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Augmented Reality applications for zoos: enhancing visitor engagement through interactive animal categorization and conservation awareness

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Abstract

This study presents the AR Zoo Solo Safari application, developed to enhance visitor engagement in wildlife education through interactive AR content. Built using Blender 3D, Unity 3D, and Vuforia, it utilizes markerless tracking and a user-centered design framework. Rigorous testing confirmed efficient performance with a main menu loading time under seven seconds. User acceptance testing, based on the Technology Acceptance Model, revealed high ease-of-use (85%) and learning (84%) scores. These results validate the application's effectiveness in delivering immersive, zoo-based educational experiences, supporting its use by educators and conservationists for promoting reproductive classification and conservation awareness.

Keywords: Augmented Reality; Wildlife Conservation; Zoo Education; Application Performance, Technology Acceptance Model

1. Introduction

Augmented Reality (AR) has demonstrated significant potential in transforming visitor engagement within informal learning environments such as zoos. By overlaying interactive digital content onto real-world settings, AR enriches the educational experience, as evidenced by prior studies [1]. For example, Chen et al.[1] emphasize that AR/VR-assisted platforms improve knowledge retention and interactivity, while Ishida and Amimoto [2] highlight the benefits

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of Mixed Reality systems for hands-free access to contextual animal information. Syiem et al. [3] further propose a design framework integrating educational objectives with exhibit characteristics.

The development of AR applications for educational purposes, especially within a zoo context, harnesses immersive technologies to enhance wildlife education and engage children through gamified interactive experiences [4], [5]. The effectiveness of AR in merging real-world observation with digital enhancements has been demonstrated to foster a deeper understanding of biodiversity and conservation [4][6]. Moreover, the integration of AR into mobile applications tailored for educational settings leverages user interface design principles and advanced interaction techniques to create engaging experiences and facilitate personalized learning [7][8][4][9]. With an emphasis on developing intuitive features that resonate with children, AR zoo applications hold significant potential to enhance learning outcomes while simultaneously reinforcing strong conservation messages [4] [10].

However, despite the significant contributions of previous studies, a fundamental gap remains in the literature regarding how AR applications can effectively integrate information about reproductive categories such as the differences between oviparous and viviparous animals and their conservation status without disrupting the natural appearance of exhibits [1][11][3]. The incorporation of AR into animal conservation education offers innovative methodologies to engage visitor and enhance their understanding of wildlife. By immersing visitors in realistic simulations, the application fosters empathy and may inspire long-term behavior changes supporting conservation [12]. Such experiences facilitate experiential learning, which has been shown to improve knowledge retention about endangered species and their ecological roles [13]. This study introduces an AR application focused on animal reproduction and conservation awareness to address gaps in zoo-based education.

2. Methods

2.1. Research Approach and Design

This study employed a user-centered design (UCD) framework to develop and evaluate an AR Zoo Solo Safari. The UCD process followed iterative phases empathize, define, ideate, prototype, and test to ensure that user needs were central throughout the development cycle. Initial stakeholder interviews and onsite observations were conducted with zoo visitors and staff (such as animal educators) to identify both practical and pedagogical requirements [1][3]. The result of the discussion in designing the AR Zoo Solo Safari application is that the application can be downloaded by visitors independently in the form of APK. The marker used is markerless, namely using the information board in front of the animal so that it does not change the design that has been applied at the zoo. The information presented complements the knowledge of the existing animal information board and is equipped with the sound of the animal. And a game menu to train visitors' knowledge in recognizing animals in the zoo.

2.2. Application Development

Based on the requirements gathered during the UCD process, the AR application was designed to integrate interactive content with existing zoo infrastructure. Existing zoo signage was leveraged as AR markers to avoid altering the established layout of information boards. The application categorizes animal data by reproductive type distinguishing between oviparous and viviparous species and supplements this categorization with detailed descriptions, animal sounds, and conservation status indicators. The requirement design of the developed AR application is shown in Fig. 1. The operational environment required for the development of the AR Zoo Solo Safari application encompasses several key aspects across both software and hardware domains. In terms of software, the project utilizes Blender 3D for creating detailed 3D models of animals, Unity 3D Game Engine for building the AR application into an APK, and the system uses markerless tracking via Vuforia, compatible with Android devices, future versions aim to support iOS. On the hardware side, development is carried out on a computer equipped with an Intel Core i7 processor based on a 64-bit (x64) architecture, running Windows 11 and featuring 16 GB of RAM. Additionally, the target mobile device for application testing is an Android smartphone running Android version 14 with a minimum of 8 GB of RAM. (Ishida & Amimoto, 2023). Fig. 2 illustrates how AR overlays appear over existing signage using markerless tracking, preserving exhibit aesthetics.

