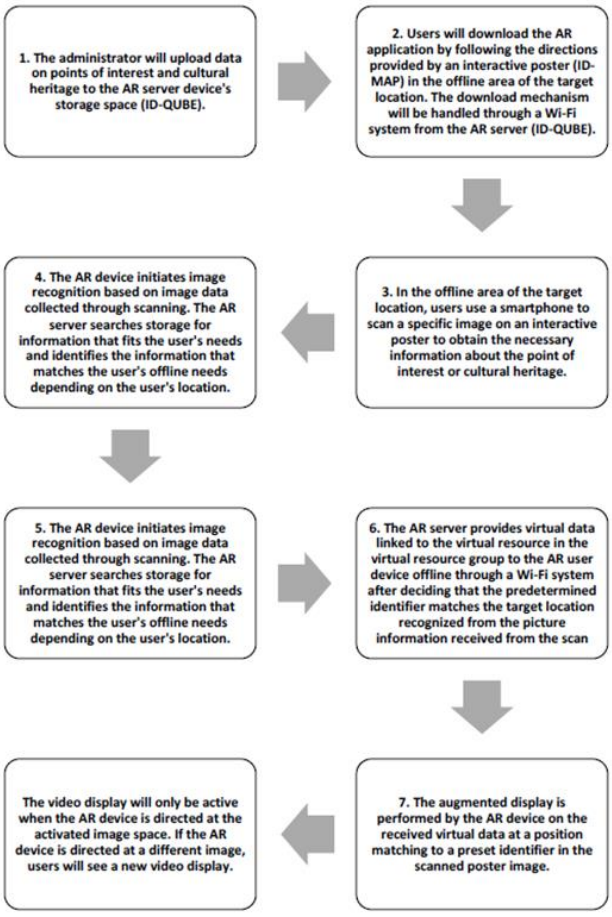


Figure 4: Flowchart illustrating the overall offline interaction method based on AR, detailing the sequence of data uploading, user interaction, and AR content display.

2. Data Collection

Data related to rural tourism and cultural heritage—including historical facts, local attractions, and multimedia elements like videos and 3D models—was collected and uploaded to ID-QUBE. The ID-MAP posters display trigger images that, when scanned, provide users with relevant AR content. Figure 3 illustrates how ID-MAP facilitates interaction with homestays, cultural sites, and tourist destinations by overlaying augmented information on real-world imagery.

3. Prototype Implementation

The prototype consists of several components detailed in Figures 5, Figure 6, Figure 7, Figure 8 and Figure 9, which depict the physical design and internal configurations of ID-QUBE. This includes a Raspberry Pi for data storage, a router for wireless data transmission, and solar-powered components like batteries and charge controllers. The modular design ensures the system is lightweight, portable, and easily installed in diverse rural environments. Solar energy enables 12-hour daily operation without reliance on conventional power sources.

