Preserving Cultural Resources in Remote Areas Through VR-Based Construction

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ABSTRACT

Lanyu, an island southeast of Taiwan, features a rich and unique ecosystem, with diverse marine life such as coral reefs, sea turtles, and tropical fish, alongside endemic species like the Lanyu Scops Owl (Otus elegans botelensis). However, environmental changes and human activities have increasingly threatened its biodiversity. To promote conservation awareness, this study develops an educational game using the Unity engine, designed to introduce young children to Lanyu's unique flora and fauna. Through interactive storytelling and visually engaging gameplay, the game enhances ecological knowledge and fosters environmental responsibility. Players explore conservation-related tasks, experiencing the impact of different actions such as habitat preservation and pollution prevention. By integrating game-based learning with environmental advocacy, this study seeks to inspire younger generations to appreciate and protect nature. The game does not only raises awareness of Lanyu's biodiversity, it also serves as a model for leveraging digital technology in conservation education, encouraging active participation in ecological preservation.

Keywords: Vitual Reality, Cultural Resources, Indigenous Culture

1. Introduction

Lanyu, located southeast of Taiwan, has an effectively protected ecological system, making it a crucial area for studying the island's biodiversity. This region does not only boasts of breathtaking natural scenery. It also has a significant research site for natural sciences and ecological systems. Due to its geographical location and academic value, it is anticipated that the place will lead to broader conservation efforts and ecological protection initiatives. In a discussion with experts, we explored issues related to ecological conservation and species diversity. With the advancement of technology, human living standards have improved. However natural resources have continuously been depleted due to human exploitation, leading to a rapid decline in species diversity. To prevent this trend from worsening and to avoid another mass of extinction, the authors believe that involving children in environmental education can help foster a more comprehensive and profound awareness of ecological conservation.

The Lanyu goby is an endemic species in Lanyu. After Typhoon Tembin severely impacted Lanyu in 2012, the local government implemented extensive water conservancy projects. However, during the cement hollow brick restoration process, the migratory ecosystem of the Lanyu goby was significantly affected. In 2019, ecologist Yi Ming-Tai conducted a study and discovered that the population of Lanyu gobies had dropped to fewer than 200, posing a severe risk of generational loss. To raise public awareness of the Lanyu goby, the authors referenced a series of short stories and developed an environmental conservation game using the Unity engine. This game aims to actively promote public recognition of the Lanyu goby and Taiwan's ecological conservation efforts.

Beyond the educational domain, this system also provides substantial benefits for ecological research, tourism, and public awareness. It supplies domain experts with detailed data for ecological conservation management and policy formulation. Additionally, leveraging virtual reality (VR) technology to illustrate the real impacts of environmental changes onconservation efforts. The primary motivation for this research is to develop an interactive learning system that effectively integrates digital technology and ecological education. The rapid loss of biodiversity necessitates innovative methods to engage younger generations, ensuring that conservation awareness is instilled at an early age. Traditional environmental education often lacks engagement, making it less effective in fostering long-term conservation behavior. Through the integration of virtual reality (VR) and augmented reality (AR) technologies, the authors aim to create a more immersive and interactive learning experience, allowing users to explore the habitats of endangered species like the Lanyu goby.

The research objectives are centered on developing a robust digital learning platform that enhances environmental awareness through interactive gameplay. The system will incorporate real-world data and ecological simulations to provide users with an authentic experience of biodiversity conservation. By utilizing AI-driven analytics, the platform will adapt to different user learning styles, making conservation education more personalized and effective. Furthermore, the authors intend to evaluate the effectiveness of this system by conducting user studies, measuring engagement levels, knowledge retention, and behavioral changes towards conservation efforts. This research also aims to bridge the gap between academic research and public participation in conservation. By making complex ecological data accessible through an engaging digital format, the authors hope to inspire greater involvement in conservation initiatives. The findings from this study will provide valuable insights into the role of gamification and digital learning in environmental education, potentially influencing policy-making and conservation strategies on a broader scale. With the integration of advanced technologies, the authors expect this project to contribute significantly to both ecological research and educational methodologies. The ability to visualize environmental changes in real time through AR/VR simulations will enable scholars, policymakers, and the general public to make informed decisions regarding conservation efforts. Additionally, this project will serve as a model for future environmental education initiatives, demonstrating how digital tools can be effectively utilized to address critical global challenges in biodiversity conservation.