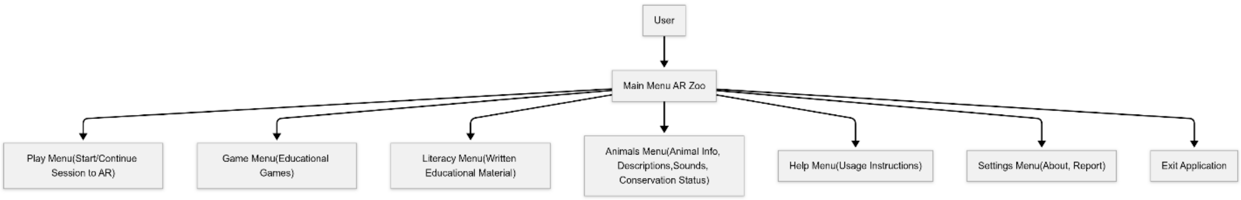

Fig. 1. Designing features for user needs when accessing the AR Zoo application

Fig 2. Markerless design for AR Zoo Solo Safari application complete with animal extinction level status. The green status level color is low risk, yellow is threatened, and red is endangered

Fig. 3 illustrates the navigation structure of the Solo Safari Zoo AR application, which enables users to access various features, including the main menu, educational content on oviparous and viviparous animals through the literacy menu, an interactive game section, and the play menu for markerless scanning within the zoo environment.

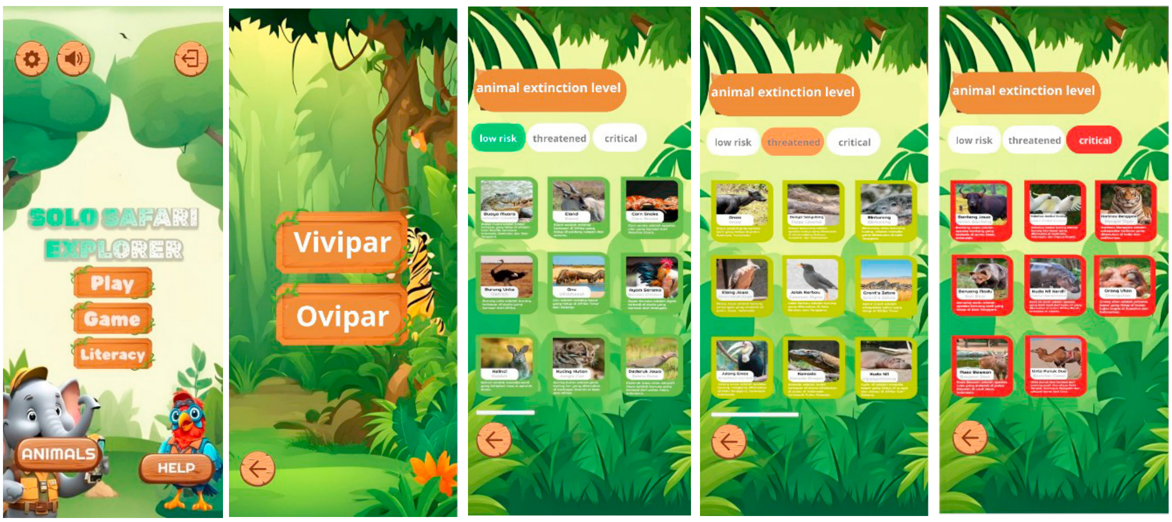

Fig. 3. Navigation design to access the Solo Safari Zoo AR application features.

