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Original Research

Android-Based Markerless Augmented Reality for Interactive Visualization of Lava Tour Merapi (Case Study: Amtra Journey)

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ABSTRACT

The Lava Tour Merapi is a key tourist destination located in Sleman Regency, providing educational experiences about the history of Mount Merapi's eruptions. However, most tourism information is still primarily provided by tour guides, which restricts visitors' ability to access information on their own. This study aimed to create an Android-based markerless Augmented Reality (AR) application to offer interactive tourism information for the Lava Tour Merapi. Using a Research and Development (R&D) approach with the Waterfall software development model, the study included stages such as requirements analysis, system design, implementation, testing, and maintenance. The application was developed with Unity and Blender, and it implemented markerless AR combined with the Global Positioning System (GPS) to show three-dimensional virtual objects based on the user's location, eliminating the need for physical markers. Functional testing was conducted utilizing the Black Box Testing method. The results indicated that all features of the application such as package selection, route selection, destination information, interactive maps, 3D visualizations, and audio playback functioned correctly according to the specified requirements. The application ultimately provides an interactive service for location-based tourism information, allowing visitors to access destination details more easily and improving their overall tourism experience.

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1 INTRODUCTION

Tourism has emerged as one of the most rapidly expanding sectors in the global economy, playing a crucial role in regional development, job creation, and boosting local economies. The swift progress in digital technology has shifted tourists' expectations from traditional sightseeing to more engaging, customized, and tech-enhanced travel experiences [1]. Digital transformation has therefore become an important strategy for improving tourism competitiveness and visitor satisfaction through the integration of innovative technologies into tourism services [2]. The Indonesia Tourism Outlook 2023–2024 highlights that digital technologies like Artificial Intelligence (AI), Virtual Reality (VR), and Augmented Reality (AR) are anticipated to increasingly enhance tourism experiences and promote sustainable tourism development. Among these, Augmented Reality has garnered significant interest for its ability to seamlessly blend virtual content with real-world settings, enabling tourists to access contextual information interactively via mobile devices [3, 4].

Lava Tour Merapi, situated in Sleman Regency within the Special Region of Yogyakarta, stands as a prominent disaster tourism spot in Indonesia, providing both educational and historical insights into Mount Merapi's eruption [5]. This destination features a variety of attractions, such as Museum Mini Sisa Hartaku, Bunker Kaliadem, Rumah Mbah Maridjan, Batu Alien, Stonehenge, Plunyon Kali Kuning, Tebing Gendol, along with other volcanic heritage sites, all accessible through different travel packages. Although the site holds significant tourism potential, information about it is mainly conveyed through verbal narratives by tour guides and traditional information boards. This method restricts visitors from independently accessing information about the destination and fails to offer interactive or location-specific tourism experiences [6]. As a result, the information visitors receive can vary based on the presence of tour guides, and those exploring on their own have limited access to contextual details about each site [7].

The increasing adoption of mobile technology has encouraged the development of location-based tourism information systems to improve tourists' travel experiences [8]. Markerless Augmented Reality (AR) is one of the technologies that enables virtual objects to be displayed based on users' geographical locations by utilizing the Global Positioning System (GPS) and smartphone sensors without requiring physical markers [9, 10]. Compared with marker-based AR, markerless AR provides greater flexibility for outdoor tourism because tourists can directly access digital information according to their current locations [11].

Several previous studies have demonstrated the implementation of Augmented Reality in tourism applications. Siregar and Hutabri developed a marker-based AR application to introduce tourist attractions in Batam [12], while Insyiroh et al. designed an AR application using marker card detection for introducing tourism icons in Surabaya [13]. Other studies also reported that location-based AR can improve tourist engagement, navigation, and destination interpretation through interactive visualization [6, 14].

Although previous studies have confirmed the effectiveness of AR in tourism, most implementations still rely on marker-based approaches or focus only on destination visualization [6, 12]. Research integrating markerless location-based AR with GPS, travel package selection, route management, interactive maps, three-dimensional visualization, and audio narration remains limited, particularly for Lava Tour Merapi [15]. This limitation provides an opportunity to develop a more comprehensive tourism information system that supports independent destination exploration.

Therefore, this study aims to develop an Android-based markerless Augmented Reality application utilizing GPS technology to provide interactive tourism information for Lava Tour Merapi. The proposed application integrates destination information, three-dimensional visualization, travel package selection, route navigation, interactive maps, and audio explanations into a single mobile application. The developed application is expected to improve visitors' access to tourism information while enhancing their overall tourism experience [14].