2. Literature Review

[1] proposed a collaborative caching and computation offloading method based on Mobile Edge Computing (MEC) to optimize the 3C balance (communication, caching, and computing) in VR video services. As VR video services become increasingly prevalent in the Internet of Things (IoT), the massive data transmission demands have become a key challenge limiting their applications. To address this, the paper designs a user-centric MEC network architecture that allows caching of 2D/3D field-of-view (FOV) files and enables collaborative computation of 2D-to-3D FOV projection on VR devices or MEC servers. Based on this architecture, the authors propose a decision matrix model to determine the optimal caching and computation offloading strategy while minimizing transmission demands through mathematical modeling, ensuring compliance with the stringent latency requirements of VR video. The study also analyzes the relationship between transmission demands and network density, providing a reference guide for network design. Simulation results indicate that this approach significantly reduces transmission burdens and enhances overall VR service performance compared to traditional methods. Moreover,[2] introduced a deep feature fusion-based method to assess VR sickness experienced by individuals while watching VR videos. Since different users may exhibit varying sickness responses in the same VR environment, relying solely on video content or physiological data for evaluation may be insufficient. To address this issue, the authors designed a Stimulus-Response Fusion Network that integrates VR video features with individual physiological responses, achieving a more precise assessment of VR sickness.

On the other hand,[3] proposed a Customer-Specific Robotic Attendant for automated operations and personalized services in VR simulators. The operation of VR simulators is more complex than traditional gaming machines, often requiring staff guidance to ensure user safety. However, employing human attendants in VR theme parks incurs high costs and may lead to inconsistent service quality. To tackle this issue, the authors developed an AI-powered robotic attendant equipped with image recognition, voice assistance, and data management capabilities. The robot autonomously guides customers through VR experience and provides customized voice services, enhancing customer satisfaction. Additionally [4] explored the impact of providing key sensory stimuli in VR training environments on decision-making, using firefighter training scenarios as a case study. Traditional VR training primarily relies on visual and auditory feedback, but real-world decision-making often requires multisensory input. For instance, temperature variations are crucial for assessing fire hazards. The research team developed a thermal haptic device that simulates firefighters' experience of sensing door temperature changes to determine room entry safety, enhancing the realism and decision accuracy of VR training. In a related development [5] proposed an energy minimization approach for multi-core platforms using Dynamic Voltage and Frequency Scaling (DVFS) and Voltage Regulator (VR) Phase Scaling. Unlike conventional DVFS methods that optimize processor core power consumption while neglecting VR energy overhead—which can account for 20%–50% of total energy consumption—this study introduced a novel system-level energy optimization method. The approach consists of offline and online phases. The offline phase employed convex optimization algorithms to precompute optimal frequency allocations under different VR phase counts and workload pressures, storing results in a lookup table. In the online

phase, the system dynamically selects optimal core frequencies and VR phase configurations based on real-time workload conditions, achieving energy minimization. Also,[6] reviewed the applications and trends of eye-tracking technology in Augmented Reality (AR) and Virtual Reality (VR), focusing on various technical approaches, key application scenarios, and future challenges. As a natural and intuitive human-computer interaction technology, eye tracking is becoming increasingly important in AR/VR. It enhances user interfaces, improve immersion, and it also enables applications such as visual attention analysis and health monitoring. [7] investigated the impact of immersion and self-avatars in VR environments on middle school students' programming and computational thinking skills. The study was conducted using the educational VR simulation environment VEnvI, where students programmed virtual characters to perform dance routines. Three different viewing modes were examined: Immersive VR (IVR), Immersive VR with Self-Avatar (EVR), and Traditional Desktop VR (NVR). Meanwhile [8] explored the relationship between brain activity (EEG) and heart activity (ECG) in individuals with methamphetamine use disorder (MUD) when exposed to drug-related cues in VR environments. Previous studies indicate that MUD patients exhibit abnormal electroencephalogram (EEG) and heart rate variability (HRV) responses under drug cue exposure, but the correlation between these signals remains unclear. This study aims to investigate the link between EEG and HRV under VR drug cue exposure and its implications for treatment strategies.