In the AR Zoo Solo Safari Application, the user is positioned at the center of the navigation structure, emphasizing their role as the primary agent of interaction. Extending directly from the user are several key menu options: the Main Menu, which provides access to all primary features of the application; the Play Menu, which allows users to start or continue an interactive session; the Game Menu, which offers educational and entertaining game content; and the Literacy Menu, which displays written educational materials. Additionally, the Animals Menu presents detailed animal information including descriptions, sounds, and conservation status to enrich the visitor's learning experience.

To further support the user, the diagram includes a Help Menu for usage instructions, a Settings Menu containing options such as "About" and "Report" for feedback, and a Mute/Unmute function to toggle the application sound. Finally, an Exit option is provided to allow users to close the application. This diagram's design, with direct navigation links connecting the user at the center to each menu option, illustrates a clear and intuitive structure that grants the user full control over their interactions and seamless switching between different functionalities as needed.

2.3. Testing Procedure

A multi-phase evaluation strategy was implemented to assess the application's functionality, performance, and user acceptance testing.

2.3.1. Functionality and Performance Testing

Functionality testing is carried out in two functionalities, namely first testing the functionality of the application side with the black box method and second testing the application function in scanning markerless in the zoo. Application performance was tested with a variety of devices that have 6 GB, 8 GB and 12 GB of memory. Tests were also carried out in various lighting conditions in the field, from low light to high light and at several marker distances of 1, 1.5, and 2 meters. Measurements are made with an indication of whether virtual information can be presented properly or not.

2.3.2. User Acceptance Testing

The application was evaluated using attributes defined by [14], specifically targeting Ease of Use and Learning. Each attribute was assessed through four dedicated questions per category, all formulated on a Likert scale, and administered to 30 respondents. The sample consisted of 30 respondents (ages 19–24), primarily with prior exposure to mobile learning tools and AR applications. The Likert scale ratings were defined as follows: 1 indicates "very unfavorable," 2 corresponds to "not good," 3 represents "sufficient," 4 signifies "good," and 5 denotes "very good." In addition, an acceptance analysis was conducted using a questionnaire that incorporated Technology Acceptance Model (TAM) instruments to assess the acceptance of the AR Zoo Solo Safari application. The study also performed validity testing to determine the degree of validity and feasibility of the questionnaire instrument, along with reliability testing to ascertain its consistency. The Pearson correlation coefficient (as shown in Eq. 1) was employed to evaluate the instrument's validity..

$$r_{xy} = \frac{n\sum X_i Y_i - (\sum X_i)(\sum Y_i)}{\sqrt{(n\sum X_i^2 - (\sum X_i)^2)(n\sum Y_i^2 - (\sum Y_i)^2)}} \tag{1}$$

With r_{xy}'s represent the correlation coefficient, where n denotes the number of trial respondents, X is the score for each individual item, and Y is the overall score across all items. To evaluate the significance of these correlation results, a t-test is applied. The criterion for significance involves comparing the computed t-value (t-count) with the critical value (t-table). If the t-count exceeds the t-table value, the item is deemed valid. The t-count is calculated as shown in Eq. 2.

$$t_{count} = \frac{r_{xy}\sqrt{(n-2)}}{\sqrt{1-r_{xy}^2}} \tag{2}$$

The reliability of the descriptive test can be assessed using the Cronbach's alpha Eq. 3.

$$r_n = \frac{n}{n-1}\left(1 - \frac{\sum_{n-1}^{n} S_i^2}{S_t^2}\right) \tag{3}$$

r_n is a reliability coefficient, *n* is many items, S_i^2 is a variance of i question, S_t^2 is a total score variance.
TAM analysis uses descriptive analysis namely the percentage of criterium scores and the total score of data collection results Eq. 4.

$$P = \frac{\sum SH \ x \ 100\%}{\sum SK} \quad (4)$$

With P is the percentage of respondents' answers, $\sum SK$ is the criterium score and $\sum SH$ is the total data collection score.