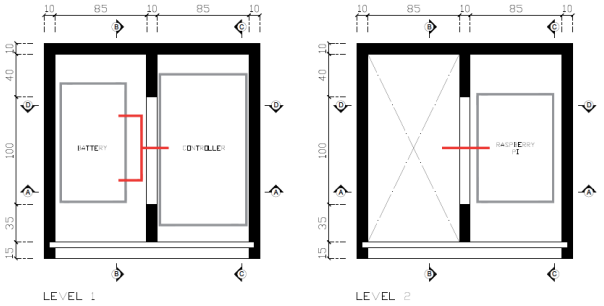


Figure 5: Level 1 and Level 2 plan of ID-QUBE

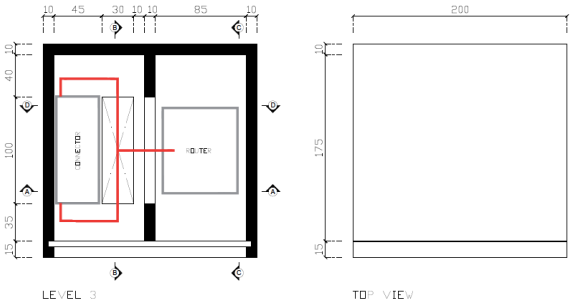


Figure 6: Level 3 plan and Top View of ID-QUBE

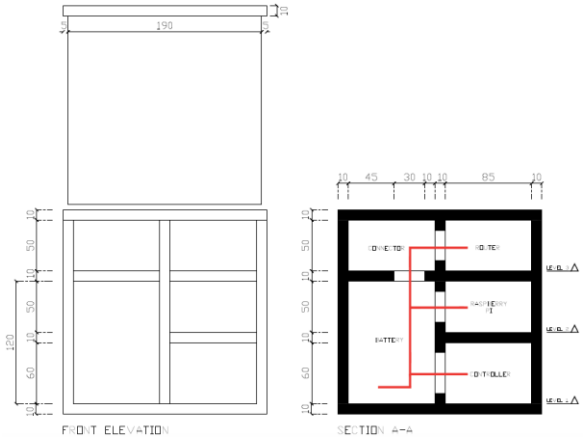


Figure 7: Front Elevation and Section A-A view of ID-QUBE

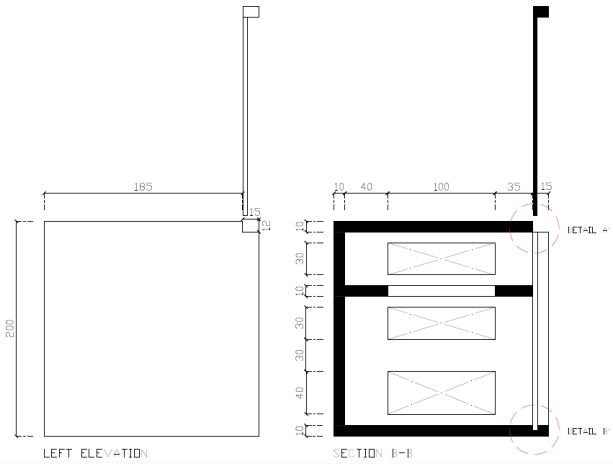


Figure 8: Left Elevation and Section B-B view of ID-QUBE

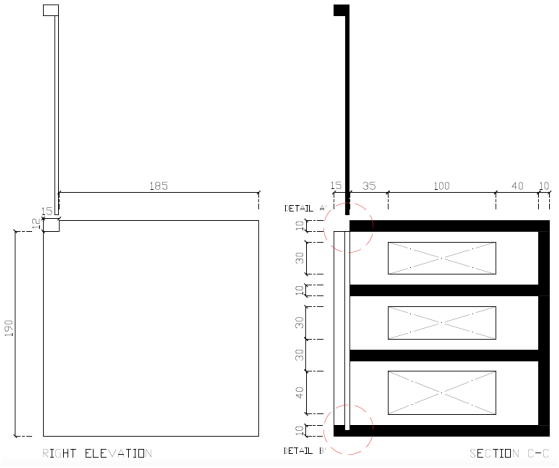


Figure 9: Right Elevation and Section C-C view of ID-QUBE

RESULT

1. User Interaction Testing

The systems were tested in Pa' Lungan, small village at Bario, Sarawak, Malaysia, a renowned eco-tourism destination. ID-MAP posters were strategically placed in key locations, such as tourist centers and homestays. Tourists downloaded the AR app via the ID-QUBE's local Wi-Fi system (Figure 10), scanned images on ID-MAP, and accessed AR-enhanced content, including videos and interactive narratives of local attractions.

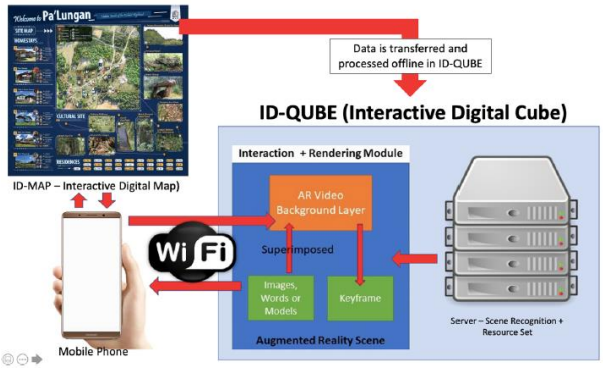


Figure 10: Schematic diagram illustrating the AR system layout connecting ID-QUBE and ID-MAP.