2 RESEARCH METHODS

This study employed the Research and Development (R&D) approach to develop an Android-based markerless Augmented Reality application for Lava Tour Merapi tourism. The software development process adopted the Waterfall model because it provides a systematic and sequential development process consisting of five phases: requirements, design, implementation, testing, and maintenance [16–18]. The research workflow is illustrated in Figure 1.

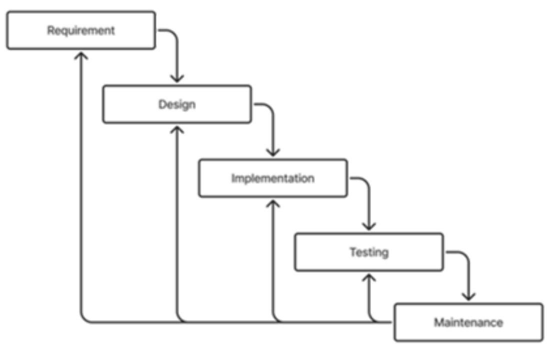

Figure 1. Waterfall Software Development Model

2.1 Requirements

This stage covers software requirements, software inputs and outputs, and software constraints. Furthermore, the analysis at this stage aims to ensure that all user requirements have been clearly identified before entering the system design phase [19].

2.2 Design

This stage describes the programming requirements from the inspection stage to the design drawings with the aim that they will generally be executed in the program at the next stage [20].

2.3 Implementation

In this stage, the system begins by developing small programs called units, which are coordinated in the next stage. Each unit is created and tested for usability, which is called unit testing [20].

2.4 Testing

In the testing stage, all units created in the implementation stage are coordinated into the system after testing is carried out by each unit. After integration, the entire system is tested to check for any failures or errors [20].

2.5 Maintenance

The maintenance stage is carried out after the application is implemented, which aims to maintain the smooth performance of the application and to make repairs to bugs and errors that may not have been detected during the testing stage [21].

3 RESULTS AND DISCUSSION

3.1 Requirements Analysis

The requirements analysis phase involved gathering information through direct observation, conducting interviews with Amtra Journey, and reviewing relevant literature to pinpoint both functional and non-functional needs of the application. From this analysis, the application was crafted to deliver engaging tourism information, featuring key components such as options for selecting tourism packages, choosing travel routes, interactive maps, detailed destination insights, 3D visualizations, and audio narration. Furthermore, the application was developed to function offline by integrating tourism data directly into Unity assets and Scriptable Objects, which removes the reliance on an external database.

Table 1. Functional Requirements

No	Functional Requirement	Description
1	Tour Package and Route Management	The system allows users to select, view, and change travel packages and specific destination routes.
2	Markerless Augmented Reality	The system renders location-based 3D objects, provides interactive AR navigation controls, and plays educational audio narrations.
3	Destination Information System	The system displays comprehensive details of tourist attractions, including text descriptions and images.
4	Interactive Travel Map	The system visualizes the travel route and tracks the user's real-time position using GPS.

3.2 System Design

The system design phase turned the identified requirements into application models and interface designs. It features an application architecture with several interconnected modules, such as package selection, route management, destination information, interactive maps, and a markerless Augmented Reality module. Navigation between these modules is crafted to ensure a simple and intuitive user experience.

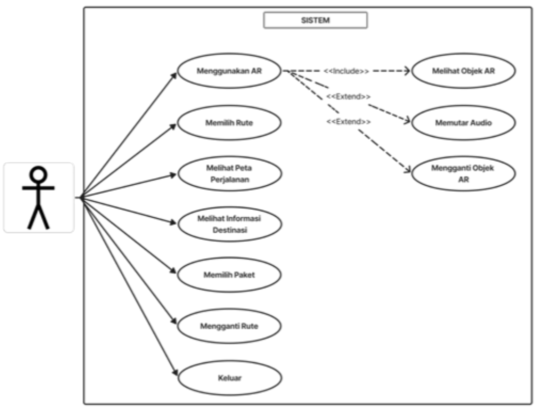

Figure 2. Use Case Diagram

The use case diagram in this application (Figure 2) illustrates the interaction between the user and the system. Users can select a tour package and route before entering the main menu. From the main menu, users can access the travel map, destination information, and augmented reality (AR) features. In the AR feature, users can view 3D objects based on their location, play audio explanations, and move between AR objects. Additionally, users can view detailed destination information and change their route as needed.