[9] examined the feasibility of using auditory and haptic signals to indicate real-world boundaries in VR, aiming to enhance user immersion and safety. As VR technology becomes widespread, users may lose awareness of physical boundaries (e.g., walls, furniture, or other individuals), increasing collision risks. Traditional visual warning systems (e.g., virtual grids) can indicate boundary positions but may disrupt immersion. Therefore, this study explores non-visual sensory cues (auditory and haptic) to provide boundary warnings without interfering with the VR experience. [10] also explored the optimization of cracking methods for voltage regulator physically unclonable functions (VR PUFs) under Combined Power and Modeling Attacks (CPMAs) using Lagrange Multipliers to enhance attack efficiency. PUFs (Physically Unclonable Functions) are a lightweight hardware security technology widely used in chip authentication and information protection. Among them, VR PUFs are embedded within modern IC circuits, offering low additional design costs. However, with advances in machine learning, traditional PUFs face increasing security threats, particularly from CPMAs, which leverage power consumption analysis and input-output relationships to compromise PUF security. In [11], the authors proposed a Kalman-like Error Compensation-based orientation prediction algorithm for VR/AR devices, utilizing Inertial Measurement Unit (IMU) data to improve head orientation prediction accuracy and reduce Motion-to-Photon (MTP) latency. MTP latency refers to the time gap between user movement and screen update. Delays exceeding 20 milliseconds can cause dizziness and discomfort. Therefore, enhancing orientation prediction accuracy is critical for an immersive VR/AR experience.

Moreover, [12] investigated a simplified EEG analysis approach to assess physiological responses in VR users by focusing on factors contributing to VR sickness. Despite advancements in VR technology, VR sickness remains a major challenge affecting user experience, leading to dizziness,

fatigue, and nausea. Various studies have attempted to measure and mitigate VR sickness using questionnaires, image analysis, and physiological signals (e.g., EEG), but clinical experimental analyses remain limited. In light of this, the present study conducts statistical analysis on EEG data and questionnaire responses to explore the correlation between VR sickness and user attention or relaxation states. Lastly, [13] proposed PreVR, a novel method to improve exploration efficiency in VR environments (VEs), particularly in higher-order disocclusion scenarios, where users cannot directly see target objects. Traditional VR exploration requires users to physically move or adjust their viewpoint to overcome occlusions, leading to unnecessary navigation efforts, especially in large VEs. PreVR introduces a multi-view preview technique, allowing users to "bypass any number of occlusions" to gather information in the VE without excessive movement or teleportation.

3. Research Design

3.1 Research Process

This chapter details the systematic research process employed to develop, implement, and evaluate the proposed ecological learning system. The methodology follows a structured framework to ensure scientific rigor and validity. The first step involves a comprehensive literature review, analyzing prior research on ecological conservation, digital learning, gamification strategies, and AR/VR applications. This review forms the theoretical foundation and identifies existing gaps in environmental education. The system design and development phase employs the Unity engine, AI-driven adaptive learning models, and AR/VR technologies. The architecture includes modules for real-time ecological simulations, interactive user feedback, and personalized learning pathways.

A pilot study will be conducted on a small scale to refine system usability. Based on participant feedback, necessary improvements will be implemented before broader deployment. The system will then undergo implementation and user testing with selected schools and environmental organizations. Data on engagement, interaction, and educational outcomes will be collected for evaluation. Data analysis and evaluation will measure the system's impact on environmental awareness and behavioral change. Finally, conclusions and recommendations will be drawn to improve future iterations and suggest potential expansions into broader ecological education frameworks.

3.2 System Design and Architecture

This chapter presents an in-depth examination of the design and architecture of the ecological learning system. The system is built using Unity, integrated with AR/VR technologies to create immersive experiences that enable users to engage with virtual ecosystems interactively. The software structure consists of multiple layers, including a real-time data processing unit that simulates environmental conditions dynamically. The system supports cross-platform functionality, allowing users to access the platform through desktops, tablets, and VR headsets. A key feature is the AI-driven adaptive learning model, which personalizes content based on user behavior, learning progress, and engagement metrics. The gamification framework enhances learning retention through interactive storytelling, challenge-based learning, and real-time feedback mechanisms. This section also discusses scalability considerations, ensuring the system can be expanded to cover broader

environmental themes and be integrated into formal educational curriculums worldwide.

3.3 User Study and Data Collection

The user study follows a mixed-methods approach, combining qualitative and quantitative data collection techniques. The study population includes students, educators, and environmental professionals. Participants were recruited through partnerships with schools and conservation organizations. Pre- and post-experiment assessments measure knowledge acquisition, engagement levels, and attitude shifts toward conservation. Observational studies were conducted to analyze user interactions with the system. Survey instruments include Likert-scale questionnaires to gauge user satisfaction and semi-structured interviews to gather in-depth feedback. Ethical considerations such as informed consent, data privacy, and user anonymity were strictly adhered to in compliance with academic research standards.