2. System Evaluation and Feedback

The final stage involved evaluating system performance through feedback from local users, tourists, and stakeholders. Key considerations included ease of use, scalability, and adaptability. Locals received training to update digital content using ID-QUBE's user-friendly interface. Figure 11 illustrates the simplicity of the interactive process, highlighting how users scanned images on ID-MAP to retrieve AR content effectively.

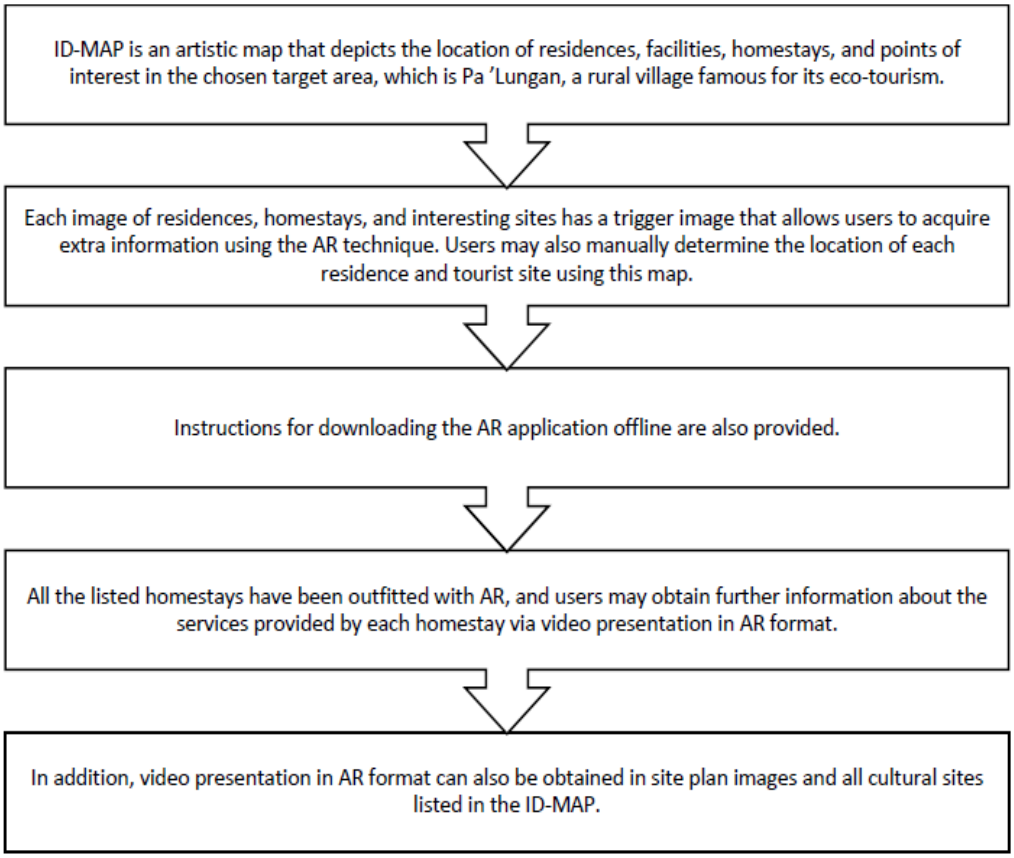


Figure 11: Flowchart detailing the interaction processes on AR Interactive Digital Map (ID-MAP), explaining how users scan images to retrieve AR content.

Insights from feedback demonstrated that this offline AR approach could be extended to other rural areas globally. The customizable features of ID-QUBE and ID-MAP allow adaptation to varying cultural and tourism contexts, supporting sustainable development.