3.3 Application Implementation

The implementation of the Android-based application is designed to operate entirely offline to accommodate the unstable internet connectivity in the Lava Tour Merapi area. The system embeds all tourism data, 3D assets, and audio files directly within Unity using Scriptable Objects, eliminating the reliance on dynamic external databases.

a Tour Package and Route Management

The initial interaction in the application requires tourists to determine their preferred travel itinerary. To facilitate this, the system provides a structured module that categorizes options based on the time of visit and the desired trip duration.

Figure 3. Tour Package and Route Selection Interfaces

Figure 3 illustrates the integrated tour package and route selection interfaces. The system provides choices between standard and sunrise packages. Once a user selects a specific duration (short, medium, or long), the corresponding sequential destinations for that route are dynamically generated and displayed. This ensures that tourists have a clear overview of their journey before proceeding.

b Main Dashboard and Navigation

After completing the initial route selection and confirmation, users are directed to the central navigation hub of the application. This dashboard is designed to provide quick and intuitive access to all core functionalities during the tour.

Figure 4 shows the main dashboard interface, highlighting the specific route chosen by the tourist along with the list of destinations included in that package. From this menu, users can seamlessly access the AR module ("Mulai AR"), textual destination information ("Informasi Wisata"), the travel map ("Peta Perjalanan"), and an option to switch routes if needed.

c Markerless Location-Based AR System

To deliver an immersive educational experience, the core Augmented Reality functionality integrates the device's Global Positioning System (GPS) to continuously monitor the user's coordinates in real-time. When the user enters the predefined radius of a tourist destination, the markerless AR module is triggered utilizing plane detection via raycasting.

Figure 5 demonstrates the AR interface accurately rendering a contextual 3D model directly onto physical surfaces without requiring printed markers. In this instance, it displays the damaged motorcycle frame at Museum Mini Sisa Hartaku. The interface is also equipped with interactive audio narrations and navigation

Figure 4. Main Dashboard and Route Navigation Menu

buttons at the bottom of the screen, allowing users to seamlessly switch between multiple 3D assets and play educational voiceovers.

d Interactive Map and GPS Tracking

Navigating the volcanic terrain autonomously requires a reliable offline tracking system. Therefore, the application features an interactive map that interacts directly with the device's location services to monitor the user's progress without relying on an active internet connection.

Figure 6 displays the travel map interface, which visually plots the sequence of destinations based on the selected route. Unlike standard routing maps, this system utilizes dynamic markers that automatically update their status—changing in size and color—when the user physically arrives at the designated radius of a location. This mechanism provides a clear visual indicator and ensures that the AR features are unlocked at the correct geographical coordinates.

Figure 5. Markerless Augmented Reality Interface

3.4 Black Box Testing Results

To evaluate the functional reliability of the developed application, Black Box testing was conducted. This testing phase aimed to verify whether all features operate according to the specified functional requirements without examining the internal source code. The tests were performed on two different smartphone devices operating on Android 11 and Android 15 to ensure stability, interface responsiveness, and sensor accuracy (specifically GPS, accelerometer, and gyroscope) across varying hardware specifications. The summarized scenarios and results of the Black Box testing are presented in Table 2.

Table 2. Summary of Black Box Testing Results

No	Tested Feature	Testing Scenario	Expected Result	Status
1	Package and Route Selection	Selecting a specific tour package and confirming the generated route via popup.	The system successfully registers the choice and navigates to the main dashboard.	Valid
2	Main Dashboard Navigation	Accessing the AR, destination information, map, and change route menus.	The system opens the correct respective modules smoothly.	Valid
3	Markerless AR & Audio	Triggering the AR camera within the destination radius, interacting with 3D objects, and playing audio.	Contextual 3D models render correctly on physical surfaces, and audio plays without lag.	Valid
4	Interactive Map & GPS	Displaying the travel route and monitoring the user's real-time movement.	The map accurately tracks the user's location and updates destination markers dynamically.	Valid

As shown in Table 2, the testing results indicate that all functional modules of the application performed accurately and reliably across different devices. The offline data architecture successfully managed the package and route selections without errors, while the interactive map dynamically tracked the user's location using the background GPS service. Furthermore, the markerless Augmented Reality module properly utilized plane

Figure 6. Interactive Offline Map with Real-time GPS Tracking

detection to render 3D assets only when the user entered the correct geographical radius, accompanied by synchronized audio narrations. Based on these outcomes, the application is deemed fully functional and suitable for deployment as an interactive, location-based tourism guide at Lava Tour Merapi.