3. Results and Analysis

3.1. Functionality and Performance Testing

The AR Zoo Solo Safari application was subjected to black box testing on 15 key components, including buttons for Play, Game, Literacy, Animals, Help, Settings (with About and Report), Animal information (name, details, sound, status), Question, Back, and Exit. All components performed as expected, confirming that the user interface is robust and user-friendly. Functionality testing of the AR Zoo Solo Safari application was conducted on three devices with different memory capacities: Xiaomi 13T (12 GB RAM), Realme 6 (6 GB RAM), and Samsung A55 (8 GB RAM). On each device, the initial loading time of the app took seven seconds to reach the main menu. In each test, the app scenes ran smoothly, and the AR component effectively tracked under the given lighting conditions. In addition, the 3D animal models were successfully rendered on all devices, demonstrating that the performance remains robust and reliable regardless of the device's memory specifications.

Field tests revealed challenges such as fluctuating sunlight, signage obstruction, and unstable data signals affecting initial AR loading. The lighting intensity tests were conducted at Solo Safari Zoo to assess the AR application's performance under various environmental conditions. The tests involved two markers Komodo and Kakatua Raja evaluated at different lux levels. For the Komodo marker, detection was successfully achieved at 28 lux, 38 lux, and 416 lux. Similarly, the Kakatua Raja marker was effectively detected at 2,791 lux, 4,431 lux, and even at a high intensity of 11,428 lux. These results confirm that the AR application reliably tracks markers across a broad range of lighting conditions encountered at the zoo, thereby supporting robust functionality in diverse environmental settings.

The AR Zoo Solo Safari application was evaluated under varying distances to assess its markerless detection capabilities at the zoo. Two markers, one labeled "Komodo" and the other "Kakatua Raja," were tested using two devices the Xiaomi 13T and the Samsung A55 at distances of 1 meter, 1.5 meters, and 2 meters. In every case, both devices successfully detected the markers at all tested distances. This consistent performance demonstrates that the application’s markerless detection algorithm is robust and reliable, even as the distance between the device and the exhibit increases. Consequently, the application is well-suited for dynamic zoo environments, ensuring that visitors experience a seamless and immersive AR interaction regardless of their proximity to the target exhibits. The test at Solo Safari zoo is shown in Fig. 4.

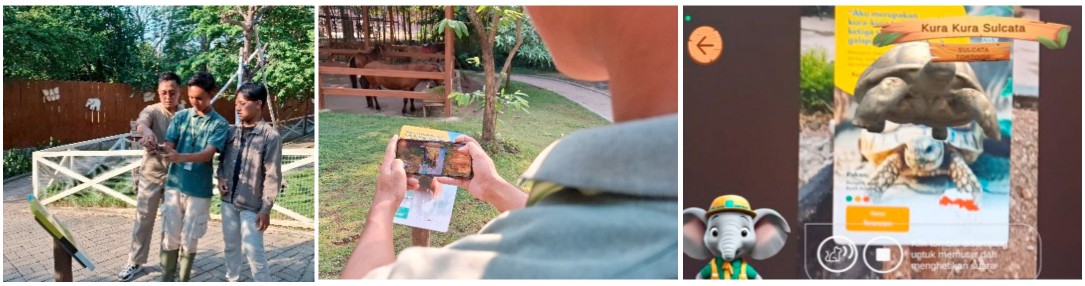

Fig. 4. Testing the AR Zoo Solo Safari application at the zoo location involves officers and visitors with variations in distance and light in detecting markerless.

3.2. User Acceptance Testing

The user acceptance testing for the AR Zoo Solo Safari application was conducted using an online questionnaire administered via Google Forms, which also collected respondents' personal data to capture demographic insights. The questionnaire was designed based on instruments from the Technology Acceptance Model (TAM) and the Questionnaire for User Interaction Satisfaction (QUIS), focusing on critical factors such as perceived usefulness, ease of use, and overall satisfaction [15][16][17][18]. Research has indicated that effective AR applications can significantly enhance learning outcomes when users feel confident navigating the technology [19]. In this study, the questionnaire comprised eight questions evenly distributed across two key aspects (see Table 1). The first four questions assessed ease of use and the remaining four questions evaluated learning effectiveness. The respondents involved in this study were 30 respondents, with 17 male and 13 female respondents, the age range of respondents ranged from 19 to 24 years old. The results of the validity calculation for each questionnaire question are presented in Table 2.