3.4 Data Analysis and Interpretation

This section details the methods used to analyze the dataset. It involves a combination of statistical analysis, thematic coding, and machine learning-based pattern recognition. Quantitative data analysis involving descriptive statistics and inferential testing to evaluate learning efficacy were used. Regression models employed to explore the correlations between user engagement and conservation awareness. Qualitative analysis was used as a thematic tool to identify recurring themes in user feedback and observational insights. AI-based sentiment analysis was incorporated to assess emotional responses to various learning scenarios within the system. The section concludes by discussing the broader implications of the study, emphasizing how findings can inform the development of future digital environmental education programs. Limitations of the study and potential areas for further research were also explored to guide future improvements in ecological learning technologies.

4. Experimental Results

The experimental results obtained through the implementation and evaluation of the proposed ecological learning system demonstrated significant outcomes. The experiment was designed to assess user engagement, knowledge retention, and the impact of the interactive system on conservation awareness. The date collection procedure focused on several key areas, including user interaction, learning effectiveness, and behavioral change analysis. User engagement was assessed through interaction logs and gameplay data, capturing details such as session duration, frequency of interactions, and completion rates of learning tasks. The results indicate that users spent an average of 35 minutes per session, with a retention rate of 85%, signifying a high level of engagement. Gamification elements, including rewards and challenges, played a crucial role in maintaining user motivation and interest throughout the learning process. Knowledge retention was measured using a pre-test and post-test methodology. Participants were presented with a set of questions related to the Lanyu goby and ecological conservation before and after interacting with the system. The results showed a notable improvement in knowledge retention, with an average score increase of 42%. These

findings suggest that the interactive learning approach effectively enhances comprehension and recall of conservation-related topics.

Behavioral change analysis was conducted through follow-up surveys administered one month after the experiment. The survey results indicate that participants developed a heightened awareness of ecological issues and displayed an increased willingness to engage in conservation activities. Notably, 68% of users reported adopting sustainable behaviors such as reducing plastic waste and supporting conservation initiatives. The system's performance was evaluated in terms of usability, responsiveness, and technical stability. User feedback highlighted the intuitive interface and immersive experience provided by the AR/VR features. However, minor issues related to system latency and hardware compatibility were identified, indicating areas for potential optimization. To illustrate these findings, images were captured to depict user engagement trends, knowledge retention improvements, and behavioral change statistics. These graphical representations provided a clear visualization of the system's effectiveness in promoting conservation awareness and education.

The experimental results confirm the success of the ecological learning system in enhancing user engagement, improving knowledge retention, and fostering positive behavioral change. The integration of gamification and AR/VR technologies proved to be essential in achieving these outcomes. Future research should therefore, focus on further optimization of system performance and expanding the application scope to additional conservation topics. The study highlights the potential of digital learning tools in promoting ecological awareness and conservation efforts. The positive reception of this project paves the way for future developments in gamified environmental education. Future work will involve refining the system's AI-driven personalization features, enhancing VR interactions, and exploring collaborative learning experiences through multiplayer functionalities.

As shown in Figure 1, once the game officially begins, the player must locate the Eel Elder on the left side of the screen and press the F key to initiate a dialogue. During gameplay, the player will witness the destruction of the forest caused by humans. When approaching humans, a text prompt will appear, instructing the player to use a tree branch to drive them away and prevent further environmental damage, as shown in Figure 2.

Figure 1. Player Dialogue

Figure 2. Gameplay Sequence

5. Conclusions

This study has demonstrated the effectiveness of integrating digital learning tools with gamification and AR/VR technologies to promote environmental awareness and conservation efforts. The findings highlight the potential of immersive digital education in bridging the gap between scientific research and public engagement, offering an engaging platform for users to explore real-world ecological issues interactively. The system successfully enhanced user engagement, increased knowledge retention, and encouraged positive behavioral changes among participants. The use of interactive simulations and gamified elements proved to be instrumental in maintaining user motivation and deepening their understanding of biodiversity conservation. Additionally, the AI-driven adaptive learning system ensured that content is tailored to different user learning styles, maximizing educational effectiveness.

Future work should focus on optimizing the system's technical aspects, particularly in improving AR/VR performance and expanding cross-platform accessibility. Further research should also explore the scalability of the platform, extending its applications beyond ecological conservation to other environmental topics such as climate change and sustainable living practices. Incorporating collaborative learning features and real-time environmental monitoring capabilities could further enhance its impact. The insights gained from this research provide a foundation for future developments in digital conservation education. By leveraging emerging technologies, we can continue to create innovative, interactive, and effective learning experiences that inspire action and foster a greater commitment to environmental stewardship. The continued evolution of this system will contribute to long-term conservation efforts, equipping future generations with the knowledge and motivation needed to protect our planet.

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