DISCUSSION

The findings demonstrate that the offline AR systems, ID-QUBE and ID-MAP, effectively enhance user engagement and provide valuable cultural and tourism information without requiring internet connectivity. This offers a practical solution for rural tourism, particularly in areas where internet infrastructure is limited or unavailable. Furthermore, the systems empower local communities to manage and update content independently after initial setup and training, ensuring long-term sustainability.

1. Cultural Preservation through Digital Innovation

One of the key contributions of the proposed systems is their role in preserving and promoting local culture. Cultural heritage is a primary attraction in rural tourism but often faces risks of dilution in the face of modernization. By offering immersive, interactive digital platforms, ID-QUBE and ID-MAP enable tourists to engage with local culture in a meaningful way. This approach aligns with the concept of “digital heritage,” which leverages technology to preserve and transmit intangible cultural elements [14]. These systems present an alternative to static museum exhibitions, positioning culture as a dynamic, living entity.

2. Empowerment of Local Communities

The offline nature of the systems addresses the technological gap in rural areas, allowing communities to actively participate in the digital economy. By providing user-friendly tools, locals are empowered to manage and update tourism content, fostering ownership and agency. This aspect is critical to sustainable tourism development, ensuring that economic benefits remain within the community [15]. From a social science perspective, this demonstrates how technology can shift from being an exploitative force to one that promotes empowerment and inclusion.

3. Sustainable Tourism Development

The reliance on solar-powered systems underscores the importance of sustainability in rural tourism. By using renewable energy, ID-QUBE addresses infrastructural challenges while aligning with global efforts toward eco-friendly tourism practices [16]. This approach is particularly relevant in eco-tourism destinations such as Pa' Lungan, where preserving natural landscapes and minimizing environmental impacts are priorities. Solar integration ensures the system is not only environmentally sustainable but also economically viable for long-term use.

4. Bridging the Digital Divide

The offline functionality of the systems plays a pivotal role in reducing the digital divide between urban and rural regions. Lack of internet connectivity has historically limited rural communities' access to digital resources. ID-QUBE and ID-MAP provide a scalable, offline solution for engaging with digital tourism, enabling even the most remote communities to benefit from technological advancements [17]. This model fosters social equity and inclusion, demonstrating how digital innovation can create economic opportunities in underserved areas.

5. Tourist Engagement and User Experience

The systems offer a transformative way for tourists to engage with cultural content. By facilitating a multi-sensory and interactive experience, ID-QUBE and ID-MAP surpass traditional forms of cultural tourism, such as guidebooks or static displays. Marker-based applications allow tourists to explore local culture in a self-directed, immersive manner, aligning with trends in personalized tourism experiences [18]. Enhanced engagement fosters emotional and intellectual connections to the destination, leading to increased economic benefits for local communities.

6. Challenges and Recommendations

Despite their advantages, the systems face challenges such as high initial setup costs, which may deter adoption in resource-constrained communities. While the systems are designed for ease of use, the need for initial training and ongoing technical support presents an additional barrier. To address this, partnerships with governmental agencies and NGOs are recommended to subsidize costs and ensure long-term viability. Furthermore, ongoing training programs should be implemented to enable local stakeholders to maintain and update the systems effectively.

CONCLUSION

This study demonstrates the feasibility and effectiveness of offline AR systems, such as ID-QUBE and ID-MAP, for enhancing rural tourism and cultural heritage preservation. By integrating solar-powered devices and offline data transmission capabilities, these systems provide scalable, sustainable solutions that address the digital divide in underserved regions. The findings highlight the transformative potential of AR in promoting cultural heritage, empowering local communities, and fostering economic growth in rural settings.

The research underscores the importance of inclusive technological solutions tailored to the unique needs of rural tourism. ID-QUBE and ID-MAP empower communities by enabling them to manage and update content independently, fostering a sense of ownership and sustainability. Additionally, these systems offer tourists immersive and engaging cultural experiences, bridging the gap between traditional methods and modern technological advancements.

Future efforts should focus on reducing initial setup costs, expanding training programs for local stakeholders, and fostering collaborations with governmental and non-governmental organizations to support widespread adoption. These initiatives will ensure the long-term viability and scalability of such systems, contributing to sustainable tourism development and cultural preservation worldwide.

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