3.5 Discussion

This study successfully developed and implemented an Android-based markerless Augmented Reality (AR) application integrated with Global Positioning System (GPS) technology for the Lava Tour Merapi. The primary finding of this research demonstrates that the integration of GPS-based location tracking with raycasting plane detection enables the real-time, contextual visualization of 3D objects without the need for physical markers. Furthermore, the applied offline-first architecture, which embeds 3D assets, audio narrations, and route data directly within Unity using Scriptable Objects, proved highly effective. This design directly addresses the primary field challenge of unstable internet connectivity in the volcanic area, ensuring seamless functionality regardless of network availability.

The valid Black Box testing results across devices running Android 11 and Android 15 reinforce the system's stability and responsiveness. These findings align with previous studies indicating that location-based AR can significantly enhance tourist engagement, navigation, and destination interpretation [6, 14]. However, this study advances beyond prior implementations (such as those by Siregar and Hutabri [12], and Insyiroh et al. [13]), which predominantly relied on marker-based approaches. By adopting a markerless, location-based paradigm, this application offers substantially greater flexibility for outdoor tourism. It allows visitors to access dynamic, contextual information autonomously based on their real-time geographical coordinates, eliminating the constraints of scanning physical markers or QR codes.

From a practical standpoint, the implementation of this system delivers significant value to both tourism service providers, such as Amtra Journey, and the visitors. The integrated tour package and route management, coupled with the interactive offline map, provides clear itinerary guidance, reducing tourist confusion and optimizing tour duration. The synchronization of 3D visualizations with educational audio narrations fundamentally transforms the information delivery paradigm. Information that was previously dependent on the verbal narratives of tour guides or static information boards is now converted into an immersive, interactive, and self-guided learning experience. This shift directly supports the digital transformation and sustainable development of disaster tourism in Indonesia [5].

Despite its successful implementation, this study acknowledges certain limitations. First, the graphical fidelity of the current 3D assets is relatively basic and could be enhanced to provide a more realistic and highly immersive experience. Second, the accuracy of location tracking is inherently dependent on the hardware quality of the user's device GPS. In areas with rugged volcanic topography, deep valleys, or dense canopy, GPS signals are prone to drift or temporary loss, which may affect the precise triggering of the AR features at specific destination radii.

Based on these limitations, several directions for future research are recommended. First, future iterations should focus on optimizing the visual quality of the AR models, potentially by utilizing high-resolution photogrammetry techniques. Second, integrating hybrid tracking algorithms that combine GPS data with Inertial Measurement Unit (IMU) sensors or Visual-Inertial Odometry (VIO) could maintain tracking precision in areas with weak GPS signals. Finally, incorporating more dynamic interactive elements, such as gamification or educational quizzes at each destination point, and expanding the dataset to encompass broader regional tourism information around Mount Merapi, would further elevate and personalize the user experience in future developments.

4 CONCLUSION

This study successfully developed an Android-based markerless Augmented Reality (AR) application to serve as an interactive tourism information medium for Lava Tour Merapi. By employing the Waterfall development model and utilizing Unity, the application integrates Global Positioning System (GPS) technology to trigger location-based AR features without the need for physical markers. The system effectively addresses the internet connectivity constraints in the volcanic area by embedding all 3D assets, audio narrations, and travel route data directly into the application's offline architecture. The developed application significantly enhances the overall tourist experience by transitioning traditional, guide-dependent information delivery into an independent and immersive digital exploration. Black Box testing confirmed that all core modules—including tour package selection, the interactive offline map, and markerless AR rendering—operate reliably across different Android devices. This technological integration provides a scalable digital framework for disaster tourism, ensuring that all visitors receive equitable, engaging, and highly contextual educational content based on their precise geographical coordinates. Despite its successful implementation, the current system has certain limitations, particularly concerning the graphical fidelity of the 3D assets and the reliance on hardware-specific GPS accuracy in challenging topographies. Future research should focus on optimizing the visual quality of the augmented reality models and incorporating advanced tracking algorithms to improve sensor precision. Furthermore, integrating more interactive elements and expanding the dataset to include broader regional tourism information could further elevate the user experience in future iterations.

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DECLARATIONS

Author Contributions:

Farid Panjasela Ramadhani: Conceptualization, Methodology, Software, Writing–original draft.
Dita Danianti: Supervision, Methodology, Writing–review & editing.
Ahmad Subhan Yazid: Data curation, Validation, Formal analysis.
Dhina Puspasari Wijaya: Visualization, Resources, Validation.

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During the preparation of this work, the authors used Qwen AI in order to improve the language and readability of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the final content of the published article.

Additional Information:
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