Table 1. Research Questionnaire Instrument

Variable	Code	Indicator
Ease of use	P1	Ease of accessing the AR application
	P2	Ease of using the navigation buttons
	P3	Ease of exploring each feature of the AR application
	P4	Ease of recognizing the navigation buttons within the AR application
learning	P5	Clarity of the presented 3D animal models
	P6	Clarity in identifying the sounds of each animal
	P7	Clarity of the information regarding the animals' conservation status
	P8	Clarity in selecting between oviparous and viviparous animals

Table 2. validity test results

Code	Corrected Item - Correlation Value	Valid/invalid
P1	0.343	Valid
P2	0.766	Valid
P3	0.837	Valid
P4	0.827	Valid
P5	0.764	Valid
P6	0.802	Valid
P7	0.895	Valid
P8	0.638	Valid

In Table 2, the t-count value exceeds the critical t-table value of 1.697, indicating that all questionnaire items are valid. Moreover, a Cronbach's Alpha of 0.7 or above confirms that the research instrument is reliable. In this study, the TAM variable achieved a Cronbach's Alpha of 0.8, which surpasses the threshold, affirming the reliability of all the study variables.

Tabel 3. TAM Research Description

Variable	Min	Max	Mean	Standard Deviation
Ease of use	3	5	4.250	0.473
Learning	3	5	4.208	0.486

Based on Table 3, respondents rated the ease of using the AR Zoo Solo Safari application at 4.250, indicating that it is very user-friendly. Similarly, the learning experience through the AR application received a rating of 4.208, reflecting ease of learning. Table 4 presents the descriptive statistical results derived from the TAM research on the AR Zoo Solo Safari application.

Table 4. Descriptive Statistics Results

Variable	nI	$\sum \boldsymbol{SK}$	$\sum \boldsymbol{SH}$	P
Ease of use	4	600	510	85%
Learning	4	600	505	84%

on Table 4, the responses for the Ease of Use variable fall within the agreement category, with an 85% presentation value, indicating that the AR Zoo Solo Safari Application is user-friendly. Similarly, the Learning variable achieved a percentage value of 84%, suggesting that learning about the animals at Solo Safari is easily facilitated through the AR application, which effectively categorizes animals into oviparous and viviparous groups along with providing comprehensive information on their conservation status.

3.3. Discussion of Findings

The AR Zoo Solo Safari application demonstrates a promising integration of AR technology to enhance wildlife conservation education. Our study found that the application delivers robust performance, as evidenced by a main menu loading time of seven seconds and high user satisfaction ratings 4.250 for ease of use and 4.208 for learning. These findings are consistent with those reported by [20], who observed that AR applications can significantly enrich visitor engagement and improve comprehension in zoo settings.

The design of the application was driven by a user-centered approach, utilizing Blender 3D for detailed model creation, Unity 3D for building the application, and Vuforia for accurate AR marker tracking. This combination proved effective, corroborating the work of [21][22], who highlighted that high-quality visuals and intuitive navigation are crucial for successful AR experiences. Our results contribute to a growing body of evidence that immersive AR solutions can transform traditional zoo education by enabling interactive digital media, which simplifies learning about animal reproduction classifications and conservation statuses. While effective in Solo Safari, deployment in other zoos may face challenges including infrastructure differences and content localization.

4. Conclusion

In conclusion, our study demonstrates that the AR Zoo Solo Safari application significantly enhances wildlife conservation education by delivering interactive, detailed information on animal reproductive classifications and conservation statuses. Performance testing confirmed that the application is robust, with a build process of approximately one minute and a main menu loading time of around seven seconds. Moreover, the AR functionality performed reliably under various lighting intensities and marker distances, ensuring a smooth user experience in real-world zoo environments. The TAM assessment further highlighted the application's effectiveness, with the Ease of Use variable receiving an average rating of 4.250 translating to an 85% agreement level among users and the Learning variable achieving a score of 4.208 (84% agreement). The application provides zoo educators with a flexible tool to contextualize animal learning, enhancing visitor engagement and conservation awareness. While the AR Zoo Solo Safari app shows promising results, implementation in other zoos may face challenges such as infrastructure differences and localized content needs. The current GIS-based navigation feature is not fully optimized, and the application is currently available only on Android devices. Future development will explore adaptive AI features, support for iOS, and content co-design with zoo educators to maximize engagement.

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